ULTRA-FINE ELECTROSPUN NANOCOMPOSITE FIBERS OF POLYMER-CONDUCTIVE POLYMER-NANOPARTICLE

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อัลตราไฟน์อิเล็กโทรสปันนาโนคอมโพสิตไฟเบอร์ของสารพอลิเมอร์ – พอลิเมอร์นำกระแส –
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วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
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ประสิทธิ์ พิเศษวีรยศ : อัลตราไฟน์อิเล็กโทรสปันนาโนคอมโพสิตไฟเบอร์ของสารพอลิเมอร์ – พอลิเมอร์นำกระแส – อนุภาคนาโน (ULTRA-FINE ELECTROSPUN NANOCOMPOSITE FIBERS OF POLYMER-CONDUCTIVE POLYMER-NANOPARTICLE) อ. ที่ปรึกษาวิทยานิพนธ์หลัก : ศ.ดร.พิชญ์ ศุภผล , อ. ที่ปรึกษาวิทยานิพนธ์ร่วม : ผศ.ดร.เติมศักดิ์ ศรีคิรินทร์, ผศ.ดร.สมศักดิ์ แดงติ๊บ, 153 หน้า.

งานวิจัยนี้ได้ทำการสร้างรวมถึงศึกษาคุณสมบัติ และตรวจสอบ อัลตราไฟน์ไฟเบอร์ของสารพอลิเมอร์ที่ผสมด้วยสารพอลิเมอร์นำกระแส สารพอลิเมอร์ผสมด้วยอนุภาค นาโน และนาโนคอมโพสิตของสารพอลิเมอร์ที่ผสมด้วย สาร พอลิเมอร์นำกระแสกับอนุภาคนาโน โดยได้มีการศึกษารายละเอียดเกี่ยวกับลักษณะทางสัณฐานที่เกี่ยวข้องรวมถึงรูปร่าง และขนาดของอัลตราไฟน์ไฟเบอร์ที่ผสมด้วยพอลิเอทิลีนไดออกซีไทโอฟีน-พอลิสไตรีนซัลโฟเนต และอนุภาคเงินนาโน ในการนี้ได้มีการพิจารณานำกระบวนการอิเล็กโทรสปินนิ่งมาใช้สำหรับการสร้างอัลตราไฟน์นาโนคอมโพสิตไฟเบอร์ของสารพอลิเมอร์ พอลิเมอร์นำกระแส และ อนุภาคเงินนาโน กระบวนการดังกล่าวเป็นเทคนิคพิเศษที่ต้องใช้หลอดฉีดพร้อมหัวเข็ม อุปกรณ์ให้ความต่างศักย์ไฟฟ้าและเป้าอลูมิเนียมฟอยล์ ในการศึกษาการสังเคราะห์อัลตราไฟน์นาโนคอมโพสิตไฟเบอร์ที่สร้างขึ้นโดยกระบวนการอิเล็กโทรสปินนิ่งนั้นได้มีการสรุปผลภายใต้เงื่อนไข คือ ให้ความต่างศักย์ไฟฟ้าตั้งแต่ช่วง 12.5 ถึง 22.5 กิโลโวลต์ กำหนดระยะห่างระหว่างหัวเข็มที่ฉีดไฟเบอร์กับเป้ารับไฟเบอร์เท่ากับ 15 เซนติเมตร โดยใช้เวลานาน 5 นาทีสำหรับการสร้างไฟเบอร์แบบสุ่ม และใช้เวลานาน 20, 30 และ45 นาที สำหรับการสร้างไฟเบอร์แบบเรียงในทิศทางเดียวกันทั้งไฟเบอร์ขนานเชิงเดี่ยว และไฟเบอร์ขนานแบบกลุ่มประสานที่สร้างจากการผสมสารพีวีเอด้วยสารพีดอด-พีเอสเอส และสารของอนุภาคเงินนาโนที่ความเข้มข้นต่างๆ ซึ่งผู้วิจัยได้ทำการวัดค่าเส้นผ่าศูนย์กลางของไฟเบอร์ได้ประมาณ 0.1 ถึง 0.33 ไมโครเมตร

งานวิจัยนี้แสดงให้เห็นว่า อัลตราไฟน์นาโนคอมโพสิตไฟเบอร์ของสาร พอลิเมอร์ พอลิเมอร์นำกระแส และ อนุภาคนาโนที่สร้างขึ้น สามารถนำกระแสไฟฟ้าได้ดีขึ้นถ้าเพิ่มความเข้มข้นของสารพีดอด-พีเอสเอสและอนุภาคเงินนาโน โดยค่าการนำกระแสของไฟเบอร์ที่ใช้เทคนิคการสร้างแบบไฟเบอร์ขนานเชิงเดี่ยวอยู่ในช่วง 4.23 ถึง 92.18 S/cm และสำหรับไฟเบอร์ขนานแบบกลุ่มประสานจะอยู่ในช่วง 1.94 to 13.57 S/cm

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PRASIT PISESWEERAYOS: ULTRA-FINE ELECTROSPUN NANOCOMPOSITE FIBERS OF POLYMER-CONDUCTIVE POLYMER-NANOPARTICLE. ADVISOR : PROF. PITT SUPAPHOL, Ph.D., CO-ADVISORS : ASST. PROF. TOEMSAK SRIKHIRIN, Ph.D., ASST. PROF. SOMSAK DANGTIP, Ph.D., 153 pp.

In this research, ultra-fine fibers of polymer – conductive polymer blend, polymer – nanoparticle and polymer – conductive polymer – nanoparticle nanocomposite are fabricated, characterized, and investigated. Poly(3,4-ethylenedioxythiophene)/ poly(styrenesulfonate) blended with silver nanoparticles and correlated morphology are studied in details including the shapes and sizes of ultra-fine fibers. Electrospinning processes are considered as ultra-fine nanocomposite fibers of polymer-conductive polymer-nanoparticle formation. (This specific technique requires a syringe with a needle, a high voltage unit, and an aluminum foil (screen) as a collector.) The fabrication conditions for the electrospinning processes in the synthesis of ultra-fine nanocomposite fibers in this study are initially summarized whereby voltages between 12.5-22.5 kV are applied on a collecting distance of 15 cm in 5 minutes for random fiber formation and 20, 30, and 45 minutes of both aligned single fiber and aligned fiber mat formation which are generated from PVA blended with various PEDOT/PSS and AgNPs concentrations. The fiber diameters resulting from these permutations by the researcher in this review varied from 0.1 μm to 0.33 μm.

This research illustrates the ultra-fine electrospun nanocomposite fibers of polymer-conductive polymer-nanoparticle which conduct higher electrical conductivity when loading higher PEDOT/PSS, and AgNPs concentrations to form ultra-fine fibers. The range of conductivity is varied from 4.23 to 92.18 S/cm, under the aligned single fibers technique, and from 1.94 to 13.57 S/cm, under the aligned fiber mat technique.

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LIST OF ABBREVIATIONS

PVA	Poly(vinyl alcohol)
PEDOT/PSS	Poly(3,4-ethylenedioxythiophene)/ poly(styrenesulfonate)
AgNPs	Silver nanoparticles
P3DDT	Poly-3-dodecylthiophene
PEO	Polyethylene Oxide
P3HT	Poly-3-hexylthiophene
PCL	Poly(ε-caprolactone)
$AgNO_3$	Silver Nitrate
PAN	Polyacrylonitrile
PPy	Polypyrrole
PMO-PPV	Poly(2-methoxy-5-octoxy)-1,4-phenylene vinylene)-alt-1,4-(phenylene vinylene)
MEH-PPV	Poly[2-methoxy-5-(2-ethylhexyloxy)-p-phenylenevinylene]
PPV	Poly(phenylene vinylene)
PS	Polystyrene
PANI	Polyaniline
PLCL	Poly(L-lactide-co-ε-caprolactone)
PHT	Poly(3-hexylthiophene)
PTA	Phosphotungstic Acid

CHAPTER I

INTRODUCTION

Conductive polymers and their applications have been approached, developed and implemented in recent years mostly in the laboratory and manufacturing. The successful commercial applications of the conductive polymers have continuously improved in efficiency when delivering their intrinsic properties. Mostly, the conductive polymers have been investigated by researchers in terms of electrical and optical properties. Over past 20 years, these types of polymer have attracted much interest because they simultaneously show their physical and chemical properties and the electrical characteristics of metals [1]. Indeed, these polymers have a high commercial potential to generate an even greater range of innovative consumer and industrial products such as diodes, biosensors, electrochemical devices, light-emitting diodes (LEDs), photovoltaic cells, and field-effect transistors (FET) [2]. Thus, many researchers are focusing on doing more research on conductive polymers by using the novel techniques and the variety nanomaterials of conductive polymers to produce nanoparticles, nanorods, thin films, ultra-fine fibers and etc. Moreover, nanocomposite will play a key role in the rapidly developing area of conductive ultra-fine fibers due to the possibility of conductivity enhancement with low cost technology. Nanocomposites are the primary material to improve electrical properties due to its blending of other higher conductivity materials with traditional conducting polymers.

This has stimulated many researchers to focus their areas of interest on "the development of synthesis, fabrication and processing methodologies of conductive polymers with the specific properties of electrical and optical conductivities". Now there is much emphasis placed on the development of suitable materials for their applications which is the subject of our scientific effort. In this few years, the techniques of blended materials have become popular and familiar with experienced researchers for studying and investigating the electrical conductivities. Although the most researchers have been gained the advantages of this technique, they still need to fix the limitations and problems of material properties during fabrication processes. However, the critical concern in the development of conductive ultra-fine fibers is how to improve their electrical and optical properties within acceptable economies of production.

In this study, ultra-fine electropsun fibers of polymer – conductive polymer blend, polymer – nanoparticle nanocomposite and polymer – conductive polymer – nanoparticle nanocomposite be fabricated, characterized and investigated. Among various conductive polymers, PEDOT has advantage of environmental stability, non-toxicity and easy process. They have great potential for nanoapplications such as the fields of nanoelectronics, nanomedicine and bio-sensing. PEDOT/PSS blended with silver nanoparticles and correlated with morphology will be studied in details including the shapes and sizes of ultra-fine fibers. The physical property and electrical conductivity of these ultra-fine fibers blends and their nanocomposites will be studied by varying the concentrations of conductive polymers and nanoparticles.

CHAPTER II

BACKGROUND AND THEORETICAL CONTEXT

2.1 Conductive Polymers

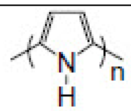
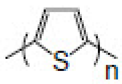
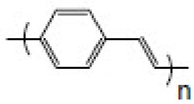
Among the various polymer solutions, conducting or conjugated polymers have attracted researcher's attention most since they have been discovered to have electrical and optical properties. The extremely essential aspect of conducting polymers is their ability to exhibit like metal or semiconductors such as electronic conductors. They have the advantages of more flexibility, ease of use, and extremely small size. Moreover, their nanostructures are regarded as larger in special surface areas and lighter in weight. These materials have been developed mostly by physicists, engineers and chemists for such electronic devices as field-effect transistors (FETs), light-emitting diodes (LEDs), electronic sensors and others utilizing their optical and electrical properties.

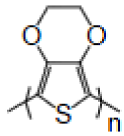
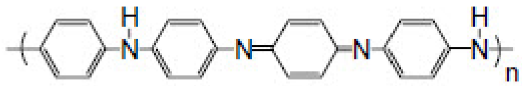
Conductive polymers are a specific class of organic polymers which consists of Carbon (C) and Hydrogen (H) atoms. The alternating single and multiple bonds (e.g. double bonds such as C=C-C=C-C...C=C-C) along the main chain of the molecular structure of conductive polymers or conjugated polymers are major features of these materials to exhibit ¶-conjugation electrons and repeat themselves along the chain. Their unique properties of ¶-conjugation electrons are the primary differences from other traditional polymers or plastic materials which are electrical insulators. In contrast, conductive polymers exhibit electrical conductivity at room temperature. A delocalised bond structure in the backbones of the conductive polymers over their entire molecules is the identifying characteristic which causes such ¶-orbital arrangements. The term of the conjugation lengths are defined as the distances (of the delocalization) of ¶-conjugation electrons that are confined along them.

There are many classes of conductive polymers such as polyacetylene, polyaniline, polypyrrole, polythiophene, Poly (3, 4-ethylenedioxythiophene) (PEDOT), and poly (phenylene vinylene) [3] to name a few. These conductive polymers with a short brief of their families and molecular structures are illustrated in Table1.

In comparison, conventional conductive polymers such as polythiophene, polyaniline, and polypyrrole have undergone significant improvements and their properties enhanced, especially in charge storage devices with their specialized conductivity requirements. Since metallic materials like gold, silver, carbon, and conducting polymers have been used to prepare nanomaterials, many researchers are expressing exponential interest in blending nano-metal-materials into conductive polymers collectively called nanocomposites.

Table 1 Sample conductive polymers and their molecular structures [3, 4].

Conductive Polymers	Molecular Structures
Polyacetylene (PA) PA is a linear chain type conjugated hydrocarbon polymer which has increased its conductivity by chemical doping.	
Polypyrrole (PPy) PPy is very widely utilized as a synthesis medium because it can be easily prepared via the oxidation process of pyrrole monomers.	
Polythiophene (PT) PT finds its most useful application in the development of environmentally and thermally stable materials. There is a variety of applications using PT such as in sensors, light emitting diodes, and field-effect transistors.	
Poly (phenylene vinylene) (PPV) PPV can be synthesized by specific methods such as Wessling–Zimmerman and the Gilch polymerization technique.	

Conductive Polymers	Molecular Structures
Poly(3,4-ethylenedioxythiophene) (PEDOT) PEDOT is formed by 3, 4-ethylenedioxylthiophene or EDOT monomer. It was prepared by using standard oxidative or electrochemical polymerization methods. PEDOT was found to be an insoluble polymer, yet performed some very interesting properties such as high conductivity, transparency in oxidized thin film, high stability in an oxidized state, optical transparency, and moderate band gap.	
Polyaniline (PANI) PANI has the great potential amongst conducting polymers due to its multiple redox states. There are many applications of PANI with its enhanced conductivity.	

2.2 Electrospinning Process

There are various techniques-- such as drawing extrusion, melt spinning, vapors grown and electrospinning-- to fabricate fibers [5]. Generally, the selected techniques depend on the researcher's purpose and their final application target segment. Electrospinning process has been extensively used in ultra-fine fibers fabrication as it is considered a relatively simple process for producing polymeric ultra-fine fibers and microfibers. The electrostatic processing strategy can be used to fabricate fibrous polymer mats comprising of fiber diameters ranging from several microns down to 100 nm or less [6]. The advantages of this well known process are continuous production and inexpensive process. This technique is used to precisely control the number of the filaments produced by changing voltage at the biased collector, viscosity, and the other conditions. Subsequently, the diameter of the fibers is varied by a post-deposition stretching process.

The process uses an electric field to generate and elongate charge jet and deposit polymer fibers onto a target substrate. Main components of electrospinning apparatus can be categorized into three parts i.e. (1) a syringe or capillary tube with a needle of small diameter; (2) a high voltage supplier; and (3) an aluminum foil (screen) as collector as shown in Figure 1. The effectiveness of the electrospinning process is determined by the preparation and control of a mixture of polymer solutions producing the ultra-fine fibers, the collecting distance and the various intensities of the electric field which is biased by adjusting the high voltage supplier.

The factors affecting ultra-fine fibers transformation in polymer solutions will be delved into in the further review. Focus will be extended to the areas of **solution variables** (in terms of solvent properties, polymer properties (dipole moment/ dielectric constant/ boiling point) and solution properties (concentration/ viscosity/ conductivity/ surface tension)); **processing parameters** (such as needle size, applied voltage, collecting distance, and polarity); and **ambient parameters** (such as humidity, air flow rate, and temperature).

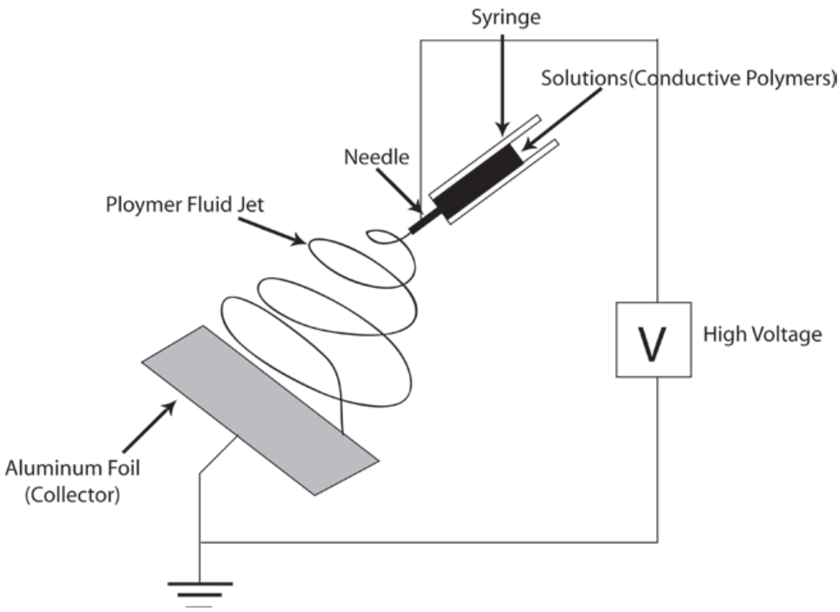


Figure 1 Schematics electrospinning apparatus

2.3 Electrospun Ultra-fine Fibers

There are multiple methodologies evolved for the production of conducting polymers such as thin films, nanoparticles, nanocomposite and ultra-fine fibers. Normally, polymeric ultra-fine fibers are generated with diameters in the nanometer to micrometer range by an electrospinning process as illustrated in Figure 1. The conductive polymers are typically dissolved in proper solvent and these solutions can be formed as ultra-fine fibers by electrospinning process. The ultra-fine fibers synthesis is the favorite laboratory exercise due to their special properties of extremely high surface area-to-volume ratios compared to conventional nonwovens. Moreover, the advantages of ultra-fine fibers fabricated by these processes for a variety of applications are high length to diameter ratio, high porosity with small pore size of nonwoven fabric, low bulk density, and flexibility in surface functionalities.

2.4 Nanoparticles

Presently, nanoparticles are becoming a part of our daily life in the form of textiles, cosmetics, food packaging, biosensors, etc. The commercial applications blended with nanoparticles such as wound dressing, detergents or antimicrobial coatings are already launched in the market. Nanoparticles are defined as particles with the sizes of 100 nm or less. The properties of nanoparticles are different from bulk material properties (larger in size than 100nm). The advantage of nanoparticles mainly is high surface area to volume ratio. Moreover, the optical properties of nanoparticles as fluorescence are crucially applied for a variety of industrial applications. Their potential applications are mostly developed in biomedical and engineering areas.

Jyongsik Jang [4] found that spherical Polypyrrole (PPy) nanoparticles have been synthesized by chemical oxidation polymerization with the aid of surfactant or stabilizer in an aqueous solution. The microemulsion polymerization has been extensively utilized to synthesize various nanometer-sized conducting polymer particles. In order to synthesize conducting polymer nanoparticle as a core, various water soluble polymers such as poly (vinyl alcohol) (PVA), poly (vinyl methyl ether), cationic and anionic polyelectrolytes have been used as polymeric stabilizers. This water soluble polymer is physisorbed onto the surface of conducting polymer core due to hydrogen bonding in most cases.

2.5 Electrical Conductivity

Since conjugated polymers can be fabricated to emphasize their electrical property through doping, significant current research has focused in the field of conducting polymer films. On the other hand, nanostructures such as ultra-fine fibers, nanotubes, and nanowires have seen more extensive commercial development due to their functional properties. Of this threesome, ultra-fine fibers have the advantages of more flexibility, ease of use, and minute size. Moreover, their nanostructures are considered to have a larger critical surface area to weight ratio. Their unusual conducting properties led to studies enhancing their functional efficiency and extending the application base, especially those utilizing their electrical characteristics.

In essence, the synthesis and subsequent applications of electronically conducting polymers is based on their specially delocalized band-like electronic structure of their conjugated molecules. The conductive ability of ultra-fine fibers has been identified in terms of transport charge carriers along the polymer backbone, in particular, as the carriers hop among polymer chains. The basic description of their electrical and transport properties has been well discoursed in traditional conductive polymers studies. In this regard, the theory of **Band Energy** of materials is commonly called upon to illustrate the difference between metal (conductors), semiconductors, and insulators as depicted in Figure 2.

There is no energy gap between valence and conduction band in metal. Therefore, the metal, Figure 2(a), is easily induced to conduct electricity under an applied electric field. On the other hand, for insulators in Figure 2(c), the large amount of electrons already in the highest occupied band (valence band) results in a wide gap whereby electrons cannot move freely under an electric field. In Figure 2 (b), the valence band is filled with electrons while the conduction band is illustrated without electrons in ground state. Under the right conditions, the electrons can jump over the narrow band gap from the valence band, full with electrons, to the conduction band. This underscores the partial conductivity of semiconductors.

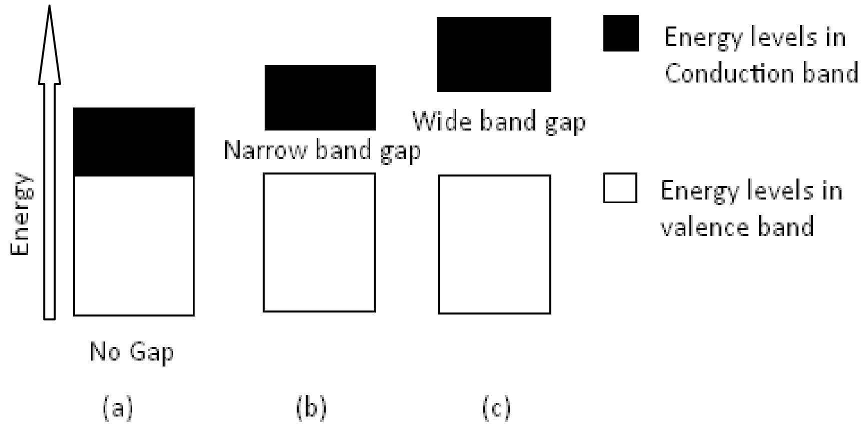


Figure 2 Simple band structure: (a) no energy gap---metal, (b) narrow band gap---semiconductors, and (c) wide band gap---insulators

The electrical conductivity of polymers can find similarities to the band energy of semiconductors previously schematically depicted in Figure 2. In Figure 3, the band structure of electrically conductive polymers is illustrated as the band gap energy of solid state semiconductors. The energy space divide, forbidden energy states, between the highest occupied and lowest unoccupied molecular orbital, is called the **band gap**. The lower band, Highest Occupied Molecular Orbital (HOMO) is called the **valence** band and the top band, the Lowest Unoccupied Molecular Orbital, is referred to as the **conduction** band.

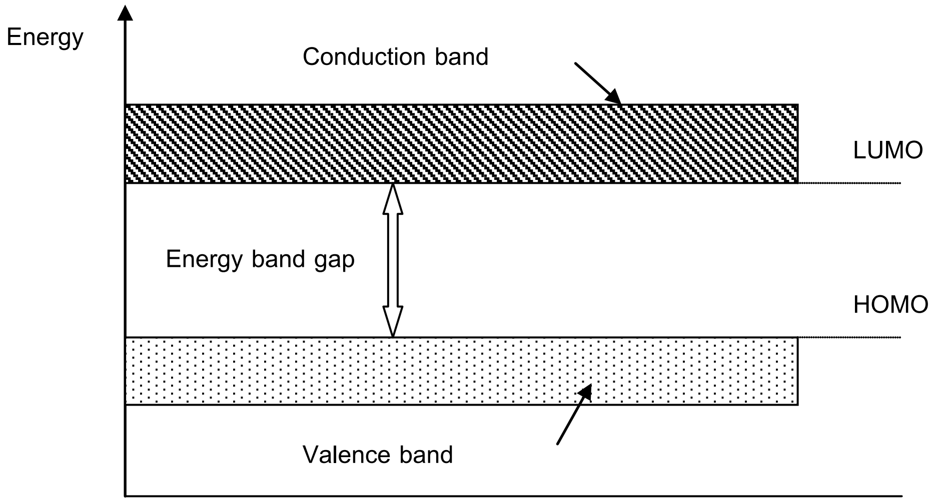


Figure 3 The band structure of electronically conductive polymer

LUMO: Lowest Unoccupied Molecular Orbital

HOMO: Highest Occupied Molecular Orbital

Presently, advanced studies emphasize the enhancement of polymer electrical properties via the development of nouveau techniques and new combination of materials such as nanocomposites. These composites are the primary substrate on which future improvements to material electrical properties are expected. This is due to their blending of other higher conductive elements with traditional conducting polymers.

It is useful to note here that polymer conductivity is frequently quantified by the equation below. Electrical Conductivity, σ, is determined in terms of the density of charge carriers (number of electrons = n), the mobility (μ) of the charge carriers, and charge carriers (q) as

$$\sigma = n\,\mu\,|q|$$

where the unit of conductivity, σ, is measured in $S.cm^{-1}$; the unit of number of charge carriers, n, in cm^{-3}; the unit of mobility of the charge carriers, μ, in $cm^{2}.V^{-1}.s^{-1}$; the unit of charge carried by carriers, q, is Coulomb [3]

CHAPTER III

LITERATURE REVIEW

3.1 Electrospinning of Blend Conductive Polymers

Amongst the various polymer solutions, conductive polymers have attracted researcher's attention most ever since they were discovered to have electrical and optical properties. Electrospun conducting fibers are produced from various substrates such as blend solutions (conductive and nonconductive polymers), template synthesis and hybrid solutions [1, 7, 8]. Ioannis S. Chronakis et al. [1] utilized electrospinning process to study conductive polypyrrole nanofibers which were obtained using polyethylene oxide (PEO) as template polymer in aqueous solutions. They also prepared pure (without carriers) polypyrrole conductive ultra-fine fibers by electrospinning organic solvent soluble polypyrrole using the functional doping agent di(2-ethylhexyl) sulfosuccinate sodium salt (NaDEHS). They reported that electrospun conducting fibers blended with water soluble polypyrrole using the functional doping agent NaDEHS with PEO.

Additionally, Andrea Bianco and his group [5] also used the electrospinning technique for obtaining functionalized polymeric fibers. They blended polyethyleneoxide (PEO), poly-3-dodecylthiophene (P3DDT) and spun from a chloroform solution. The fibers diameters were approximately 1 μm and both polymer components occurred in the fibers as separated phases. Washing the fibers with acetonitrile, the PEO matrix was completely removed. This process is fast, long lasting and homogenizes fibers of P3DDT.

Rajesh et al. [7] reviewed the recent progress in the development of nano-structured conducting polymers / nanocomposites for sensor applications. They investigated and presented an overview of various recent synthetic approaches involving template free and template oriented techniques suitable for the growth of nanomaterials from conjugated polymers, and the advantages of their applications in production of nanodevices.

The electrospinning process followed by a suitable washing step is to make it possible to orient fibers with a high molecular level. This was highlighted by Rui Chen et al. [8] who studied the properties of $AgNO_3$ / polyacrylonitrile hybrid ultra-fine fibers which were also prepared using an electrospinning technique.

The fiber diameters resulting from diverse electrospinning studies are shown in Table 2. The researchers applied voltages between 7-40 kV and relied on a specific collecting distance and solution type. The fiber diameters resulting from the studies varied from 70 nm up to 5.8 μm. The diameter size varied according to collecting distances, applied voltages, the jet sizes and the polymer contents in the jet fluids. As shown, the results of the experiments produced some polymer ultra-fine fibers with diameters in excess of 1 μm and a smallest size of 70 nm.

Table 2 Summary of electrospinning conditions for conductive polymers.

No.	Materials	Concentration	Applied voltage and collecting distance	Fiber diameters	References
1.	PPy/PEO	PEO:1.5 and 2.5 wt% PPy: 20 to 80wt%	30 kV, 20 cm	70-300 nm	[1]
2.	P3DDT/PEO	10.8 wt% in $CHCI_3$	7-13 kV, 30 cm	938 nm	[5]
3.	PS/MEH-PPV	8.5, 16, 23.5% (w/v) in Chloroform and 1,2-Dichloroethane	12-21 kV, 10 cm	Chloroform: 2.31±0.66 to 5.11±0.68 μm 1,2-Dichloroethane: 1.25±0.37 to 1.66±0.58 μm	[9]
4.	PS/MEH-PPV	8.5 % (w/v) in 1,2-Dichloroethane (DCE)	7.5 to 15 kV, 10 cm	0.165 μm to 1.190 μm	[10]
5.	PPy/PAN; AgNO3	10 wt%, 36 wt%, 52 wt%, 62 wt% and 69 wt% in PAN	~13.7 kV, 12 cm	300-750 nm	[8]
6.	P3HT-PEO	75 wt% in THF or CHCl3	14 kV, 10 cm	400-500 nm	[11]

No.	Materials	Concentration	Applied voltage and collecting distance	Fiber diameters	References
7.	P3HT:PCL	11-13 wt% in CHCI3	18 kV, 7 cm	300 nm/ 250 nm after removing PCL	[12]
8.	PMO-PPV	0.2 g PMO-PPV (or 0.2 g $Eu(ODBM)_3phen$) and 1 g PMMA in 10 mL mixed solvent composed of chloroform and tetrahydrofuran and *N,N*-dimethylformamide (2:1:1).	40 kV, 15-20 cm	70-200 nm	[13]
9.	PPV/PVA	0.6 wt% (PPV 50 :PVA 50)	10 kV, 20 cm	250-1000 nm	[14]
10.	PPV	0.4 wt% in ethanol/water	15 kV, 20 cm	653 nm	[15]
11.	PVP/MEH-PPV	6 wt%/ (0.1 wt%, 0.4 wt%, 1.0 wt%, 3.0 wt%)	17 kV, 20 cm	1.2 µm (MEH-PPV 1.0 wt%) 5.8 µm (MEH-PPV 3.0 wt%)	[16]
12.	MEH-PPV	MEH-PPV: 0.5098 g in chlorobenzene : 25 ml	15 kV, 18-25 cm	471-673 nm	[17]
13.	PANI	10.6 % to 19.1 % in hot sulfuric acid solution	12 or 18 kV, 13 cm	370 nm	[18]

3.2 Electrospinning of Poly (3, 4-ethylenedioxythiophene) (PEDOT)

Conductive PEDOT solutions are normally found as water dispersions of poly (3,4-ethylenedioxythiophene) (PEDOT)/ poly(4-styrenesulfonate) (PSS), PEDOT/PSS, which are produced as commercial products, Baytron-P, by Bayer. PEDOT is a conductive polymer depended on 3, 4-ethylenedioxylthiophene or EDOT monomer. Advantages of PEDOT properties are very attractive to many researchers in terms of high stability, moderate band gap, optical transparency in its conducting state and low redox potential. PEDOT have rather low conductivities. However, dimethyl sulfoxide (DMSO) or ethylene glycol (EG) can be used as a secondary dopant to increase their conductivities. The related researches of PEDOT are referred as followed.

J.L. Duvail et al. [19] synthesized electrochemically aqueous solution of PEDOT nanofibers by using the template method and investigated their morphology by scanning electron microscopy (SEM) and transmission electron microscopy (TEM). The researchers report a comparative study of resonant Raman spectra for the nanofibers and PEDOT films. Finally, they found that PEDOT were in an insulating state close to the metal–insulator transition, the temperature dependence of the fibers' conductance was larger than for the films, and this variation increases when the diameter was reduced.

B. J. Goo et al, [20] fabricated electrically conducting PEDOT nanofiber using the electrospinning technique. They varied electrical high voltage of 10 to 20 kV to produce these nanofibers. They investigated the capacitance properties by cyclic voltammetry (CV) and charge/discharge experiment. Additionally, they examined the surface morphology of PEDOT nano-fiber by SEM.

Wee-Eong Teo and Seeram Ramakrishna [21] introduced electrospinning as a potential technology for use as a platform for multifunctional, hierarchically organized nanocomposites. They reported that a nanocomposite system with up to five distinct levels of organization can be constructed using electrospun fibers. Additionally, they explained how electrospun multifunctional, hierarchically organized nanocomposites could be used in applications such as healthcare, environmental and defense and security.

3.3 Ultra-fine Fibers Blended with Silver Nanoparticles (AgNPs)

Among a number of nanoparticles, silver nanoparticles are created from silver, i.e. silver particles (AgNPs) of between 1 nm and 100 nm in size. AgNPs are very popular and effective for anti-microbial activity. Nowadays, AgNPs are widely synthesized in laboratory scale. However, a mass production of AgNPs for industrial scale is considered as a necessary factor for many applications.

Won Keun Son et al. [22] found that polymer nanofibers containing AgNPs on their surface could be produced by UV irradiation of polymer nanofibers electrospun with small amounts of silver nitrate ($AgNO_3$). Either electrospinning polymer solutions containing metal nanoparticles or reducing metal salts or complexes in electrospun polymer nanofibers were used to produce the incorporation of metal nanoparticles into polymer nanofibers. Finally, they found that AgNPs with an average size of 21 nm demonstrated strong antimicrobial activity.

3.4 Electrically Conductive Properties of Ultra-fine Fibers

Electrically conductive properties of ultra-fine fibers have been investigated by several groups of researchers. Ioannis S. Chronakis et al. [1] studied both the electrical conductivity and the average diameter of PPy nanofibers by varying the ratio of PPy/PEO content. They measured the conductivity by using a two-point method in accordance with ASTM 4496-04 standard. They showed that conductivity readings through the thickness of the electrospun PPy/PEO ultra-fine fibers increased by two orders of magnitude from the lowest to the highest concentration of PPy ranging from about 4.9×10^{-8} to 1.2×10^{-5} S/cm.

Alexis Laforgue et al. [11] fabricated P3HT–PEO blended with ultra-fine fibers by electrospinning process in chloroform solutions. They studied the morphology, its striated surfaces and structural arrangement of the polymers, coupled with its conductivity. The maximum electrical conductivity found for unaligned mats was 0.16 S/cm and increased to 0.3 S/cm when the ultra-fine fibers were closely aligned in a preferred direction.

Indong Jun et al. [23] investigated the effects of PANI incorporated fibers on the proliferation and differentiation of skeletal myoblasts. They implemented electrospinning process to fabricate PLCL/PANI random fibers with various concentrations of PANI. They discovered that PLCL/PANI-0 fibers did not show any detectable conductivity. In contrast to the PLCL/PANI-0 fibers, incorporation of PANI into PLCL fibers significantly increased the conductivity according to the amount of PANI; from 0.160 ± 0.046 S/cm for the PLCL/PANI-15 fibers to 0.296 ± 0.064 S/cm for the PLCL/PANI-30 fibers.

Yu Wang et al. [24] produced and measured PAN (polyacrylonitrile) ultra-fine fibers. The PAN fibers were measured before and after carbonization. Eventually PAN and PAN-based graphite ultra-fine fibers were obtained by electrospinning process and subsequent pyrolysis. The graphitization of the PAN ultra-fine fibers led to a sharp increase in conductivity to around 490 S/m. Similarly, other research groups have focused on the conductive polymer nanocomposites to continuously improve their electrical conductive properties.

The results of electrical conductivity of conducting polymers from some research groups are shown in Table 3. Among the sample solutions from Table 3, PANI, ref. 18, Qiao-Zhen Yu et al., with 370 nm fiber diameters illustrates the highest conductivity of 52.9 S/cm, while PPy/PEO, ref. 1, Ioannis S. Chronakis et al., with 70-300 nm fiber diameters indicates the lowest conductivity of 4.9×10^{-8} S/cm to 1.2×10^{-5} S/cm. The results of the tests on these materials (of P3HT-PEO, $AgNO_3$/PAN, PPy/PEO, PANI, and PLCL/PANI) are highlighted in terms of their concentration, fiber diameters and electrical conductivity. The fiber diameters derived from these solutions varied from 70nm to 750 nm, while the conductivity ranges were from 4.9×10^{-8} S/cm to 52.9 S/cm. In essence, they exhibit electrical and transport properties similar to those of traditional conductive polymers. Presently, updated techniques are focusing on new combination of materials such as nanocomposites. They are crucial to the search for improved electrical properties by blending various higher conductive materials with traditional conducting polymers.

Table 3 Summary of electrical conductivity of some conducting polymers

No.	Materials	Concentration	Fiber diameters	Conductivity	References
1.	PPy/PEO	PEO:1.5 and 2.5 wt% PPy: 20 to 80wt%	70-300 nm	4.9×10^{-8} S/cm to 1.2×10^{-5} S/cm	[1]
2.	PPy/PAN; AgNO3	10 wt%, 36 wt%, 52 wt%, 62 wt% and 69 wt% in PAN	300-750 nm	$\sim 1.3 \times 10^{-3}$ S/cm	[8]
3.	P3HT-PEO	75 wt% in THF or CHCl3	400-500 nm	0.16 S/cm and increased to 0.3 S/cm	[11]

No.	Materials	Concentration	Fiber diameters	Conductivity	References
4.	PANI	10.6 % to 19.1 % in hot sulfuric acid solution	370 nm	52.9 S/cm	[18]
5.	PLCL/ PANI	4.3% (w/v)/0mg, 5.1%(w/v)/45mg, and 6.3%(w/v)/90mg (100/0, 85/15, and 70/30)	516 ±117, 499±125, and 466±100 nm	N/A., 0.160±0.046 S/cm, and 0.296±0.064 S/cm	[23]

CHAPTER IV

EXPERIMENT PART

4.1 Scope of Work

Ultra-fine electrospun fibers of polymer – conductive polymer blend, polymer – nanoparticle nanocomposite and polymer – conductive polymer – nanoparticle nanocomposite were fabricated. Then, physical property and electrical conductivity of these ultra-fine fibers blends and their nanocomposites will be characterized. The electrical conductive ultra-fine fibers will be prepared from Poly(3, 4-ethylene dioxythiophene)/Poly (styrene sulfonate) (PEDOT/PSS) using Poly(vinyl alcohol) (PVA) as carrier. Actually, PEDOT/PSS have rather low conductivities. Although the conductivity of PEDOT/ PSS can be increased and varied by several orders of magnitude, relying on which method or technique is used for fabricating ultra-fine fibers, the reason for this characteristic is essentially unknown. So, PEDOT/PSS and its correlations with the morphology will be studied in details including the shapes and sizes of these PEDOT/PSS ultra-fine fibers. Moreover, silver (Ag) nanoparticles will be investigated in electrical conductivity after blending them into PEDOT/PSS and PVA solution to form blended ultra-fine fibers. The physical property and electrical conductivity of these ultra-fine fiber blends will study both randomized and aligned fibers by varying the applied voltages and the fiber collecting times in the electrospinning process and the concentrates of conductive polymers and nanoparticles.

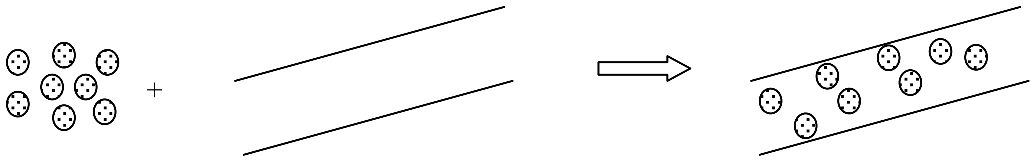
4.2 Conceptual Design for Material Structure

The following section explains an experimental method together with ultra-fine fibers fabrication system (including apparatus) and characterization that will be processed at the Petroleum and Petrochemical College, Chulalongkorn University. The electrical conductivity measurement of ultra-fine fibers will be conducted at Center of Intelligent Materials and Systems, Faculty of Science, Mahidol University.

Conceptual Design for Material Structure

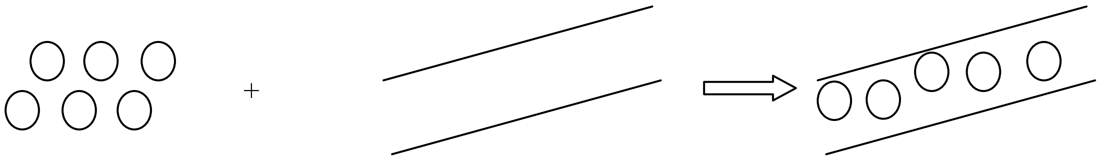
The material structure in this study will be considered a conceptual design as shown in the following diagrams.

1. Nanoparticles (AgNPs) in Ultra-fine Fiber (PVA)



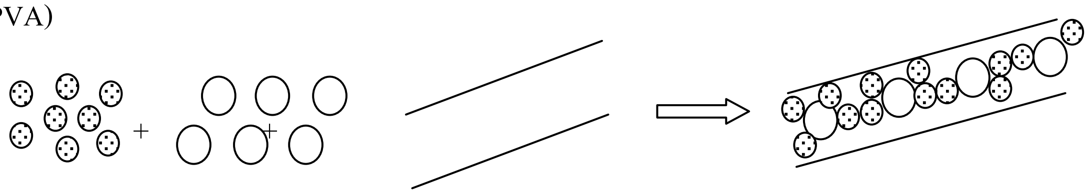
Nanoparticles (AgNPs)   Ultra-fine Fiber (PVA)   AgNPs in PVA

2. Conductive Polymer (PEDOT/PSS) in Ultra-fine Fiber (PVA)



Conductive polymer (PEDOT/PSS)   Ultra-fine Fiber (PVA)   PEDOT/PSS in PVA

3. Nanoparticles (AgNPs) and Conductive Polymer (PEDOT/PSS) in Ultra-fine Fiber (PVA)



AgNPs   PEDOT/PSS   Ultra-fine Fiber PVA   AgNPs and PEDOT/PSS in PVA

4.3 Materials

4.3.1 BAYTRON-P Poly (3, 4-ethylene dioxythiophene)/Poly (styrene sulfonate) (PEDOT/PSS) from Bayer is a blue liquid aqueous dispersion will be used as conductive polymers. BAYTRON-P is a trademark, protected for H.C. Starck GmbH, Goslar. The original concentration of PEDOT/PSS, under the centrifuge technique, is 1.2574% w/v

Physical Characteristics:

Solid content 1.2 - 1.4%

Viscosity 60 - 100 mPa.s

pH - value 1.5 - 2.5

Surface resistance max. 1 MOhm

4.3.2 Highly concentrated Silver Nanoparticles (AgNPs), about 7% w/v, were synthesized at the Center of Innovative Nanotechnology, Chulalongkorn University. The particle sizes of AgNPs after being synthesized by TEM were about 20-40 nm.

4.3.3 PVA, analytical grade, was purchased from Carlo Erba. The 12% w/v concentration of PVA in DI water was prepared by dissolving it in the 12 grams of grained PVA in 100 ml. of DI water and keeping it warm at 60°C -70°C about 3-4 hours. Finally, the 12 % w/v concentration of PVA will be diluted and mixed with PEDOT/PSS and AgNPs to form ultra-fine fibers used in the electrospinning processes with the proper ratios as shown in Table 4. In this work, PVA solutions were preserved at 10% w/v for generating any ultra-fine fibers.

4.4 Fabrication

4.4.1 Randomized Fiber Formation

The electrospinning apparatus was prepared to randomize the fiber formation as shown in Figure 1. Then, before generating fibers, all work steps were processed as follows:

1. In this work, use 1.5x1.5 cm. square size of 0.5 mm. thickness of glass substrate attached to 20x29 cm^2 of aluminum foil surface as a target (which was coated with ultra-fine fibers under the spinning process) for fiber characterization and 4-probe electrical conductivity measurement.

2. Clean all glass substrates with DI water (WDI) under the ultrasonic system, acetone and methanol before spinning processes take place.

3. Prepare all materials with the proper ratios for generating ultra-fine fibers as shown in Table 4. The fabrication processes were carried on with different mixed solutions (as

shown in Table 4). In each mixed solution, the high voltages were applied to five levels (12.5, 15, 17.5, 20, 22.5 kV) within the same conditions of collecting distance (15 cm.) and spinning time (5 min).

4. Collect fibers as shown in Figure 4

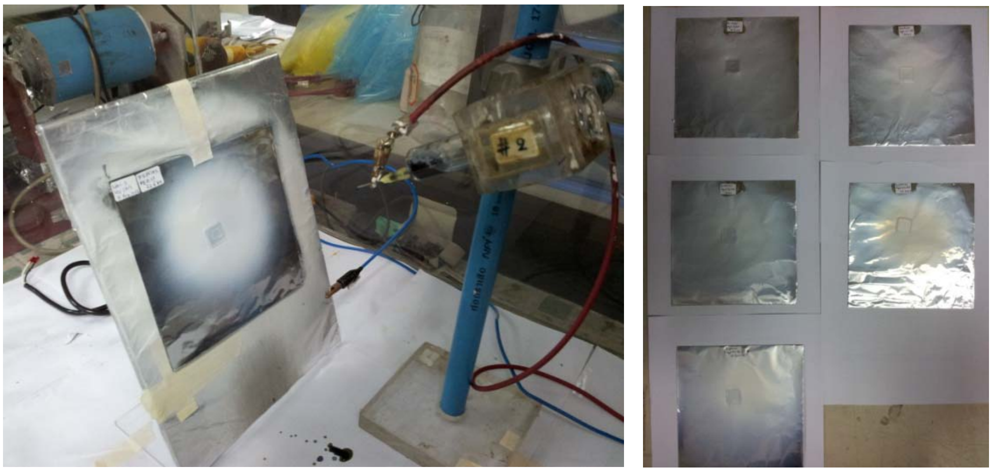


Figure 4 Collecting ultra-fine fibers on the surface of the aluminum foil

5. Repeat the processes of No.1-4 by varying the concentrates of AgNPs and the concentrates of PEDOT/PSS as shown in Table 4.

6. Characterize ultra-fine electrospun fibers by using SEM, TEM, XRD, AFM and FTIR properly.

7. Measure the electrical conductivity of randomized ultra-fine electrospun fibers by the Hall Effect Measurement as the 4-probe technique.

Table 4 Electrospinning conditions for randomized fiber (RD) formation

Fiber Types	Items	Chemical Material Mix (Concentration Ratio)	Applied Voltage (kV)	Collecting Distance (cm)	Spinning Periods (min)
RD	1	PVA 10% 6ml.: WDI 1.2ml.	12.5, 15, 17.5, 20 and 22.5	15	5
RD	2	PVA 10% 6ml.: PEDOT/PSS 0.084% 0.48ml: WDI 0.72ml.	12.5, 15, 17.5, 20 and 22.5	15	5
RD	3	PVA 10% 6ml.: PEDOT/PSS 0.052% 0.3ml.: WDI 0.9ml.	12.5, 15, 17.5, 20 and 22.5	15	5
RD	4	PVA 10% 6ml.: PEDOT/PSS 0.1% 0.57ml.: WDI 0.63ml.	12.5, 15, 17.5, 20 and 22.5	15	5
RD	5	PVA 10% 6ml.: AgNPs 0.25% 0.19ml.: WDI 1.010 ml.	12.5, 15, 17.5, 20 and 22.5	15	5
RD	6	PVA10% 6 ml.: AgNPs 0.5% 0.381 ml.: WDI 0.819ml.	12.5, 15, 17.5, 20 and 22.5	15	5
RD	7	PVA10% 6 ml.: AgNPs 0.75% 0.571 ml.: WDI 0.629ml.	12.5, 15, 17.5, 20 and 22.5	15	5
RD	8	PVA10% 6 ml.: AgNPs 0.25% 0.19 ml.: PEDOT/PSS 0.084% 0.48ml.: WDI 0.53ml.	12.5, 15, 17.5, 20 and 22.5	15	5

Fiber Types	Items	Chemical Material Mix (Concentration Ratio)	Applied Voltage (kV)	Collecting Distance (cm)	Spinning Periods (min)
RD	9	PVA10% 6 ml.: AgNPs 0.5% 0.381 ml.: PEDOT/PSS 0.084% 0.48ml.: WDI 0.339ml.	12.5, 15, 17.5, 20 and 22.5	15	5
RD	10	PVA10% 6 ml.: AgNPs 0.75% 0.571 ml.: PEDOT/PSS 0.084% 0.48ml.: WDI 0.149ml.	12.5, 15, 17.5, 20 and 22.5	15	5

4.4.2 Aligned Fiber Formation

The electrospinning apparatus for aligned fiber formation was prepared as shown in Figure 1, but only to replace the fixed square target previously mentioned in the randomized fiber formation with the high speed drum aligning fibers during the fiber generation. The high speed rotating drum was used to collect the aligned fibers while the electric filed was applied in the electrospinning system. The drum speed was set at about 1,012.13 – 1,015.56 rpm to generate well-aligned ultra-fine fibers during the electrospinning process. Then, before generating the fibers, all work steps were processed as follows:

1. Calibrate the rotating speed levels of high speed drum by varying applied voltages and counting the rotating speed in round per minute (rpm) by using the digital non-contact Tachometer, UNI-T Model UT371/372.

2. Replace the fixed square target as shown in Figure 1 with the high speed drum as the rotating target to align the ultra-fine fibers for both aligned single fibers and aligned fiber mat. The rotating speed was set at level 5, about 1,012.13 – 1,015.56 rpm for this operation. In case of aligned fiber formation with rare fiber collection like single fiber, the drum anti-clockwise rotating direction was applied. On the other hand, more fiber collection as aligned fiber mat was generated by setting the rotating drum direction under clockwise technique. The electrospinning apparatus for fiber alignment was shown in Figure 5 (a) and (b).

(a) (b)

Figure 5 High speed drum for fiber alignment (a) aligned fiber collection on the rolling aluminum foil which was attached to the rotating drum surface (b) the aligned fiber collection on the square plastic of 1.5x1.5 cm^2 with two separate rectangle ITO pieces (1.5x0.5 cm^2size of each ITO piece) on its previous surface.

3. Use 1.5x1.5 cm^2 square size of plastic substrate with the two separate1.5x0.5 cm^2 rectangle ITO bars. Figure 6, attach to aluminum foil surface as a target (which will be coated with aligned fibers under the spinning process) for fiber characterization and 2-probe electrical conductivity measurement.

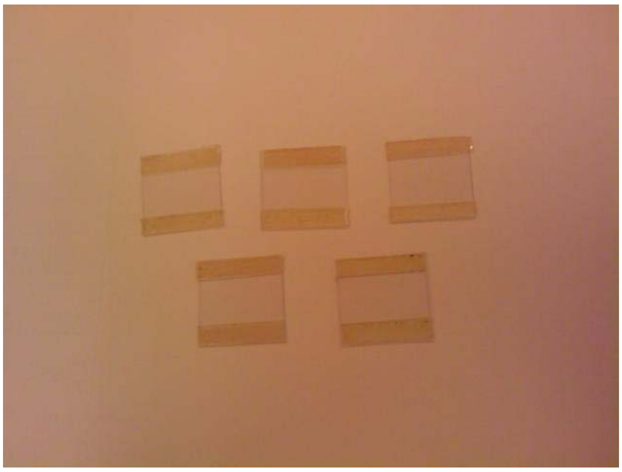


Figure 6 1.5x1.5 cm^2 square plastic, polyethylene, with two separate rectangle ITO pieces (1.5x0.5 cm^2 size for ITO piece each)

4. Prepare all materials with the proper ratios for generating aligned single fibers and aligned fiber mat as shown in Table 5 and 6 respectively. The fabrication processes were conducted with different mixed solutions. In each mixed solutions, the high voltages were applied to three levels (12.5, 15, and 17.5kV) within the same conditions of collecting distance (15 cm.) and spinning time (20, 30 and 45 min).

Table 5 Electrospinning conditions for the aligned single fiber (SF) formation

Aligned Fiber Types	Items	Chemical Material Mix (Concentration Ratio)	Applied Voltage (kV)	Collecting Distance (cm)	Spinning Periods (min)
SF	1	PVA 10% 6ml.: WDI 1.2ml.	12.5, 15, and 17.5	15	20
SF	2	PVA 10% 6ml.: PEDOT/PSS 0.084% 0.48ml: WDI 0.72ml.	12.5, 15, and 17.5	15	20
SF	3	PVA 10% 6ml.: PEDOT/PSS 0.052% 0.3ml.: WDI 0.9ml.	12.5, 15, and 17.5	15	20
SF	4	PVA 10% 6ml.: PEDOT/PSS 0.1% 0.57ml.: WDI 0.63ml.	12.5, 15, and 17.5	15	20
SF	5	PVA 10% 6ml.: AgNPs 0.25% 0.19ml.: WDI 1.010 ml.	12.5, 15, and 17.5	15	20
SF	6	PVA10% 6 ml.: AgNPs 0.5% 0.381 ml.: WDI 0.819ml.	12.5, 15, and 17.5	15	20
SF	7	PVA10% 6 ml.: AgNPs 0.75% 0.571 ml.: WDI 0.629ml.	12.5, 15, and 17.5	15	20
SF	8	PVA10% 6 ml.: AgNPs 0.25% 0.19 ml.: PEDOT/PSS 0.084% 0.48ml.: WDI 0.53ml.	17.5	15	30 and 45

Table 6 Electrospinning conditions for the aligned fiber mat (FM) formation

Aligned Fiber Types	Items	Chemical Material Mix (Concentration Ratio)	Applied Voltage (kV)	Collecting Distance (cm)	Spinning Periods (min)
FM	1	PVA 10% 3ml.: WDI 0.6ml.	12.5, 15, and 17.5	15	20
FM	2	PVA 10% 3ml.: PEDOT 0.084% 0.24ml.: WDI 0.36ml	12.5, 15, and 17.5	15	20
FM	3	PVA 10% 3ml.: PEDOT 0.052% 0.15ml,: WDI 0.45ml	12.5, 15, and 17.5	15	20
FM	4	PVA 10% 3ml.: PEDOT 0.1% 0.285ml.: WDI 0.315ml	12.5, 15, and 17.5	15	20
FM	5	PVA10% 3 ml.: AgNPs 0.25% 0.266ml.: wDI 0.334ml.	12.5, 15, and 17.5	15	20
FM	6	PVA10% 3 ml.: AgNPs 0.5% 0.533 ml.: WDI 0.067ml.	12.5, 15, and 17.5	15	20
FM	7	PVA10% 3 ml.: AgNPs 0.75% 0.799ml.: WDI – ml.	12.5, 15, and 17.5	15	20
FM	8	PVA10% 6 ml.: AgNPs 0.25% 0.19 ml.: PEDOT/PSS 0.084% 0.48ml.: WDI 0.53ml.	12.5, 15, and 17.5	15	20
FM	9	PVA10% 6 ml.: AgNPs 0.5% 0.381 ml.: PEDOT/PSS 0.084% 0.48ml.: WDI 0.339ml.	12.5, 15, and 17.5	15	20
FM	10	PVA10% 6 ml.: AgNPs 0.75% 0.571 ml.: PEDOT/PSS 0.084% 0.48ml.: WDI 0.149ml.	12.5, 15, and 17.5	15	20

Aligned Fiber Types	Items	Chemical Material Mix (Concentration Ratio)	Applied Voltage (kV)	Collecting Distance (cm)	Spinning Periods (min)
FM	11	PVA10% 6 ml.: AgNPs 0.25% 0.19 ml.: PEDOT/PSS 0.084% 0.48ml.: WDI 0.53ml.	12.5 and 15	15	30 and 45
FM	12	PVA10% 3 ml.: AgNPs 0.25% 0.266 ml.: PEDOT/PSS 0.084% 0.24ml.: WDI 0.094ml.	17.5	15	30 and 45

5. Collect fibers as shown in Figure 5

6. Repeat the processes of No.1-5 by varying AgNPs and PEDOT/PSS concentrates and collecting times as shown in Table 5 and 6.

7. Characterize aligned electrospun fibers by using SEM, TEM, XRD, and AFM properly.

8. Measure the electrical conductivity of aligned single fibers and aligned fiber mat by using the 2-probe electrical conductivity technique.

4.5 Characterization

Electrospun ultra-fine fibers, with and without silver nanoparticles and coated on the glass substrates, were characterized to study their morphologies such as the diameters of fiber by using Scanning Electron Microscope (SEM), JSM-5410LV. The SEM technique was routinely used to illustrate high-resolution images of electrospun fibers and to show chemical compositions or elements by using EDS (Energy Dispersive X-Ray Spectrometer).

The Transmission Electron Microscope (TEM), JEOL model JEM-2100, was used to identify and analyze materials mixed in the fibers. The small details in the fibers or different materials were studied at the nanometre levels. The possibility for high magnifications had made the TEM a valuable tool in this research. The EDS, optional technique in TEM, was mostly used for qualitative elemental analysis by using the software controller named JEOL untitled - analysis program (Gatan Digital Micrograph), simply to determine which elements were present in the specific area of fibers.

The Atomic Force Microscopy (AFM) was used to analyze fabricated fibers in a three-dimensional surface profile, unlike the SEM which provides a two-dimensional projection or a two-dimensional image of fibers. In this case, the non-contact or tapping mode of AFM, SEIKO model SPA 400, was used to operate for the fiber mat surface.

The X-ray Diffraction (XRD) technique was used to analyze the detailed information about the chemical composition and crystallographic structure of fabricated ultra-fine fibers.

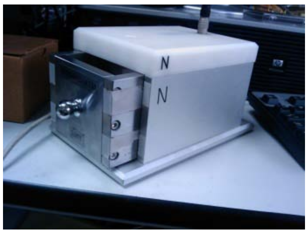
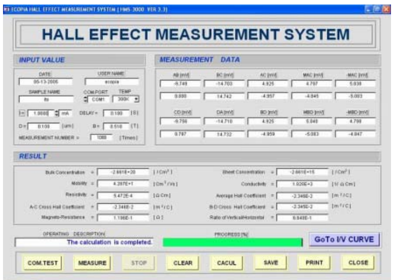
The Fourier Transform Infrared Spectroscopy (FTIR) was used to characterize ultra-fine fibers especially polymer fibers by pressing KBr Disks, with and without silver nanoparticles.

4.6 Electrical Conductivity Measurement

4.6.1 The 4-probe Conductivity Measurement

The 4-probe Conductivity Measurement, the Ecopia HMS-3000, was used to measure the electrical conductivities of electrospun ultra-fine fibers of each sample condition that randomly spread over the 1.5x1.5 cm^2 glass as shown in Figure 7.

Figure 7 4-probe Conductivity Measurement

<table>
<tr><td></td><td>
</td></tr>
<tr><td>(a) HMS-3000 with the standard 0.55T sample kit</td><td>(b) Sample holder with the PCB and IC socket on board</td></tr>
<tr><td></td><td></td></tr>
<tr><td>(c) Magnet introduced from north to south and south to north polarity</td><td>(d) Square sample glass was held by the 4 probes of the sample holder and was inserted into the magnetic chamber</td></tr>
<tr><td>
</td><td>(e) Measurement menu on the screen monitor</td></tr>
</table>

The equipment of 4-probe conductivity measurement from Figure 7 was arranged as a complete circuit for electrical measurement. The measurement steps are described as follows:

1. Connect a computer, Figure 7 (a), and magnet unit, Figure 7 (b), to the main equipment of Hall Effect Measurement System as shown in Figure 7 (a)

2. Prepare installed software, HMS 3000 v. 3.51.3(2), to record all measured data. The measurement factors displayed as abbreviations on the computer monitor, Figure 7 (e), are presented as follows:

Bulk Concentration	= Nb	Sheet Concentration	= NS
Mobility	= μ	Conductivity	= SIGMA
Resistivity	= rho	Average Hall Coefficient	= RH
A-C Cross Hall Coefficient	= RHA	B-D Cross Hall Coefficient	= RHB
Magneto-Resistance	= DELTA	Ratio of Vertical/Horizontal	= ALPHA

3. Calibrate the measurement system by setting the parameters as I = 5mA, D = 6.69 μm (depends on the fiber thickness), Delay = 0.1 [s], B = 0.55 [T], measurement number = 1000 [times]. Then, insert the sample holder including PCB and IC socket on the board, without any samples, as shown in Figure 7 (d) into the magnetic chamber and place the magnet from north to south and south to north polarity. The results of measurement factors from software menu, Figure 7 (e), are operated and saved as text files.

4. Place the sample of fiber on the surface of sample holder and follow the measurement steps from above items 1 to 3. Every condition of fiber samples is measured with the same measurement processes.

4.6.2 The 2-probe Conductivity Measurement

The 2-probe conductivity technique was implemented to measure the electrical conductivity of aligned ultrafine-fibers which were laid on 1.5x1.5 cm^2 plastics with 2 ITO separate bars. The designed circuit using the two parallel resistors for the 2-probe conductivity measurement is shown in the Figure 8 (a).

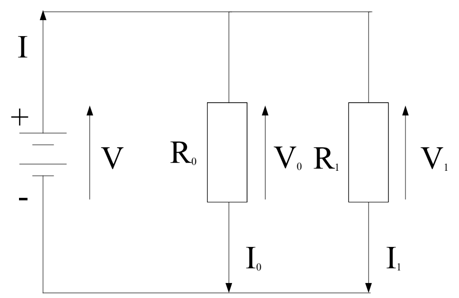
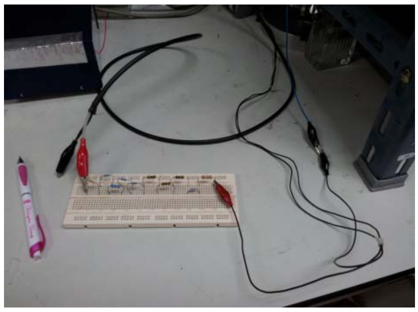
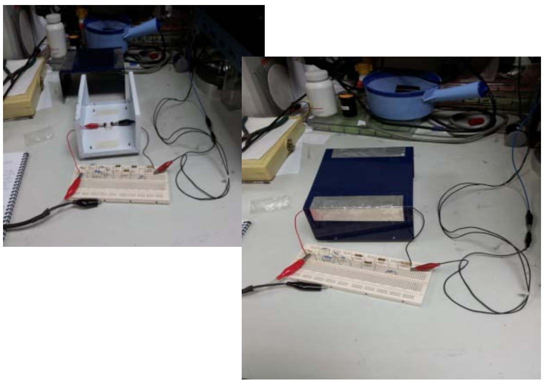
<table>
<tr>
<td>
</td>
<td></td>
</tr>
<tr>
<td>(a) The designed circuit of the two resistors is connected as a parallel circuit</td>
<td>(b) Read the serial resistances from the color bars, (R_0) = 4.352 MΩ and find the approximate R_0 by measuring the current while varying the applied voltages from 1 to 10 volts to reconfirm R_0 value by connecting the electrometer</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>(c) Connect the fiber sample, 2ITO bars on the square plastic, to the known resistances R_0 as the parallel circuit for 2-probe measurement and record the current while varying the applied voltages from 1 to 10 volts. The fiber sample is placed in the closed box for the stable current measurement</td>
<td>(d) Measure the current by using the 617 programmable electrometer, top smaller unit, while varying the voltages from 1 to 10 volts by using the 228A voltage/current source, below larger unit.</td>
</tr>
</table>

Figure 8 Designed circuit of the two resistors is connected as a parallel circuit and presents the 2-probe measurement according to the four steps from (a), (b), (c), and (d)

The supply voltage, V, shows across both resistors, R_0 and R_1 so:

$$I = I_0 + I_1 \qquad \ldots\ldots\ldots (1)$$

$$V = V_0 = V_1 \qquad \ldots\ldots\ldots (2)$$

$$V = I_0R_0 = I_1R_1 = IR \qquad \ldots\ldots\ldots (3)$$

$$R = R_0R_1 / (R_0+R_1) \qquad \ldots\ldots\ldots (4)$$

From (3) and (4)…… $V = I[R_0R_1 / (R_0+R_1)]$

$$R_0R_1 = [V(R_0+R_1)]/ I$$

$$R_1 = [V(R_0+R_1)]/ IR_0$$

$$R_1 = (VR_0 + VR_1)/ IR_0 \qquad \ldots\ldots\ldots (5)$$

$$R_1(IR_0) = VR_0 + VR_1$$

$$R_1(IR_0) - V R_1 = VR_0$$

$$R_1(IR_0 - V) = VR_0$$

$$R_1 = (VR_0)/(IR_0 - V) \qquad \ldots\ldots\ldots (6)$$

Where: V - the supply voltage (volts)

R_0 - the known resistance (ohm)

R_1 - the unknown resistance (sample) (ohm)

V_0 - the potential across R_0 (volt)

V_1 - the potential across R_1 (volt)

I_0, I_1, and I – the current flow through resistance 0, resistance 1, and the circuit respectively (amp)

The two main units of 228A voltage/current source and 617 programmable electrometer, KEITHLEY, are used to link the circuit for the 2-probe measurement technique as shown in Figure 8 (d). In case of the current measurement accuracy, a three- minute period of time is allowed for each current value record. The whole process of 2-probe measurement is presented in order as shown in Figures 8 (a), (b), (c), and (d).

CHAPTER V

RESULTS AND DISCUSSION

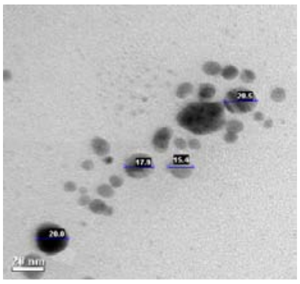
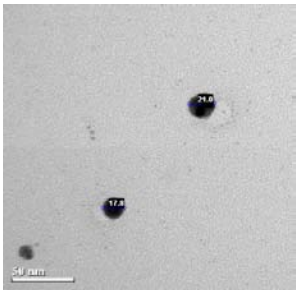
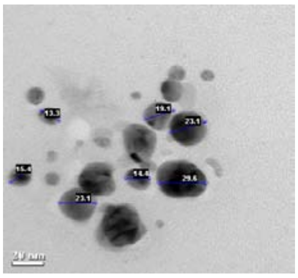
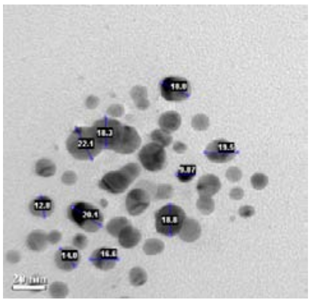
The electrospinning process is demonstrated in the experimental part using both randomized fiber and aligned fiber techniques to form the ultra-fine fibers. The fabricated conditions of the electrospinning processes in the synthesis of conductive polymers in this study are initially summarized whereby voltages between 12.5-22.5 KV are applied on a collecting distance of 15 cm. in 5 minutes for randomized fiber formation and 20, 30, and 45 minutes of both aligned single fiber and aligned fiber mat formation generated from PVA blended with various PEDOT/PSS and AgNPs concentrations. The fiber diameters resulting from these permutations by the researcher in this review varied from 0.1020 μm to 0.3300 μm (the randomized fiber diameter range = 0.114 to 0.298 μm, the aligned single fiber diameter range = 0.15 to 0.33 μm, and the aligned fiber mat diameter range = 0.102 to 0.218 μm.). In this work, the average particle size of AgNPS is 18.65 nm. From the results of spinning process, there are many randomized fibers and aligned fibers on the targets while producing the ultra-fine fibers at 20 and 22.5 kV and very few ultra-fine fibers are found when applying voltages at 12.5, 15, and 17.5 kV. In case of fiber alignment, the aligned fibers were obtained due to the effect of the sheering force of the drum rotating speed. The polymer jets were aligned very well while applying voltage from 12.5 to 17.5kV at about 1,012.13 – 1,015.56 rpm of drum speed.

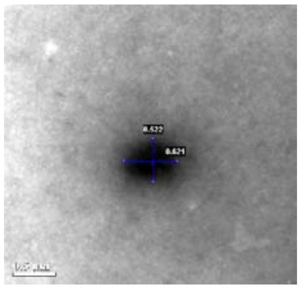
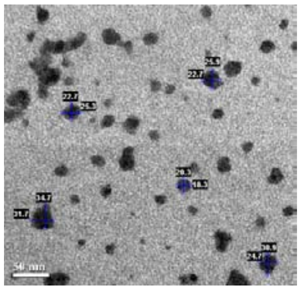
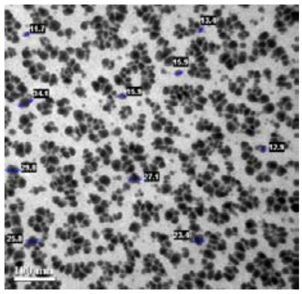
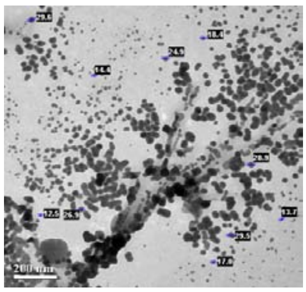
5.1 Morphology of Blended Ultra-fine Fibers

The morphology of PVA, PEDOT/PSS, and silver nanoparticles solutions mainly were investigated by SEM and TEM. The shape of AgNPs diameters and PEDOT/PSS shape in the based solution were measured through the TEM images which were taken by using sample grids before the process of fiber generations. In this part, the diameter of AgNPs and PEDOT/PSS shape both in DI water and PVA solution are presented as followed.

Table 7 Comparison of the diameter of AgNPs and PEDOT/PSS shape

(1) AgNPs concentration: 10.01% w/v (2) PEDOT/PSS concentration: 1.2574% w/v

No.	Solutions	Material Name	Particle Size/ Diameter (nm)	Standard Deviation (nm)	Average Size (nm)	TEM Images
1	AgNPs 563 µl: Water DI 2.874 ml	AgNPs	18.47	2.33	-	
2	AgNPs 563 µl: Water DI 2.874 ml	AgNPs	19.41	2.26	-	
3	AgNPs 563 µl : Water DI 2.874 ml	AgNPs	19.71	5.91	-	
4	AgNPs 563 µl: Water DI 2.874 ml	AgNPs	17.02	3.73	18.65 (item 1-4)	

No.	Solutions	Material Name	Particle Size/ Diameter (nm)	Standard Deviation (nm)	Average Size (nm)	TEM Images
5	PEDOT/PSS: Water (1:30) PEDOT-Positive Charge (Dye with 1%PTA in 1 min.)	PEDOT/PSS	570	70.71	570	
6	PEDOT/PSS: PVA 10% (Dye with 1%PTA in 0.5 min)	PEDOT/PSS	25.72	5.22	25.72	
7	AgNPs 0.3230%: PEDOT/PSS 1.2574%: PTA 1% (water based)	AgNPs & PEDOT/PSS	21.01	8.02	21.01	
8	PVA 1.5%: AgNPs 0.625825%: PEDOT/PSS 1.2574%: PTA 1%	AgNPs & PVA	21.58	7.05	21.58	

The average particle size of AgNPs, in DI water, from items number 1 to 4 of Table 7 is 18.6519 nm while the average sizes of PEDOT/PSS both in water and PVA are 25.7180, item number 5, and 570 nm, item number 6. It can confirm that average particle sizes of AgNPs in this work are smaller than that of PEDOT/PSS. The images of items number 7 and 8 of

Table 7 present the dispersion of AgNPs: PEDOT/PSS in water base and AgNPs: PEDOT/PSS in PVA.

5.1.1 SEM Measurement

5.1.1.1 The results of randomized fibers

The SEM images of randomized fiber samples were illustrated in Appendix A (1) and the SemAfore, software application, was used to measure the fiber diameters as shown in Table 8. The fiber diameters are varied from 0.1140 to 0.2980 μm range. The average diameters of each type of mixed solutions are smaller when increasing the applied voltage such as from 12.5 kV to 22.5 kV. For instance, the average fiber diameters of 10% PVA decrease from 0.1860 μm, 0.1700 μm, 0.1640 μm, 0.1560 μm , and 0.1440 μm while the applied voltages increase from 12.5 kV, 15.0 kV, 17.5 kV, 20.5kV, and 22.5kV as shown in Table 8, items number from 1 to 5 respectively. Meanwhile, the thickness of fiber sheets is measured by using SemAfore. The average thickness of randomized fiber sheets, cross section images, is 6.69 µm as illustrated in more details in Table 9.

Table 8 Summarizes the diameters of randomized fibers of different mixed solutions and applied voltages.

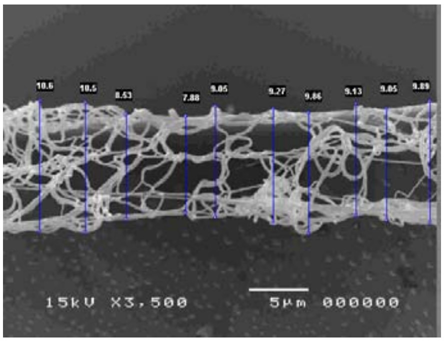
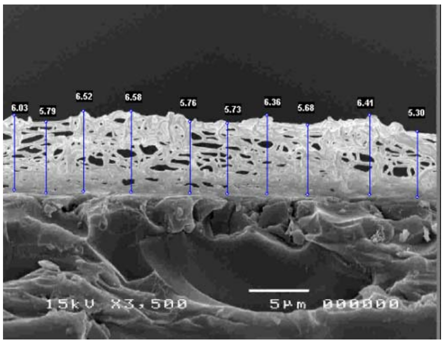
Randomized Fibers				Fiber Diameter (μm)		AgNPs Cluster (μm)	
Items	Material Concentration Ratios (w/v)	Collection Times (min)	Applied Voltages (kV)	Average Diameter	Standard Deviation	Average Widths	Length
1	PVA 10%	5	22.5	0.144	0.0114	N/A	N/A
2	PVA 10%	5	20	0.156	0.0134	N/A	N/A
3	PVA 10%	5	17.5	0.164	0.0241	N/A	N/A
4	PVA 10%	5	15	0.17	0.0122	N/A	N/A
5	PVA 10%	5	12.5	0.186	0.0152	N/A	N/A
6	PVA 10%: PEDOT 0.052%	5	22.5	0.118	0.0217	N/A	N/A
7	PVA 10%: PEDOT 0.052%	5	20	0.122	0.0217	N/A	N/A

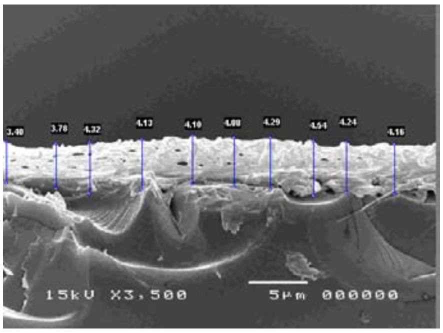
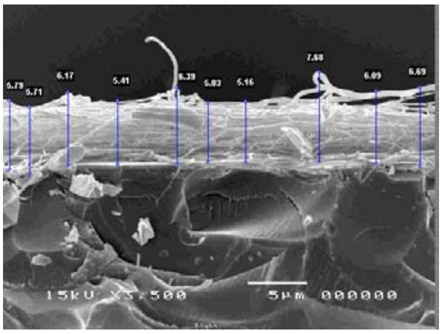
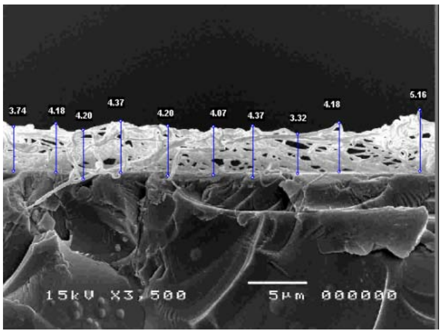
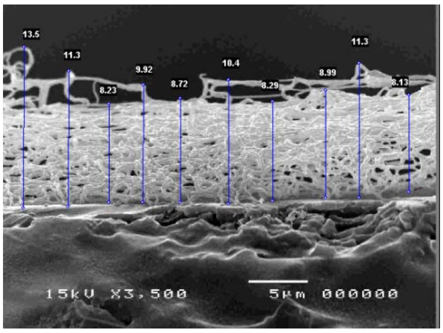
Randomized Fibers				Fiber Diameter (μm)		AgNPs Cluster (μm)	
Items	Material Concentration Ratios (w/v)	Collection Times (min)	Applied Voltages (kV)	Average Diameter	Standard Deviation	Average Widths	Length
8	PVA 10%: PEDOT 0.052%	5	17.5	0.132	0.0192	N/A	N/A
9	PVA 10%: PEDOT 0.052%	5	15	0.138	0.0164	N/A	N/A
10	PVA 10%: PEDOT 0.052%	5	12.5	0.146	0.023	N/A	N/A
11	PVA 10%: PEDOT 0.084%	5	22.5	0.134	0.0055	N/A	N/A
12	PVA 10%: PEDOT 0.084%	5	20	0.14	0.0141	N/A	N/A
13	PVA 10%: PEDOT 0.084%	5	17.5	0.152	0.0148	N/A	N/A
14	PVA 10%: PEDOT 0.084%	5	15	0.164	0.0134	N/A	N/A
15	PVA 10%: PEDOT 0.084%	5	12.5	0.168	0.0084	N/A	N/A
16	PVA 10%: PEDOT 0.1%	5	22.5	0.114	0.0207	N/A	N/A
17	PVA 10%: PEDOT 0.1%	5	20	0.12	0.02	N/A	N/A
18	PVA 10%: PEDOT 0.1%	5	17.5	0.126	0.0241	N/A	N/A
19	PVA 10%: PEDOT 0.1%	5	15	0.134	0.0321	N/A	N/A
20	PVA 10%: PEDOT 0.1%	5	12.5	0.142	0.0303	N/A	N/A
21	PVA 10%: AgNPs 0.25%	5	22.5	0.144	0.0297	1.5	2.45
22	PVA 10%: AgNPs 0.25%	5	20	0.158	0.0148	0.67	1.56
23	PVA 10%: AgNPs 0.25%	5	17.5	0.166	0.0089	0.57	1.28
24	PVA 10%: AgNPs 0.25%	5	15	0.182	0.0217	0.7367	1.84
25	PVA 10%: AgNPs 0.25%	5	12.5	0.194	0.0241	0.67	1.26
26	PVA10%: AgNPs 0.5%	5	22.5	0.12	0.0283	0.7733	2.78
27	PVA10%: AgNPs 0.5%	5	20	0.124	0.0397	0.9033	1.95
28	PVA10%: AgNPs 0.5%	5	17.5	0.128	0.0303	0.7633	2.54
29	PVA10%: AgNPs 0.5%	5	15	0.138	0.0192	0.4067	1.01
30	PVA10%: AgNPs 0.5%	5	12.5	0.162	0.0084	0.4933	1.28
31	PVA10%: AgNPs 0.75%	5	22.5	0.114	0.0297	0.5733	1.11
32	PVA10%: AgNPs 0.75%	5	20	0.118	0.0228	0.49	1.34

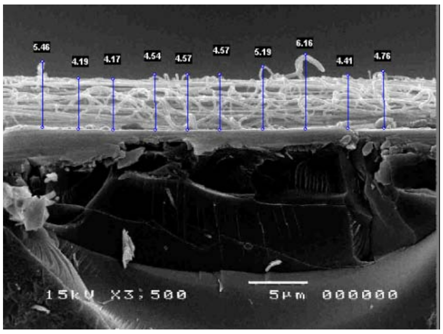
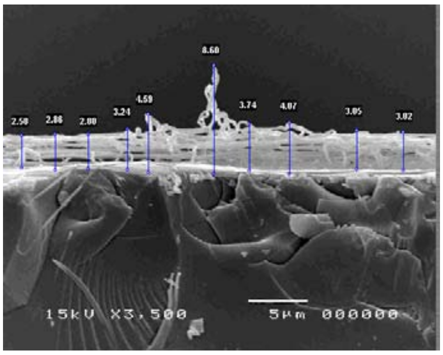
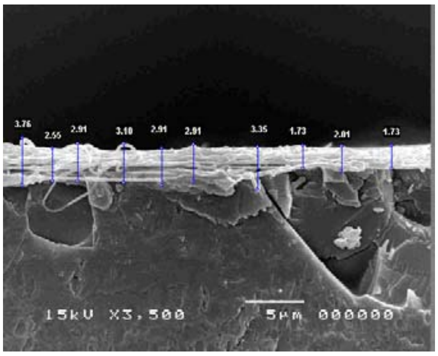
Randomized Fibers				Fiber Diameter (μm)		AgNPs Cluster (μm)	
Items	Material Concentration Ratios (w/v)	Collection Times (min)	Applied Voltages (kV)	Average Diameter	Standard Deviation	Average Widths	Length
33	PVA10%: AgNPs 0.75%	5	17.5	0.122	0.0327	0.82	1.42
34	PVA10%: AgNPs 0.75%	5	15	0.128	0.013	1.5767	1.83
35	PVA10%: AgNPs 0.75%	5	12.5	0.138	0.0192	1.07	1.73
36	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	5	22.5	0.172	0.0327	0.39	0.88
37	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	5	20	0.202	0.0259	0.5133	1.09
38	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	5	17.5	0.228	0.037	0.6933	1.67
39	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	5	15	0.24	0.01	0.6567	1.23
40	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	5	12.5	0.298	0.0228	0.6233	1.42
41	PVA10%: AgNPs 0.5%: PEDOT/PSS 0.084%	5	22.5	0.168	0.0164	0.7033	1.37
42	PVA10%: AgNPs 0.5%: PEDOT/PSS 0.084%	5	20	0.172	0.013	0.8033	1.18
43	PVA10%: AgNPs 0.5%: PEDOT/PSS 0.084%	5	17.5	0.18	0.0158	0.6567	1.51
44	PVA10%: AgNPs 0.5%: PEDOT/PSS 0.084%	5	15	0.188	0.0239	1.4567	1.68
45	PVA10%: AgNPs 0.5%: PEDOT/PSS 0.084%	5	12.5	0.208	0.0084	0.5	1.83
46	PVA10%: AgNPs 0.75%: PEDOT/PSS 0.084%	5	22.5	0.168	0.0228	0.94	1.55
47	PVA10%: AgNPs 0.75%: PEDOT/PSS 0.084%	5	20	0.178	0.0148	0.9667	1.87

Randomized Fibers				Fiber Diameter (μm)		AgNPs Cluster (μm)	
Items	Material Concentration Ratios (w/v)	Collection Times (min)	Applied Voltages (kV)	Average Diameter	Standard Deviation	Average Widths	Length
48	PVA10%: AgNPs 0.75%: PEDOT/PSS 0.084%	5	17.5	0.186	0.0167	0.3833	1.05
49	PVA10%: AgNPs 0.75%: PEDOT/PSS 0.084%	5	15	0.21	0.0141	0.6033	1.3
50	PVA10%: AgNPs 0.75%: PEDOT/PSS 0.084%	5	12.5	0.2158	0.0086	0.9933	2.28

Table 9 Summarizes the fiber thickness of randomized single fiber sheet of different mixed solutions and applied voltages

Items	Material Concentration Ratios (w/v)	Applied Voltages (kV)	Average Thickness (μm)	STDEV	SEM Images
1	PVA10%: PEDOT/PSS 0.084%	17.5	9.38	0.8575	
2	PVA10%: PEDOT/PSS 0.084%	20	6.02	0.4307	

Items	Material Concentration Ratios (w/v)	Applied Voltages (kV)	Average Thickness (µm)	STDEV	SEM Images
3	PVA10%: PEDOT/PSS 0.084%	22.5	4.10	0.3153	
4	PVA10%: AgNPs0.25% (#1)	17.5	6.01	0.7897	
5	PVA10%: AgNPs0.25% (#2)	20	4.18	0.4712	
6	PVA10%: AgNPs 0.25%	22.5	9.87	1.7460	

Items	Material Concentration Ratios (w/v)	Applied Voltages (kV)	Average Thickness (µm)	STDEV	SEM Images
7	PVA10%: AgNPs0.25%: PEDOT/PSS 0.084%(#2)	12.5	4.80	0.6266	
8	PVA10%: AgNPs0.25%: PEDOT/PSS 0.084%	15	3.86	1.7816	
9	PVA10%: AgNPs0.25%: PEDOT/PSS 0.084%	22.5	2.70	0.6844	

Moreover, the randomized fiber elements are investigated by EDS technique confirming the element of mixed solution on the aluminum foil substrates. AgNPs is denoted by the following images and is recorded by EDS as shown in Table 10.

Table 10 Element of randomized fibers of 10% PVA: 0.25% AgNPs, at 12.5 kV, is analyzed by using the EDS mode, under SEM measurement.

Spectrum label: PVA10%+AgNPs0.25%_12.5 kV

System resolution = 60 eV

Quantitative method: ZAF (4 iterations).

Analysed all elements and normalised results.

4 peaks possibly omitted: 2.14, 9.70, 11.46, 13.34 keV

Standards :

C K CaCO3 01/12/93

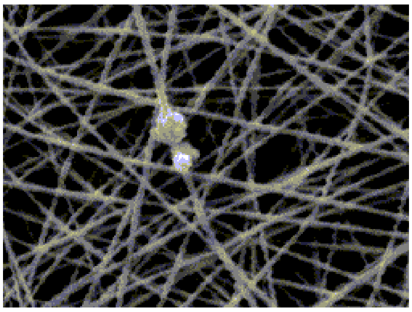
Al K Al2O3 23/11/93

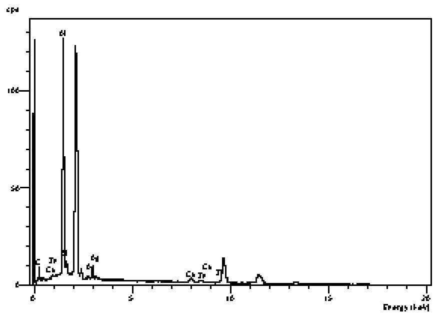
Cu K Cu 01/12/93

Ag L Ag 01/12/93

Elmt	Spect. Type	Element %	Atomic %
C K	ED	15.13	50.62
Al K	ED	15.20	22.64
Cu K	ED	2.99	1.89
Ag L	ED	66.68	24.85
Total		100.00	100.00

* = <2 Sigma





5.1.1.2 The results of aligned single fibers

The SEM images of aligned single fiber samples were illustrated in Appendix B (1) and the SemAfore, software application, was used to measure the fiber diameters as shown in Table 11. The fiber diameters are varied from 0.1520 to 0.33 μm range. The average diameters of each type of mixed solutions are smaller when increasing the applied voltage such as from 12.5 kV to 17.5 kV. For instance, the average fiber diameter of 10% PVA decreases from

0.2600 μm, 0.2040 μm, and 0.1820 μm while the applied voltages increase from 12.5 kV, 15.0 kV, and 17.5 kV as shown in Table 11, items number from 1 to 3 respectively.

Table 11 Summarizes the diameters of aligned single fibers of different mixed solutions and applied voltages.

Aligned Single Fibers				Fiber Diameter (μm)		AgNPs Cluster (μm)	
Items	Material Concentration Ratios (w/v)	Collection Times (min)	Applied Voltages (kV)	Average Diameter	Standard Deviation	Average Widths	Length
1	PVA 10%	20	17.5	0.182	0.0045	N/A	N/A
2	PVA 10%	20	15	0.204	0.0279	N/A	N/A
3	PVA 10%	20	12.5	0.26	0.043	N/A	N/A
4	PVA 10%: PEDOT 0.052%	20	17.5	0.17	0.052	N/A	N/A
5	PVA 10%: PEDOT 0.052%	20	15	0.23	0.0548	N/A	N/A
6	PVA 10%: PEDOT 0.052%	20	12.5	0.33	0.086	N/A	N/A
7	PVA 10%: PEDOT 0.084%	20	17.5	0.156	0.0182	N/A	N/A
8	PVA 10%: PEDOT 0.084%	20	15	0.168	0.0311	N/A	N/A
9	PVA 10%: PEDOT 0.084%	20	12.5	0.172	0.0084	N/A	N/A
10	PVA 10%: PEDOT 0.1%	20	17.5	0.194	0.0134	N/A	N/A
11	PVA 10%: PEDOT 0.1%	20	15	0.268	0.0249	N/A	N/A
12	PVA 10%: PEDOT 0.1%	20	12.5	0.27	0.0255	N/A	N/A
13	PVA 10%: AgNPs 0.25%	20	17.5	0.178	0.0356	N/A	N/A
14	PVA 10%: AgNPs 0.25%	20	15	0.188	0.013	N/A	N/A
15	PVA 10%: AgNPs 0.25%	20	12.5	0.21	0.0158	N/A	N/A
16	PVA10%: AgNPs 0.5%	20	17.5	0.248	0.061	N/A	N/A
17	PVA10%: AgNPs 0.5%	20	15	0.258	0.013	N/A	N/A
18	PVA10%: AgNPs 0.5%	20	12.5	0.272	0.0421	N/A	N/A
19	PVA10%: AgNPs 0.75%	20	17.5	0.152	0.0295	N/A	N/A

Aligned Single Fibers				Fiber Diameter (μm)		AgNPs Cluster (μm)	
Items	Material Concentration Ratios (w/v)	Collection Times (min)	Applied Voltages (kV)	Average Diameter	Standard Deviation	Average Widths	Length
20	PVA10%: AgNPs 0.75%	20	15	0.218	0.0084	N/A	N/A
21	PVA10%: AgNPs 0.75%	20	12.5	0.224	0.0089	N/A	N/A
22	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	45	17.5	0.158	0.0045	N/A	N/A
23	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	30	17.5	0.188	0.0192	N/A	N/A

5.1.1.3 The results of aligned fiber mat

The SEM images of aligned fiber mat samples were illustrated in Appendix B (3) and the SemAfore, software application, was used to measure the fiber diameters as shown in Table 12. The fiber diameters are varied from 0.1020 to 0.218 μm range. The average diameters of each type of mixed solutions are smaller when increasing the applied voltages such as from 12.5 kV to 17.5 kV. For instance, the average fiber diameter of 10% PVA decreases from 0.1320 μm, 0.1200 μm, and 0.1060 μm while the applied voltages increase from 12.5 kV, 15.0 kV, and 17.5 kV as shown in Table 12, items number from 1 to 3 respectively.

Table 12 Summarizes the diameters of aligned fiber mat of different mixed solutions and applied voltages.

Aligned Fiber Mat				Fiber Diameter (μm)		AgNPs Cluster (μm)	
Items	Material Concentration Ratios (w/v)	Collection Times (min)	Applied Voltages (kV)	Average Diameter	Standard Deviation	Average Widths	Length
1	PVA 10%	20	17.5	0.106	0.0114	N/A	N/A
2	PVA 10%	20	15	0.12	0.0245	N/A	N/A
3	PVA 10%	20	12.5	0.132	0.0084	N/A	N/A

Aligned Fiber Mat				Fiber Diameter (μm)		AgNPs Cluster (μm)	
Items	Material Concentration Ratios (w/v)	Collection Times (min)	Applied Voltages (kV)	Average Diameter	Standard Deviation	Average Widths	Length
4	PVA 10%: PEDOT 0.052%	20	17.5	0.102	0.013	N/A	N/A
5	PVA 10%: PEDOT 0.052%	20	15	0.108	0.0084	N/A	N/A
6	PVA 10%: PEDOT 0.052%	20	12.5	0.116	0.0055	N/A	N/A
7	PVA 10%: PEDOT 0.084%	20	17.5	0.102	0.013	N/A	N/A
8	PVA 10%: PEDOT 0.084%	20	15	0.112	0.013	N/A	N/A
9	PVA 10%: PEDOT 0.084%	20	12.5	0.122	0.0228	N/A	N/A
10	PVA 10%: PEDOT 0.1%	20	17.5	0.114	0.0114	N/A	N/A
11	PVA 10%: PEDOT 0.1%	20	15	0.12	0.0071	N/A	N/A
12	PVA 10%: PEDOT 0.1%	20	12.5	0.126	0.0055	N/A	N/A
13	PVA10%: AgNPs 0.25%	20	17.5	0.12	0.0187	0.5233	1.04
14	PVA10%: AgNPs 0.25%	20	15	0.13	0.0224	0.4433	1.05
15	PVA10%: AgNPs 0.25%	20	12.5	0.14	0.0412	0.3433	1.02
16	PVA10%: AgNPs 0.5%	20	17.5	0.12	0.0158	0.36	0.82
17	PVA10%: AgNPs 0.5%	20	15	0.13	0.0255	0.81	2.24
18	PVA10%: AgNPs 0.5%	20	12.5	0.142	0.0192	0.68	1.98
19	PVA10%: AgNPs 0.75%	20	17.5	0.136	0.0358	0.6967	1.2
20	PVA10%: AgNPs 0.75%	20	15	0.148	0.011	0.7467	2.36
21	PVA10%: AgNPs 0.75%	20	12.5	0.158	0.0311	0.4433	1.09
22	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	20	17.5	0.136	0.0297	0.64	1.2
23	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	20	15	0.156	0.0114	0.4333	1.13
24	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	20	12.5	0.192	0.0239	0.5067	1.19
25	PVA10%: AgNPs 0.5%: PEDOT/PSS 0.084%	20	17.5	0.136	0.0358	0.7267	1.33

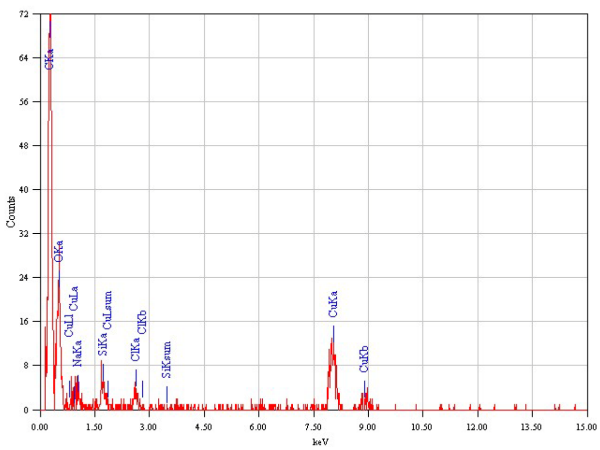
Aligned Fiber Mat				Fiber Diameter (μm)		AgNPs Cluster (μm)	
Items	Material Concentration Ratios (w/v)	Collection Times (min)	Applied Voltages (kV)	Average Diameter	Standard Deviation	Average Widths	Length
26	PVA10%: AgNPs 0.5%: PEDOT/PSS 0.084%	20	15	0.144	0.0261	0.6733	1.99
27	PVA10%: AgNPs 0.5%: PEDOT/PSS 0.084%	20	12.5	0.218	0.0228	0.8267	1.93
28	PVA10%: AgNPs 0.75%: PEDOT/PSS 0.084%	20	17.5	0.136	0.0207	0.4167	0.69
29	PVA10%: AgNPs 0.75%: PEDOT/PSS 0.084%	20	15	0.152	0.0148	0.7633	1.72
30	PVA10%: AgNPs 0.75%: PEDOT/PSS 0.084%	20	12.5	0.176	0.0313	0.4833	1.61
31	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	30	17.5	0.13	0.0274	0.7267	2.67
32	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	30	15	0.136	0.0428	0.3967	2.9
33	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	30	12.5	0.14	0.0122	0.5267	1.36
34	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	45	17.5	0.112	0.0239	0.5333	1.08
35	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	45	15	0.114	0.0114	1.1667	1.74
36	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	45	12.5	0.128	0.0259	0.6267	1.55

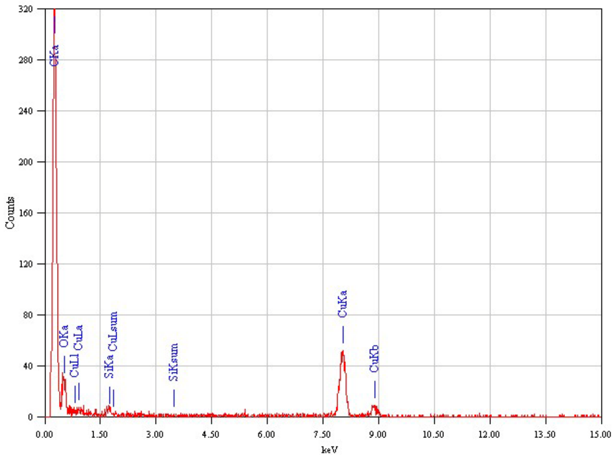
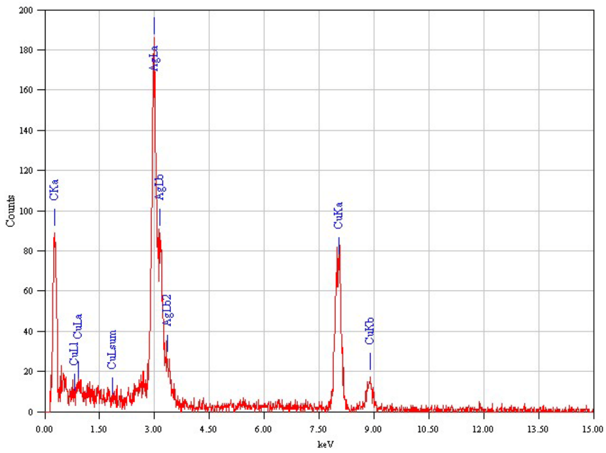
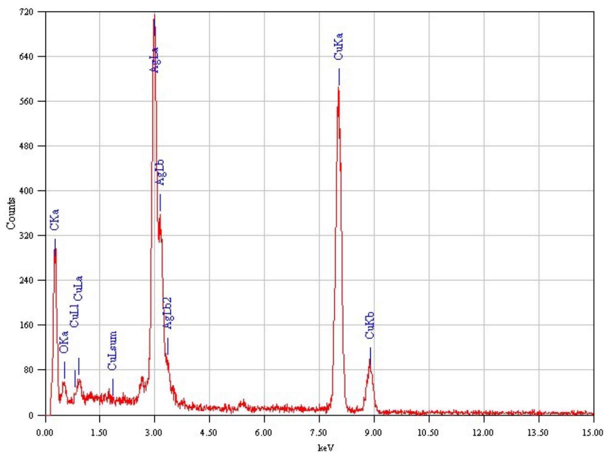
5.1.2 TEM Measurement

The TEM images of the randomized fiber, aligned single fiber, and aligned fiber mat were illustrated in Appendix A (2), B (2), and B (4) respectively. The difference of fiber patterns depends on fiber generation techniques. Thus, in case of the randomized fibers, the fabricated fibers show their images, by TEM, as a disordered direction on the sample grids which are confirmed by the SEM images. On the other hand, the fabricated fibers produced and collected on the rotation drum are mostly aligned in the same direction. Therefore, the images of aligned single fibers and aligned fiber mat technique are different from those of randomized fibers. The aligned single fibers are rarely found on the sample substrate while many aligned fibers are formed as aligned fiber mats. Furthermore, the electrospun fibers are well-alignment in a large quantity at the low applied voltages between 12.5 kV and 17.5 kV.

The EDS mode, TEM system, is used to analyze the elements of fiber materials as shown in Table 13.

Table 13 Summarizes the element analysis of randomized fibers by using the EDS mode under TEM system.

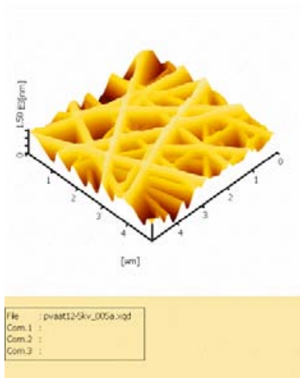
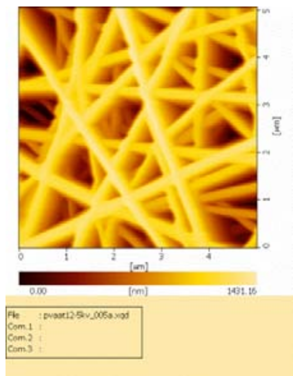
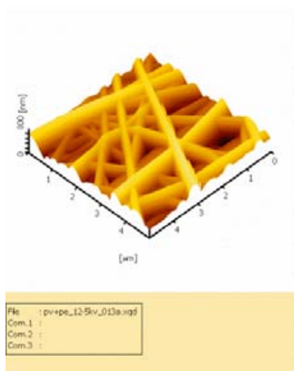
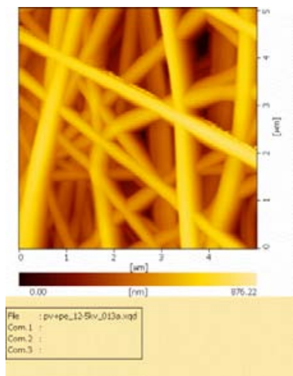
Items	Material Concentration Ratios (w/v)	Applied Voltages (kV)	EDS graph
1	PVA 10%	12.5	

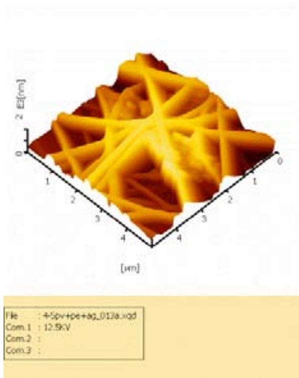
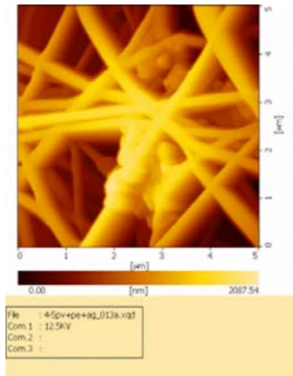
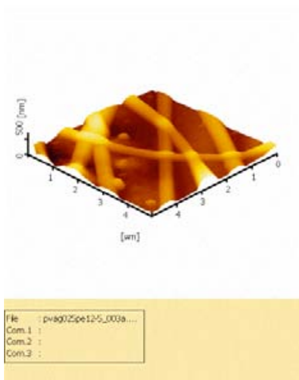
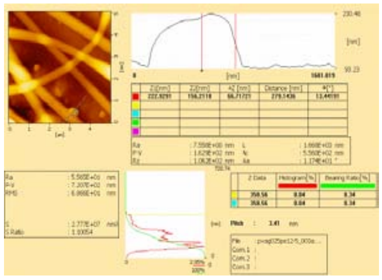
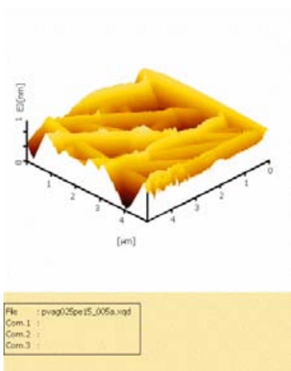
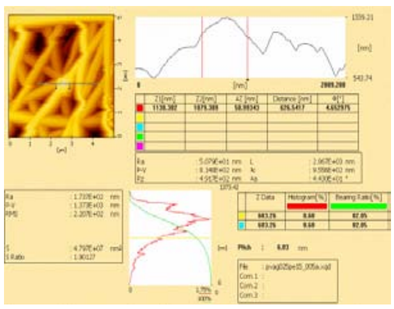
Items	Material Concentration Ratios (w/v)	Applied Voltages (kV)	EDS graph
2	PVA 10%: PEDOT 0.084%	20	
3	PVA10%: AgNPs 0.5%	12.5	
4	PVA10%: AgNPs 0.75%	12.5	

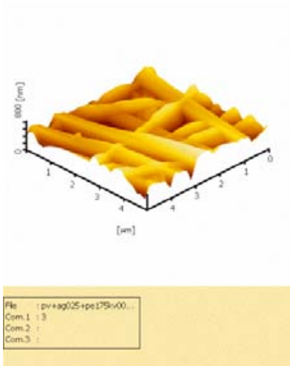
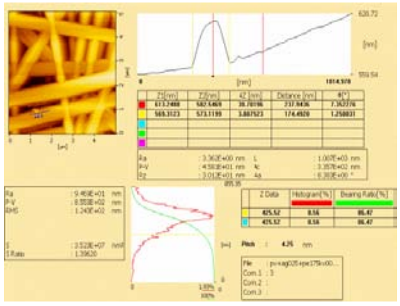
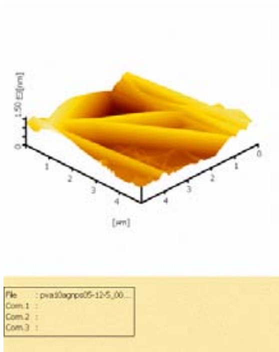
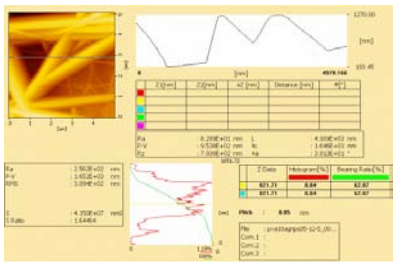
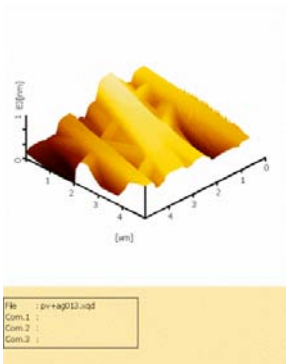
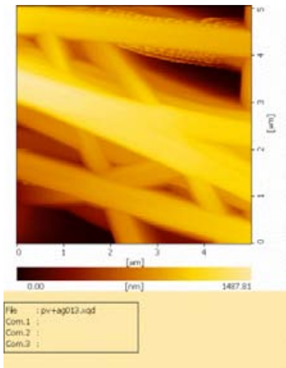
5.1.3 AFM Measurement

The three dimension images of randomized and aligned fibers, by AFM measurement, were presented in Table 14.

Table 14 Summarizes the 3 dimension analysis of randomized and aligned fibers with different conditions by using the AFM.

Items	Material Concentration Ratios (w/v)	Applied Voltages (kV)	AFM images (3D)	AFM images (Top Views)
Randomized Fibers				
1	PVA 10%	12.5		
2	PVA 10%: PEDOT 0.084%	12.5		

Items	Material Concentration Ratios (w/v)	Applied Voltages (kV)	AFM images (3D)	AFM images (Top Views)
3	PVA10%: AgNPs 1%: PEDOT/PSS 0.084%	12.5		
	Aligned Fibers			
4	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	12.5		
5	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	15		

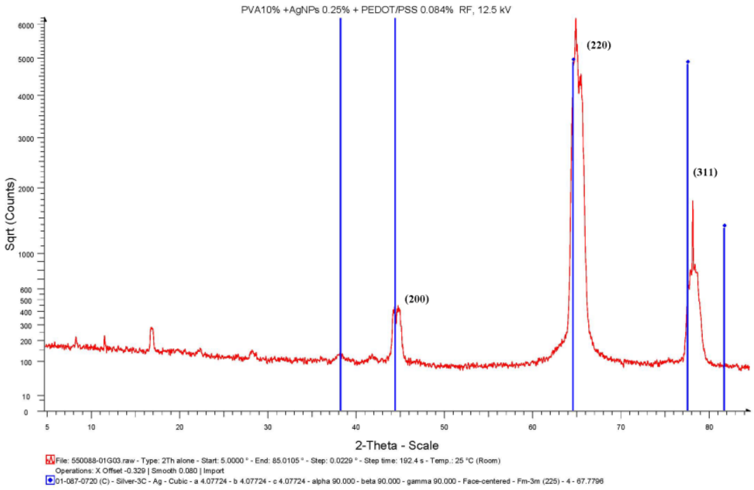
Items	Material Concentration Ratios (w/v)	Applied Voltages (kV)	AFM images (3D)	AFM images (Top Views)
6	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	17.5		
7	PVA10%: AgNPs 0.5%: PEDOT/PSS 0.084%	12.5		
8	PVA10%: AgNPs 0.75%: PEDOT/PSS 0.084%	12.5		

5.1.4 XRD Measurement

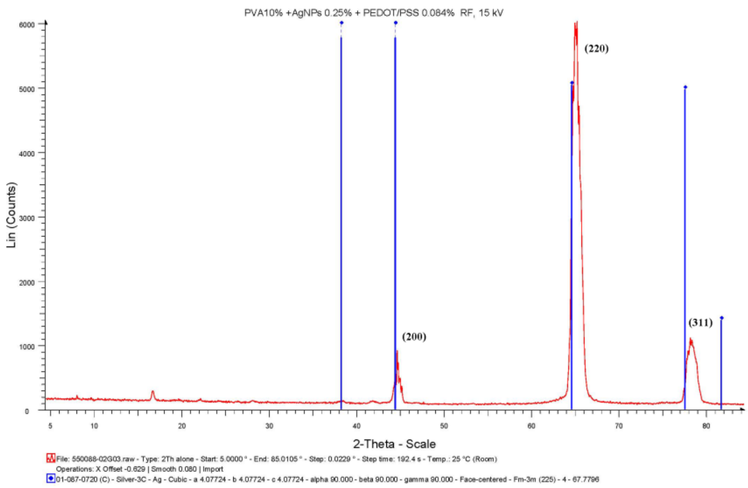
XRD is used to characterize the fiber morphology to understand more about the material structure of AgNPs such as lattice planes as shown in Table 15. The AgNPs peaks on the graph images of each condition are compared to the standard database to see the plane of lattice in Appendix F.

Table 15 Summarizes the fiber structure analysis of randomized and aligned fibers with different conditions by using the XRD.

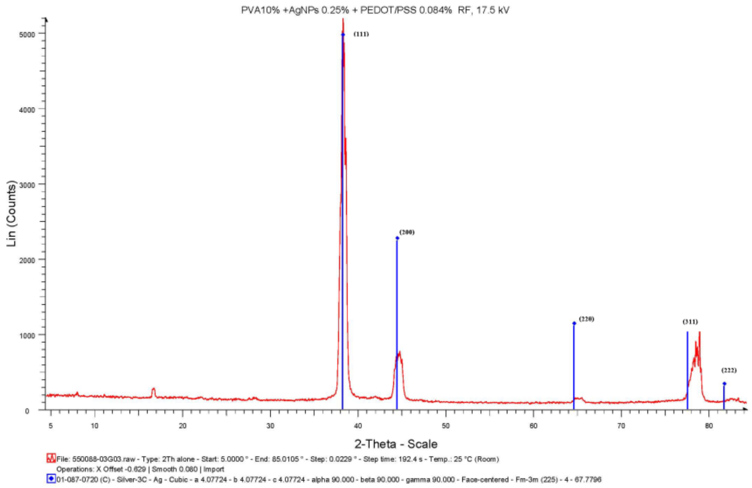
Items	Material Concentration Ratios (w/v)	Applied Voltages (kV)
Randomized Fibers		
1	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	12.5



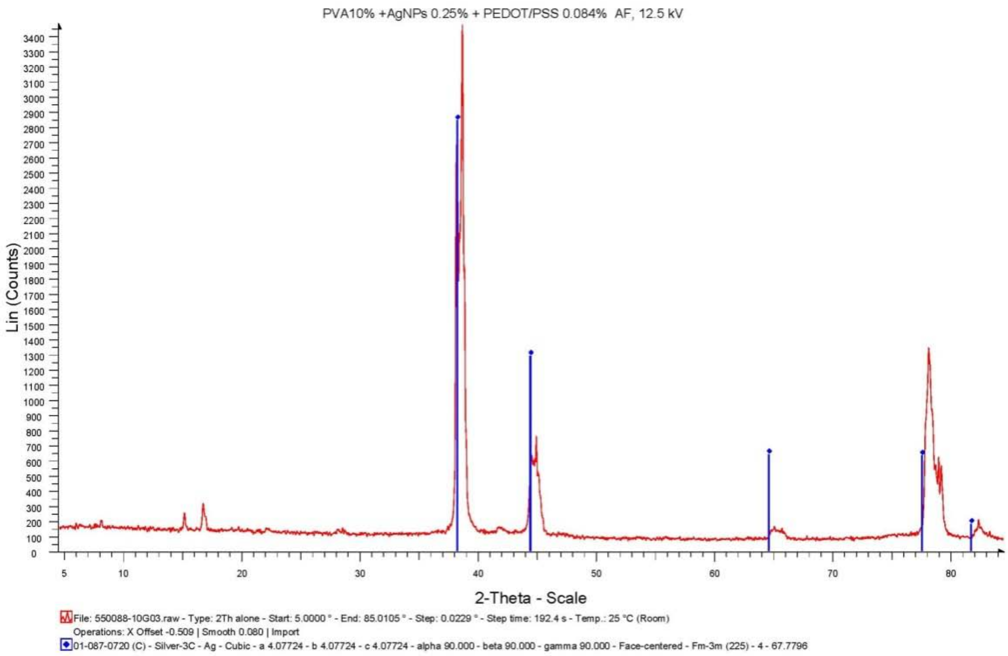
Items	Material Concentration Ratios (w/v)	Applied Voltages (kV)
2	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	15



Items	Material Concentration Ratios (w/v)	Applied Voltages (kV)
3	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	17.5



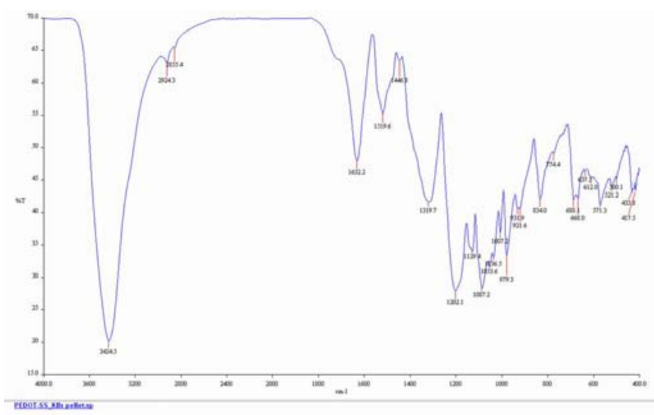
Items	Material Concentration Ratios (w/v)	Applied Voltages (kV)
Aligned Fibers		
4	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	12.5



5.1.5 FT-IR Measurement

FT-IR is used to characterize the fiber morphology to understand more about the polymer structures of PEDOT/PSS as shown in Table 16.

Table 16 Characterizes PEDOT/PSS to present the functional group by using the KBr disk, FT-IR.

Items	Material Concentration Ratios (w/v)	Applied Voltages (kV)	FTIR Images
2	PEDOT/PSS 0.084% (KBr Pellet)		 Functional Group: 201 ALKYL GROUP – GENERAL 402 HYDROXY OR AMINO COMPOUND - GENERAL

5.2 Electrical Conductivity Property

5.2.1 Type of Major Carriers and Its Mobility

The electrical conductivity property arises when loading more concentration of PEDOT/PSS and AgNPs to form the ultra-fine nanocomposite fibers. Usually, PEDOT is a conductive polymer which carries positive charges and AgNPs carries positive charges as well. The charges themselves also have conductivity property of ultra-fine nanocomposite fibers. The conductivity of PEDOT/PSS can be described as a conjugated system which is based on connected p-orbitals with delocalized electrons in the ultra-fine fibers with alternating single and multiple bonds. In this work, the charge carrier mobility is increased when increasing the concentration of PEDOT/PSS and AgNPs.

5.2.2 The 4-probe Conductivity of Randomized Fibers

The 4-probe conductivity of randomized fibers is presented in terms of resistivity. So, conductivity trend is described as shown in Table 17 and Figure 9 to 12.

Randomized Fibers

The fiber sheet thickness (D) = 6.69 μm (0.000669 cm)

Applied Voltage (kV)	Fiber Thickness (μm)	Fiber Thickness (cm)
22.5	9.7	0.00097
20	8.62	0.000862
17.5	7.54	0.000754
15	6.47	0.000647
12.5	5.39	0.000539

Table 17 Resistivity measurement result of randomized fibers by using the 4-probe measurement (in 5 minutes' time of fiber collection)

No.	Materials	Applied Voltages (kV)	Average Diameter (µm)	Sheet Resistivity (Ω/sq)	Bulk Resistivity (ohm -cm)	Conductivity (Siemens/cm)
The applied current = 10 nA						
1	PVA10%	22.5	0.144	13.20	0.012804	78.10
2	PVA10%	20	0.156	16.40	0.014137	70.74
3	PVA10%	17.5	0.164	12.10	0.009123	109.61
4	PVA10%	15	0.17	26.40	0.017081	58.55
5	PVA10%	12.5	0.186	308.00	0.166012	6.02
6	PVA10%: PEDOT/PSS 0.052%	22.5	0.118	6.38	0.006189	161.59
7	PVA10%: PEDOT/PSS 0.052%	20	0.122	9.62	0.008292	120.59
8	PVA10%: PEDOT/PSS 0.052%	17.5	0.132	9.63	0.007261	137.72
9	PVA10%: PEDOT/PSS 0.052%	15	0.138	0.42	0.000274	3653.89
10	PVA10%: PEDOT/PSS 0.052%	12.5	0.146	109.00	0.058751	17.02
11	PVA10%: PEDOT/PSS 0.084%	22.5	0.134	0.53	0.000518	1930.58
12	PVA10%: PEDOT/PSS 0.084%	20	0.14	1.08	0.000931	1074.16
13	PVA10%: PEDOT/PSS 0.084%	17.5	0.152	1.09	0.000822	1216.75
14	PVA10%: PEDOT/PSS 0.084%	15	0.164	13.10	0.008476	117.98

No.	Materials	Applied Voltages (kV)	Average Diameter (µm)	Sheet Resistivity (Ω/sq)	Bulk Resistivity (ohm -cm)	Conductivity (Siemens/cm)
15	PVA10%: PEDOT/PSS 0.084%	12.5	0.168	6.73	0.003627	275.67
16	PVA10%: PEDOT/PSS 0.1%	22.5	0.114	3.57	0.003463	288.78
17	PVA10%: PEDOT/PSS 0.1%	20	0.12	0.34	0.000290	3442.41
18	PVA10%: PEDOT/PSS 0.1%	17.5	0.126	4.40	0.003318	301.42
19	PVA10%: PEDOT/PSS 0.1%	15	0.134	3.71	0.002400	416.60
20	PVA10%: PEDOT/PSS 0.1%	12.5	0.142	6.28	0.003385	295.43
21	PVA10%: AgNPs 0.25%	22.5	0.144	18.80	0.018236	54.84
22	PVA10%: AgNPs 0.25%	20	0.158	4.59	0.003957	252.74
23	PVA10%: AgNPs 0.25%	17.5	0.166	1.27	0.000958	1044.30
24	PVA10%: AgNPs 0.25%	15	0.182	10.10	0.006535	153.03
25	PVA10%: AgNPs 0.25%	12.5	0.194	26.40	0.014230	70.28
26	PVA10%: AgNPs 0.5%	22.5	0.12	0.32	0.000314	3181.88
27	PVA10%: AgNPs 0.5%	20	0.124	19.80	0.017068	58.59
28	PVA10%: AgNPs 0.5%	17.5	0.128	21.10	0.015909	62.86
29	PVA10%: AgNPs 0.5%	15	0.138	0.13	0.000081	12364.76
30	PVA10%: AgNPs 0.5%	12.5	0.162	0.20	0.000107	9370.14
31	PVA10%: AgNPs 0.75%	22.5	0.114	41.70	0.040449	24.72
32	PVA10%: AgNPs 0.75%	20	0.118	14.90	0.012844	77.86
33	PVA10%: AgNPs 0.75%	17.5	0.122	20.90	0.015759	63.46
34	PVA10%: AgNPs 0.75%	15	0.128	33.20	0.021480	46.55
35	PVA10%: AgNPs 0.75%	12.5	0.138	0.15	0.000082	12205.84

No.	Materials	Applied Voltages (kV)	Average Diameter (µm)	Sheet Resistivity (Ω/sq)	Bulk Resistivity (ohm -cm)	Conductivity (Siemens/cm)
The applied current = 20 nA						
36	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	22.5	0.172	0.34	0.000327	3059.13
37	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	20	0.202	0.37	0.000321	3118.53
38	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	17.5	0.228	0.34	0.000253	3947.20
39	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	15	0.24	0.35	0.000224	4467.04
40	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%	12.5	0.298	0.36	0.000196	5096.94
41	PVA10%: AgNPs 0.5%: PEDOT/PSS 0.084%	22.5	0.168	0.30	0.000294	3402.40
42	PVA10%: AgNPs 0.5%: PEDOT/PSS 0.084%	20	0.172	0.62	0.000537	1862.11
43	PVA10%: AgNPs 0.5%: PEDOT/PSS 0.084%	17.5	0.18	0.31	0.000232	4306.04
44	PVA10%: AgNPs 0.5%: PEDOT/PSS 0.084%	15	0.188	0.33	0.000214	4683.62
45	PVA10%: AgNPs 0.5%: PEDOT/PSS 0.084%	12.5	0.208	0.34	0.000182	5505.30
46	PVA10%: AgNPs 0.75%: PEDOT/PSS 0.084%	22.5	0.168	0.08	0.000077	13066.26
47	PVA10%: AgNPs 0.75%: PEDOT/PSS 0.084%	20	0.178	0.11	0.000094	10643.05
48	PVA10%: AgNPs 0.75%: PEDOT/PSS 0.084%	17.5	0.186	0.11	0.000081	12280.18
49	PVA10%: AgNPs 0.75%: PEDOT/PSS 0.084%	15	0.21	0.16	0.000100	9971.58
50	PVA10%: AgNPs 0.75%: PEDOT/PSS 0.084%	12.5	0.2158	0.28	0.000149	6697.79

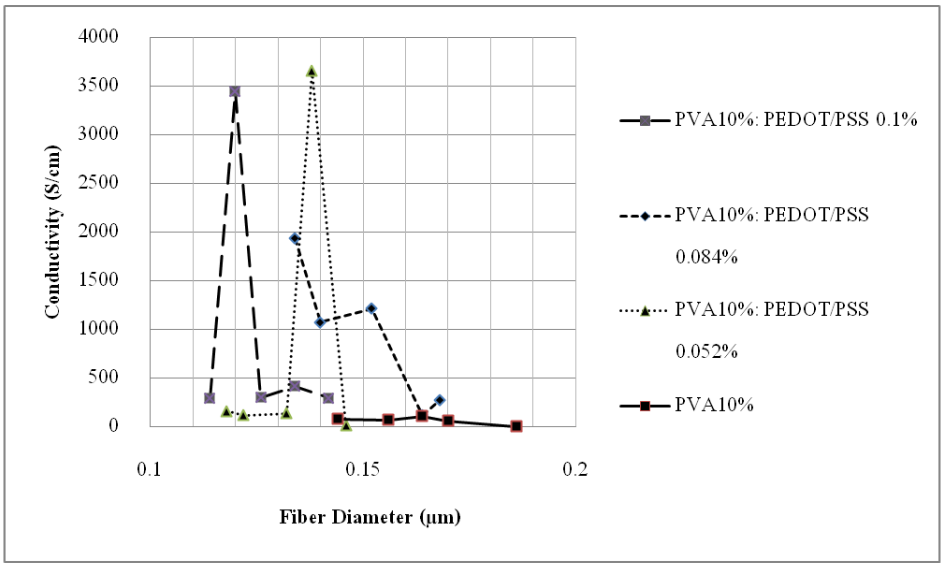


Figure 9 Average resistivity (Ω cm) of 10% PVA fibers blended with PEDOT/PSS concentrations of 0.052, 0.084, and 0.1% (each concentration was fabricated at 12.5, 15, 17.5, 20 and 22.5 K in 5 min.) by using the 4-probe measurement.

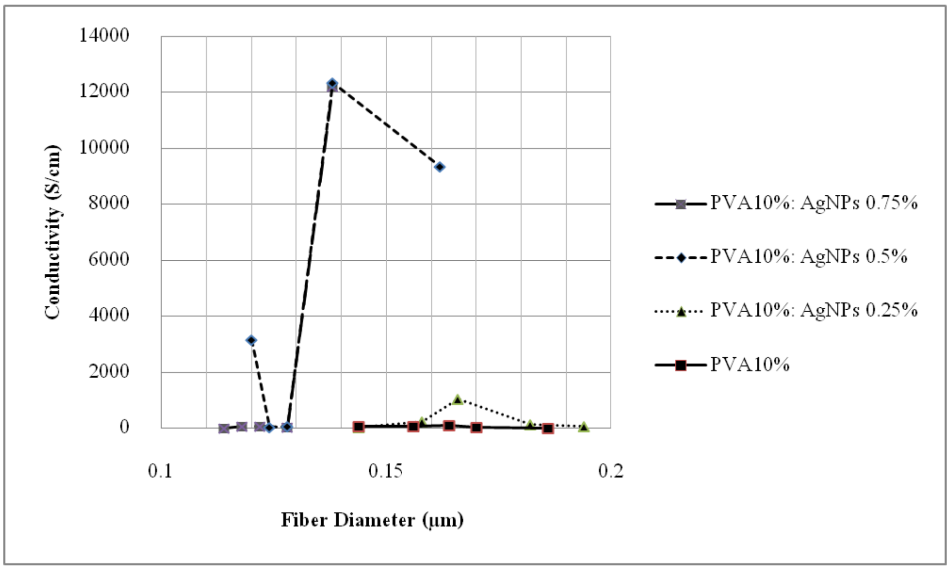


Figure 10 Average resistivity (Ω cm) of 10% PVA fibers blended with AgNPs concentrations of 0.25, 0.5, and 0.75% (each concentration was fabricated at 12.5, 15, 17.5, 20 and 22.5 kV in 5 min.) by using the 4-probe measurement.

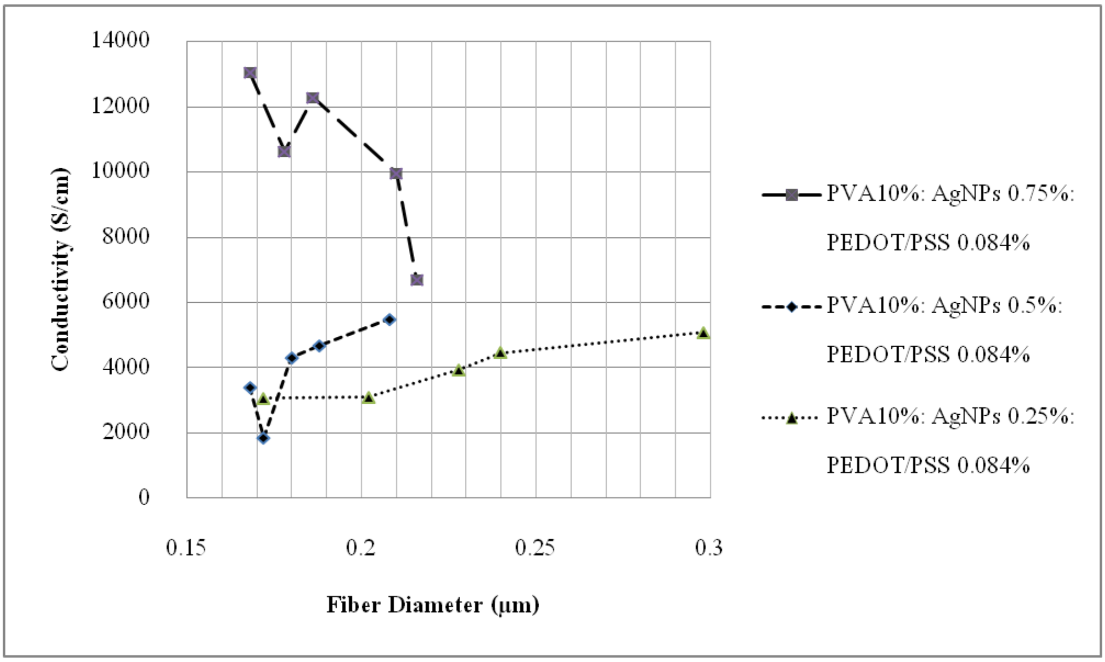


Figure 11 Average resistivity (Ω cm) of 0.084% PEDOT/PSS and 10% PVA fibers blended with AgNPs concentrations of 0.25, 0.5, and 0.75% (each concentration was fabricated at 12.5, 15, 17.5, 20, and 22.5 kV in 5 min.) by using the 4-probe measurement.

5.2.3 The 2-probe Conductivity of Aligned Fibers

The 2-probe conductivity of aligned fibers is presented in terms of resistivity. So, the conductivity trend of aligned single fibers is described as shown in Table 18 and Figure 13 to 15 while the conductivity trend of aligned fiber mat is described as shown in Table 19 and Figure 16 to 20. It means that the resistivity is decreased when current is increased.

Aligned Single Fibers

Table 18 Resistivity measurement result of aligned single fibers by using the 2-probe measurement (item no.1 to 21: under 20 minutes of fiber collecting time, item no.22: under 45 minutes of fiber collecting time, and item no.23: under 30 minutes of fiber collecting time)

Fiber Length (l) = 0.6 cm (60000 µm)

No.	Materials	Applied Voltages (kV) in 20 min.	Average Diameter (μm)	Resistance (MΩ): abs R_1 = $(V*R_0)/(I*R_0-V)$	Resistivity (Ohm.cm)	Conductivity (Siemens/cm)
1	PVA 10%	17.5	0.182	2361.2904	0.102384	9.77
2	PVA 10%	15	0.204	2228.0031	0.121371	8.24
3	PVA 10%	12.5	0.26	1803.3754	0.159577	6.27
4	PVA 10%: PEDOT/PSS 0.052%	17.5	0.17	707.9786	0.026783	37.34
5	PVA 10%: PEDOT/PSS 0.052%	15	0.23	1000.2138	0.069261	14.44
6	PVA 10%: PEDOT/PSS 0.052%	12.5	0.33	1657.0357	0.236210	4.23
7	PVA 10%: PEDOT/PSS 0.084%	17.5	0.156	664.7584	0.021176	47.22
8	PVA 10%: PEDOT/PSS 0.084%	15	0.168	824.5442	0.030463	32.83
9	PVA 10%: PEDOT/PSS 0.084%	12.5	0.172	1061.4299	0.041104	24.33
10	PVA 10%: PEDOT/PSS 0.1%	17.5	0.194	428.7931	0.021125	47.34
11	PVA 10%: PEDOT/PSS 0.1%	15	0.268	512.2734	0.048163	20.76
12	PVA 10%: PEDOT/PSS 0.1%	12.5	0.27	649.6600	0.061994	16.13
13	PVA 10%: AgNPs 0.25%	17.5	0.178	848.1452	0.035176	28.43
14	PVA 10%: AgNPs 0.25%	15	0.188	854.9982	0.039557	25.28
15	PVA 10%: AgNPs 0.25%	12.5	0.21	887.2247	0.051217	19.52

No.	Materials	Applied Voltages (kV) in 20 min.	Average Diameter (μm)	Resistance (MΩ): abs R_1 = $(V*R_0)/(I*R_0-V)$	Resistivity (Ohm.cm)	Conductivity (Siemens/cm)
16	PVA 10%: AgNPs 0.5%	17.5	0.248	810.2673	0.065233	15.33
17	PVA 10%: AgNPs 0.5%	15	0.258	822.5981	0.071675	13.95
18	PVA 10%: AgNPs 0.5%	12.5	0.272	873.0309	0.084549	11.83
19	PVA 10%: AgNPs 0.75%	17.5	0.152	765.3350	0.023146	43.20
20	PVA 10%: AgNPs 0.75%	15	0.218	814.0245	0.050639	19.75
21	PVA 10%: AgNPs 0.75%	12.5	0.224	859.7234	0.056467	17.71
22	PVA 10%: AgNPs 0.25%: PEDOT/PSS 0.084%	17.5, 45 min.	0.158	331.9741	0.010848	92.18
23	PVA 10%: AgNPs 0.25%: PEDOT/PSS 0.084%	17.5, 30 min.	0.188	442.4737	0.020471	48.85

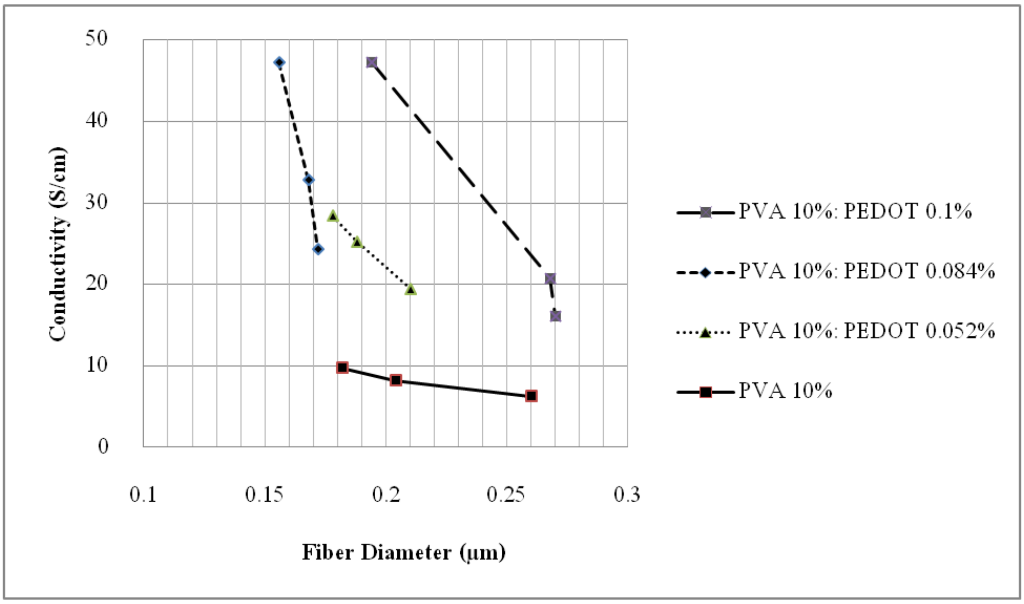


Figure 12 Conductivity of 10% PVA fibers blended with PEDOT/PSS concentrations of 0.052, 0.084, and 0.1% at the various diameters (each concentration was fabricated at 12.5, 15, and 17.5 kV in 20 min.) by using the 2-probe measurements.

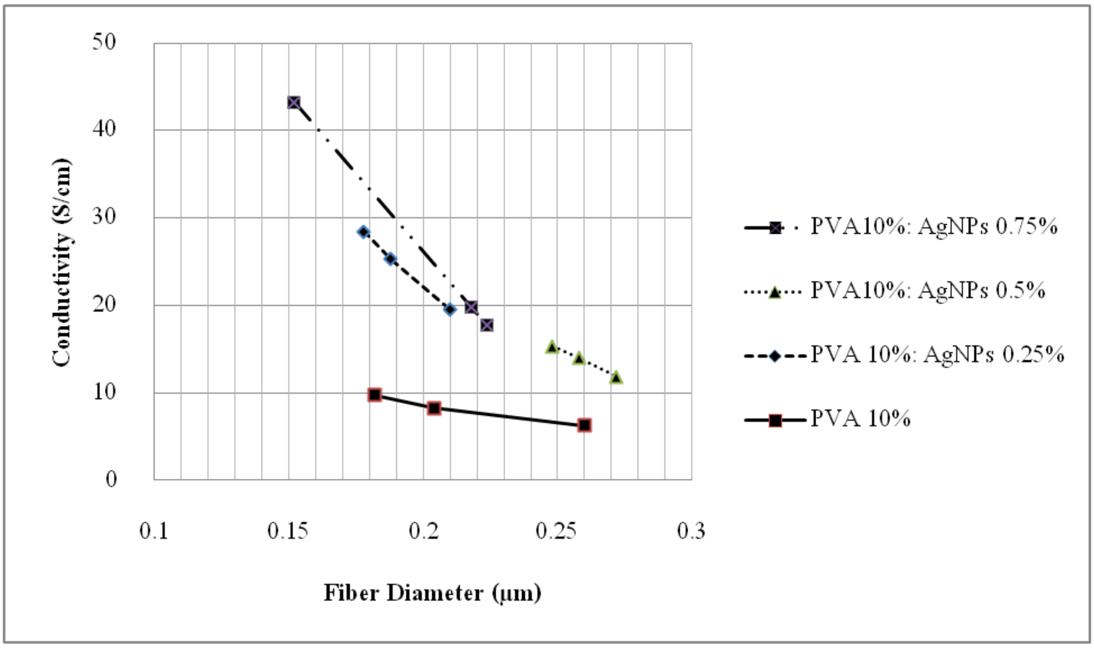
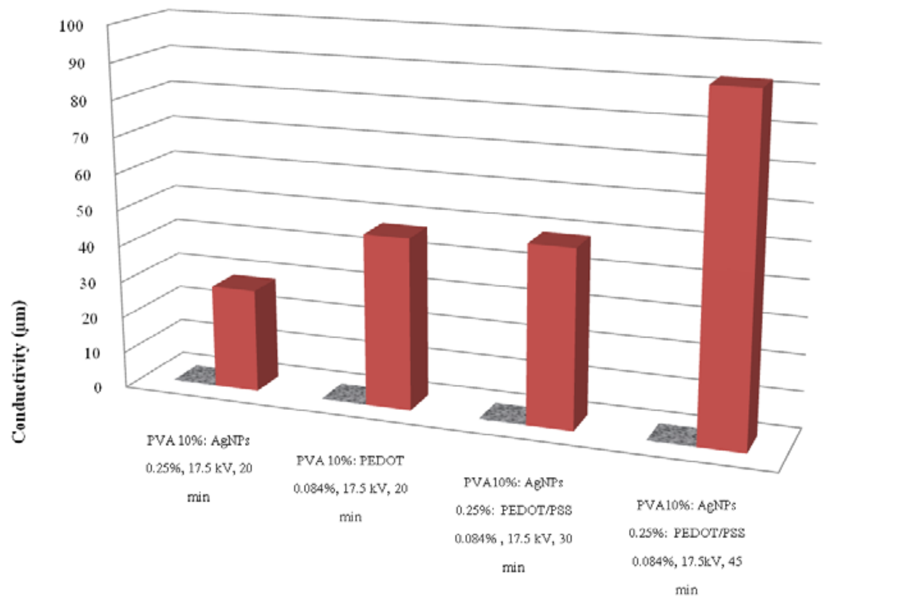


Figure 13 Conductivity of 10% PVA fibers blended with AgNPs concentrations of 0.25, 0.5, and 0.75% at the various diameters (each concentration was fabricated at 12.5, 15, and 17.5 kV in 20 min.) by using the 2-probe measurements.



	PVA 10%: AgNPs 0.25%, 17.5 kV, 20 min	PVA 10%: PEDOT 0.084%, 17.5 kV, 20 min	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084% , 17.5 kV, 30 min	PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%, 17.5kV, 45 min
Average Diameter (µm)	0.178	0.156	0.188	0.158
Conductivity (Siemens/cm)	28.4283	47.2224	48.8493	92.1813

Figure 14 Comparison of conductivity of 10% PVA fibers blended with 0.25% AgNPs, 10% PVA fibers blended with 0.084% PEDOT/PSS, and 10% PVA fibers blended with 0.084% PEDOT/PSS and 0.25% AgNPs at 17.5 kV, at the various diameters, (in 20, 30, and 45 min.) by using the 2-probe measurements.

Aligned Fiber Mat

Table 19 Resistivity measurement result of aligned fiber mat by using the 2-probe measurement (item no.1 to 30: under 20 minutes of fiber collecting time, item no.31 to 33: under 30 minutes of fiber collecting time, and item no.34 to 36: under 45 minutes of fiber collecting time)

Fiber Length (l) = 0.6 cm (60000 µm)

No.	Materials	Applied Voltages (kV) in 20 min.	Average Diameter (μm)	Resistance (MΩ): abs R_1 = $(V*R_0)/(I*R_0-V)$	Resistivity (Ohm.cm)	Conductivity (Siemens/cm)
1	PVA 10%	17.5	0.106	15439.9702	0.227089	4.40
2	PVA 10%	15	0.12	13081.9021	0.246588	4.06
3	PVA 10%	12.5	0.132	12910.4233	0.294460	3.40
4	PVA 10%: PEDOT/PSS 0.052%	17.5	0.102	10420.0946	0.141909	7.05
5	PVA 10%: PEDOT/PSS 0.052%	15	0.108	10636.7204	0.162403	6.16
6	PVA 10%: PEDOT/PSS 0.052%	12.5	0.116	11788.1059	0.207634	4.82
7	PVA 10%: PEDOT/PSS 0.084%	17.5	0.102	10377.3709	0.141327	7.08
8	PVA 10%: PEDOT/PSS 0.084%	15	0.112	10595.8637	0.173985	5.75
9	PVA 10%: PEDOT/PSS 0.084%	12.5	0.122	11439.5954	0.222879	4.49
10	PVA 10%: PEDOT/PSS 0.1%	17.5	0.114	9936.2982	0.169034	5.92
11	PVA 10%: PEDOT/PSS 0.1%	15	0.12	9964.0793	0.187818	5.32
12	PVA 10%: PEDOT/PSS 0.1%	12.5	0.126	9975.7801	0.207313	4.82
13	PVA 10%: AgNPs 0.25%	17.5	0.12	5128.5315	0.096671	10.34
14	PVA 10%: AgNPs 0.25%	15	0.13	6849.3383	0.151521	6.60
15	PVA 10%: AgNPs 0.25%	12.5	0.14	9667.9062	0.248043	4.03
16	PVA 10%: AgNPs 0.5%	17.5	0.12	4984.8048	0.093961	10.64

No.	Materials	Applied Voltages (kV) in 20 min.	Average Diameter (μm)	Resistance (MΩ): abs R_1 = $(V*R_0)/(I*R_0-V)$	Resistivity (Ohm.cm)	Conductivity (Siemens/cm)
17	PVA 10%: AgNPs 0.5%	15	0.13	6428.8499	0.142219	7.03
18	PVA 10%: AgNPs 0.5%	12.5	0.142	9165.3431	0.241916	4.13
19	PVA 10%: AgNPs 0.75%	17.5	0.136	4588.0097	0.111081	9.00
20	PVA 10%: AgNPs 0.75%	15	0.148	5727.3694	0.164217	6.09
21	PVA 10%: AgNPs 0.75%	12.5	0.158	8397.9561	0.274427	3.64
22	PVA 10%: AgNPs 0.25%: PEDOT/PSS 0.084%	17.5	0.136	6105.1072	0.147812	6.77
23	PVA 10%: AgNPs 0.25%: PEDOT/PSS 0.084%	15	0.156	5006.6356	0.159490	6.27
24	PVA 10%: AgNPs 0.25%: PEDOT/PSS 0.084%	12.5	0.192	9212.6030	0.444553	2.25
25	PVA 10%: AgNPs 0.5%: PEDOT/PSS 0.084%	17.5	0.136	4840.5768	0.117196	8.53
26	PVA 10%: AgNPs 0.5%: PEDOT/PSS 0.084%	15	0.144	5969.6689	0.162037	6.17
27	PVA 10%: AgNPs 0.5%: PEDOT/PSS 0.084%	12.5	0.218	8278.3662	0.514987	1.94

No.	Materials	Applied Voltages (kV) in 20 min.	Average Diameter (μm)	Resistance (MΩ): abs $R_1 = (V*R_0)/(I*R_0-V)$	Resistivity (Ohm.cm)	Conductivity (Siemens/cm)
28	PVA 10%: AgNPs 0.75%: PEDOT/PSS 0.084%	17.5	0.136	4453.1577	0.107816	9.28
29	PVA 10%: AgNPs 0.75%: PEDOT/PSS 0.084%	15	0.152	5598.0103	0.169301	5.91
30	PVA 10%: AgNPs 0.75%: PEDOT/PSS 0.084%	12.5	0.176	7791.8986	0.315942	3.17
31	PVA 10%: AgNPs 0.25%: PEDOT/PSS 0.084%	17.5, 30 min.	0.13	4973.1168	0.110016	9.09
32	PVA 10%: AgNPs 0.25%: PEDOT/PSS 0.084%	15.0, 30 min.	0.136	16845.1114	0.407840	2.45
33	PVA 10%: AgNPs 0.25%: PEDOT/PSS 0.084%	12.5, 30 min.	0.14	18787.4888	0.482018	2.07
34	PVA 10%: AgNPs 0.25%: PEDOT/PSS 0.084%	17.5, 45 min.	0.112	4489.4992	0.073718	13.57
35	PVA 10%: AgNPs 0.25%: PEDOT/PSS 0.084%	15.0, 45 min.	0.114	15566.0400	0.264805	3.78
36	PVA 10%: AgNPs 0.25%: PEDOT/PSS 0.084%	12.5, 45 min.	0.128	18148.9895	0.389234	2.57

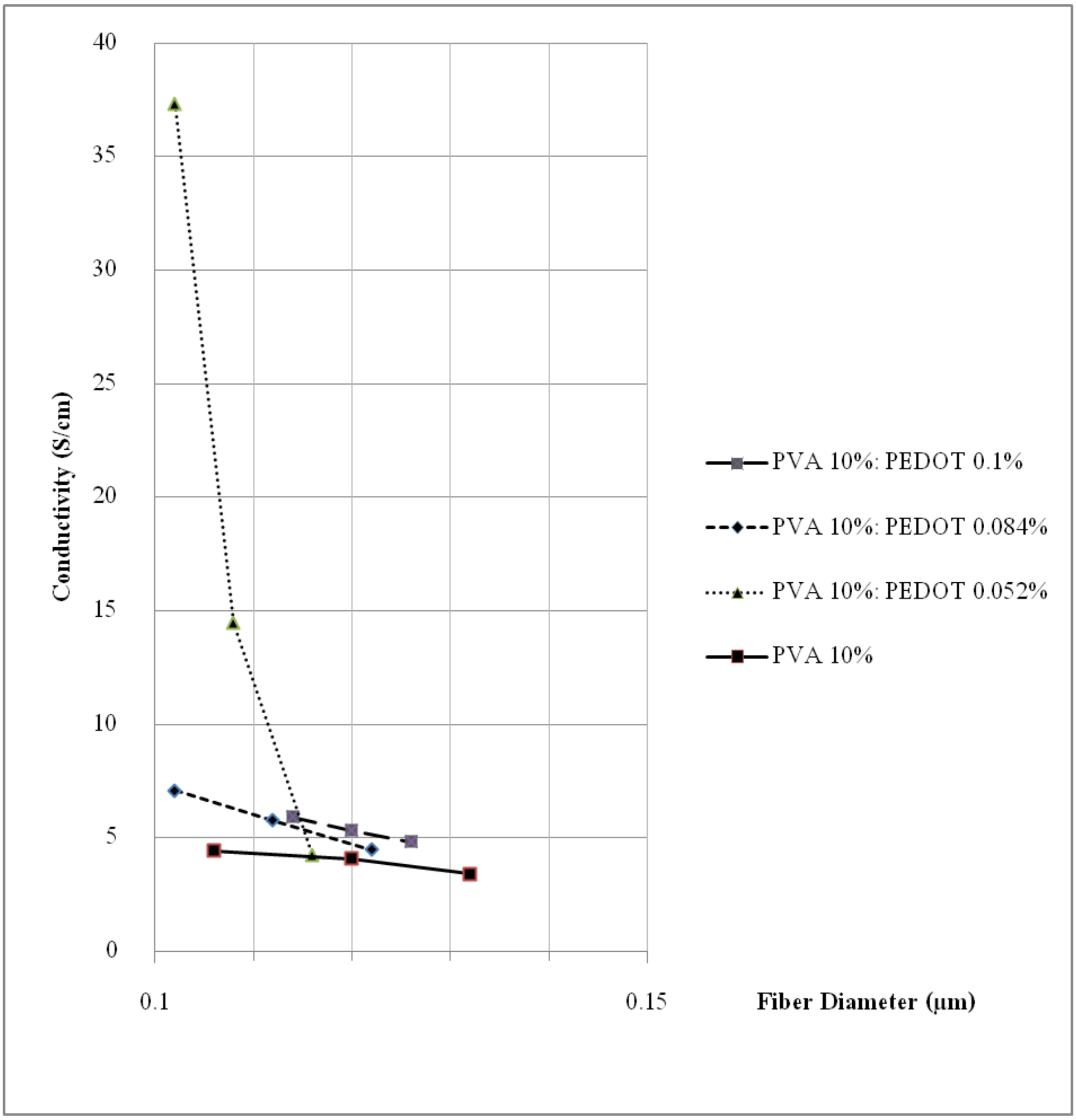


Figure 15 Conductivity of 10% PVA fibers blended with PEDOT/PSS concentrations of 0.052, 0.084, and 0.1% at the various diameters (each concentration was fabricated at 12.5, 15, and 17.5 kV in 20 min.) by using the 2-probe measurements.

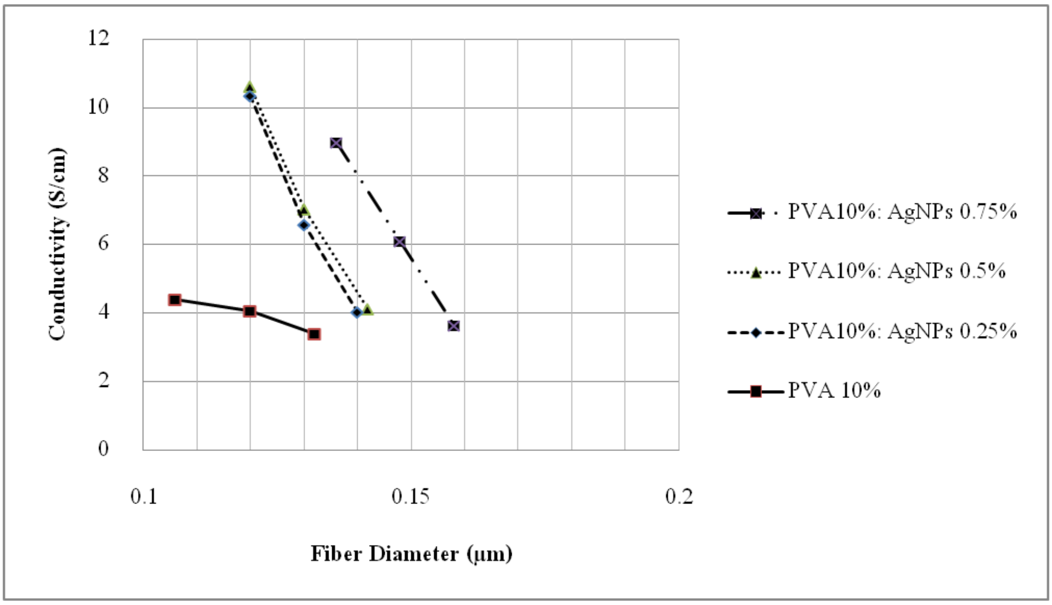


Figure 16 Conductivity of 10% PVA fibers blended with AgNPs concentrations of 0.25, 0.5, and 0.75% at the various diameters (each concentration was fabricated at 12.5, 15, and 17.5 kV in 20 min) by using the 2-probe measurement.

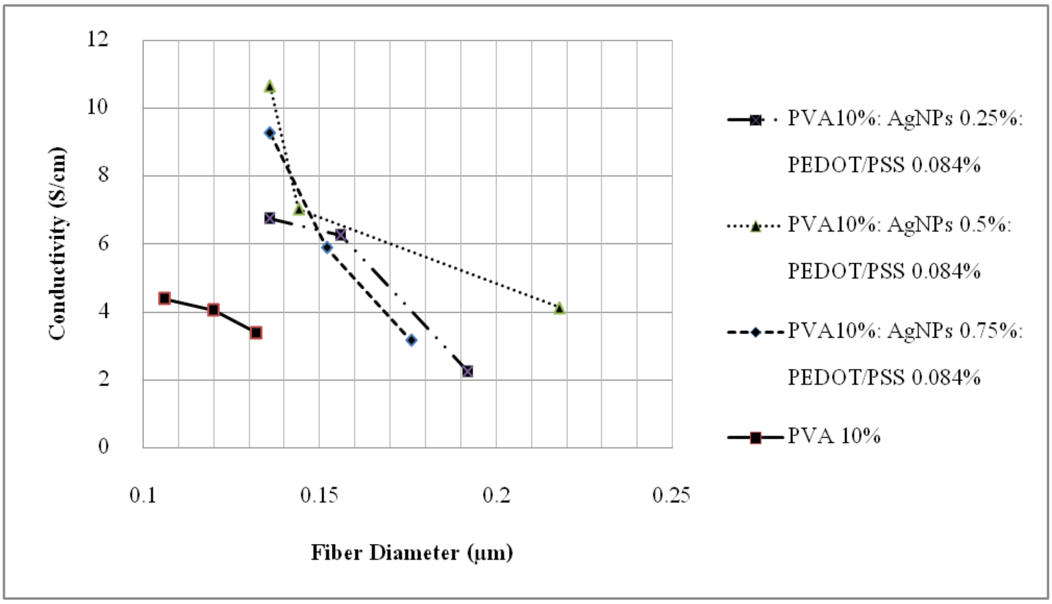


Figure 17 Conductivity of 10% PVA fibers blended with 0.084% PEDOT/PSS and AgNPs concentrations of 0.25, 0.5, and 0.75% at the various diameters (each concentration was fabricated at 12.5, 15, and 17.5 kV in 20 min.) by using the 2-probe measurement.

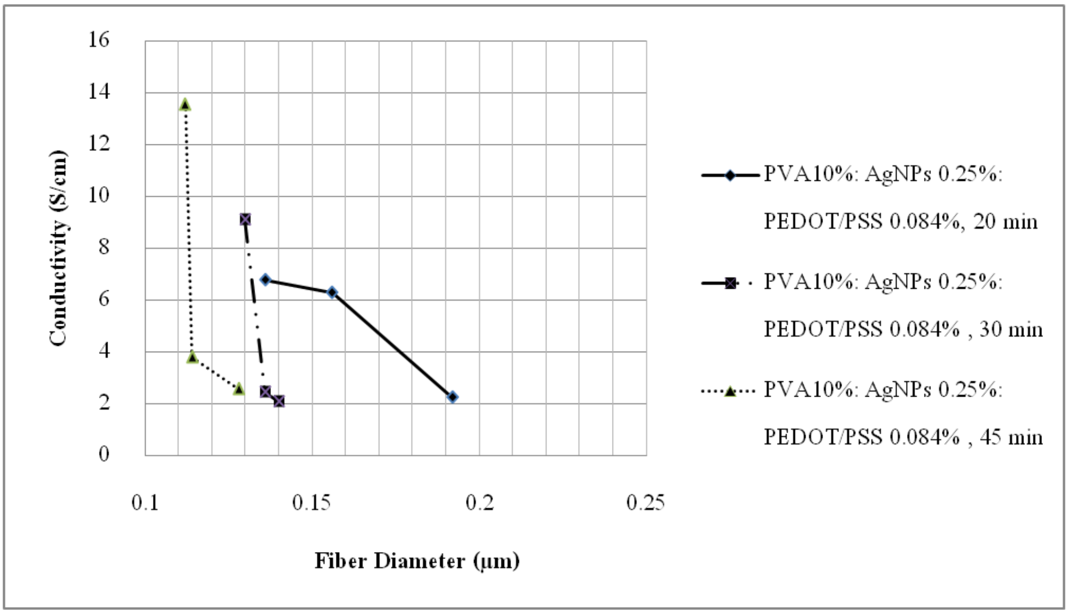


Figure 18 Conductivity of 10% PVA fibers blended with 0.084% PEDOT/PSS and 0.25% AgNPs at 12.5, 15, and 17.5 kV (in 20, 30 and 45 min) by using the 2-probe measurement.

CHAPTER VI

CONCLUSIONS AND FUTURE PROSPECTS

6.1 Conclusions

In the key points of this research, the ultra-fine electrospun nanocomposite fibers of polymer-conductive polymer-nanoparticle with the fiber diameters ranging 0.1 to 0.33 μm have been successfully produced by varying concentrations and high voltages. The three different techniques such as fiber randomization, single fiber alignment, and fiber mat alignment are implemented to generate ultra-fine fibers in order to obtain the conductive property. The relationship between ultra-fine fiber diameters and conductivity of these fibers is investigated due to the effect of various diameter sizes and ultra-fine fiber density generated by different techniques and conditions. With the higher voltage application in the electrospinning process, the higher electrostatic force affects fiber jets and formed fibers collected from the collecting target with smaller fiber diameters and denser fibers. Therefore, the conductivity of nanocomposite ultra-fine fibers is increased while loading more concentration of PEDOT/PSS and AgNPs. Because the high surface area-to-volume ratios of silver nanoparticles (AgNPs) blended in conductive polymers (PEDOT/PSS) and polymers (PVA) benefit the higher conductive property of these products. Thus, the ultra-fine electrospun nanocomposite fibers of polymer-conductive polymer-nanoparticle will yield higher electrical conductivity when loading higher PEDOT/PSS and AgNPs concentrations to form ultra-fine fibers. Finally, the developed ultra-fine electrospun nanocomposite fibers have enhanced their electrical properties within acceptable economies of production because the cost of fiber production under the electrospinning process is very low.

With the concepts of conductivity measurement, the 4-probe is used to measure the conductivity of randomized fibers since they were considered to be anisotropic samples, whereas the 2-probe is used to measure the conductivity of aligned single fibers and aligned fiber mat. Therefore, the conductive results of 4-probe and 2-probe measurements cannot be compared directly in similar conditions because their measurement techniques are based on different patterns of fibers gathering on the sample surfaces. In this regard, the conductive results of the randomized fibers are not consistent, whereas the aligned single fibers and aligned fiber mat are more consistent. Therefore, the conductive results from the 4-probe measurement are investigated to prove that the randomized fibers just obtain the conductive property, but their conductive value cannot be compared with the aligned single fibers and aligned fiber mat within the same conditions. From the measurement results using TEM, the distribution of AgNPS in the ultra-fine fibers show that most of the silver nanoparticles are not evenly spread along fiber lengths. Instead, they cluster around the fiber lengths. In this regard, it affects the conductive property of ultra-fine fibers. However, the range of conductivity is varied from 4.23 to 92.18 S/cm, under the aligned single fiber technique, and from 1.94 to 13.57 S/cm, under the aligned fiber mat technique. The highest conductivity obtained from this work is about 92.18 S/cm higher than that of 52.9 S/cm of PANI which was measured by Qiao-Zhen Yu et al. [18].

In this study, the new technique of fiber alignment has been found to generate aligned single fibers. This technique is similar to fiber mat alignment, but it is set on the clockwise high speed drum instead of the anticlockwise high speed drum in the electrospinning process. Usually, the anti-clockwise high speed drum is equipped as a target to collect many ultra-fine fibers under different applied voltages. This is due to the fact that the direction of the anti-clockwise high speed drum moves in the same direction of the fiber jets and therefore there is no force against the direction of the fiber jets, causing many fibers to gather on the drum surface. Thus, ultra-fine fibers resulted from the aligned fiber mat techniques are frequently found on the fiber collecting drum within a period of 1 to 5 minutes. However, the fibers are not well-aligned. If it takes longer up to 20 minutes, many fibers will be well-aligned. In contrast, the clockwise high speed drum, aligned single fiber technique, causes the aligned fibers to gather less on the rotating drum owing to the wind blown by the high speed drum moving against the jet direction, forcing many aligned fibers to gather on both sides of the drum. There are few aligned fibers fall onto the drum surface with a longer period of 20 minutes. Thus, the clockwise high speed drum technique is suitable for generating aligned single fibers. Apparently, with the pictures taken by TEM and SEM, the fibers from two fiber alignment techniques will be well-aligned if voltages between 12.5 and 17.5 kV are applied. If the spinning process for fiber alignment is applied with voltage lower than 12.5 kV or higher than 17.5 kV, the fibers will not be well-aligned.

The researcher has contributed substantially to the whole electrospinning process. As for the measurement part, the researcher has worked mostly on the 4- probe measurement and 2-probe measurement while using SEM, TEM, XRD, AFM, and FT-IR in the measurement process.

6.2 Future Prospects

Electrospinning process is mostly applied to further research and development in this field of study since it can be used for generating fibers by incorporating various polymers. Ultra-fine fibers were found to possess some unique characteristics such as a high surface area per unit mass, noticeable conductive and mechanical properties, a light weight coupled with a low production cost.

The presence of conductive polymers in the fields of nano-sensors, nano-electronics and nano-medicine are being continuously widened both in laboratory research and in industrial applications. Currently, the critical concern in the future development of conductive ultra-fine fibers applications is how to improve their electrical, optical and mechanical properties within acceptable economies of production.

At this stage, it is important to note some considerations that are hindering the progress of conductive ultra-fine fibers development. To begin with, the electrospinning process itself has some limitations especially regarding consistency of fiber diameters. Bead defect can also be problematic. Another is the current lack of recognition given to this important scientific field which in turn has resulted in insufficient research and development funding to seek out new materials for greater commercial applications.

The findings of this study will be useful for further research on electrical conductivity improvement and for further implementation in nano-electronic applications and nanosensors. The research on ultra-fine fibers blended with nanoparticles will be beneficial to further research in Thailand. Moreover, the cost of production will be reduced and beneficial to the economy. Finally, the fabrication technique and efficiency of nanocomposite will be improved and enhanced by using the new scientific method which can distribute silver nanoparticles along the length of ultra-fine fibers on a consistent rather than a clustered basis.

Last, but not least, improvements in the designs of electrospinning equipment and more sophisticated production processes need to be refined which ultimately lower manufacturing costs and enhance commercial applications. The latter is essential to intensify Research and

Development on conductive ultra-fine fibers and progress here, in turn, is a handshake to its greater industrial utilization.

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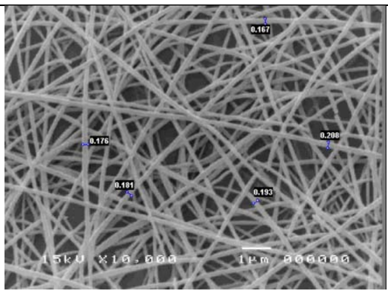
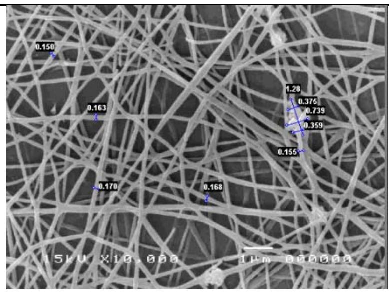
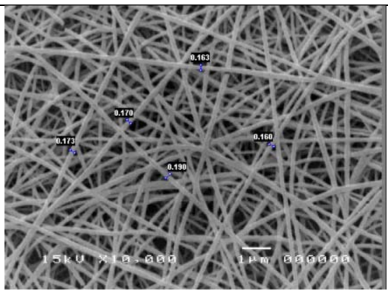
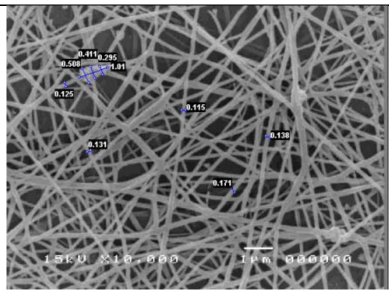
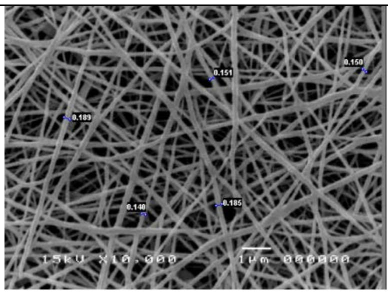
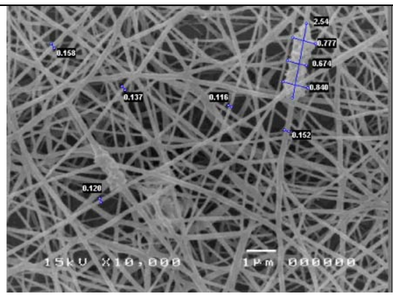
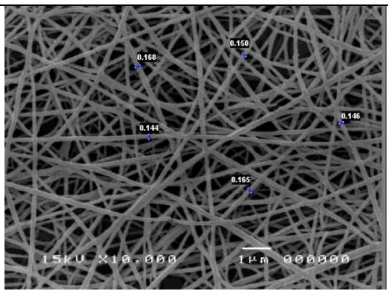
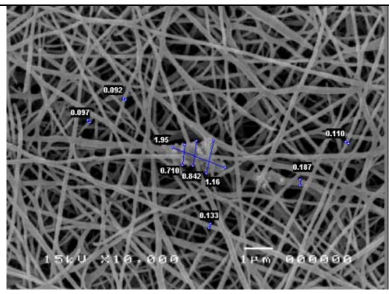
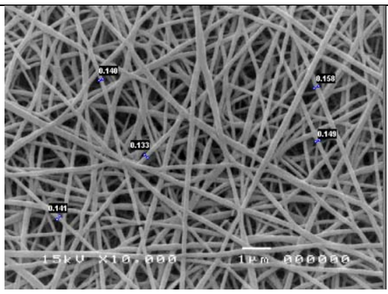
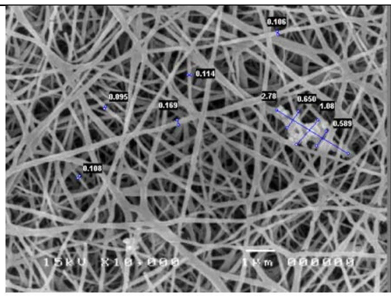
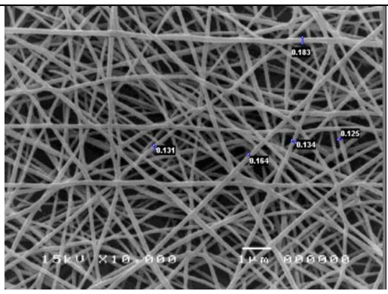
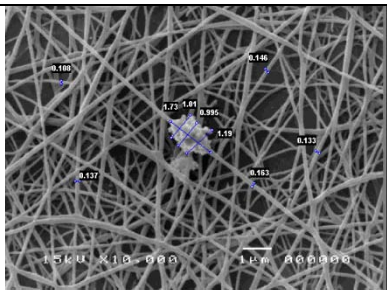
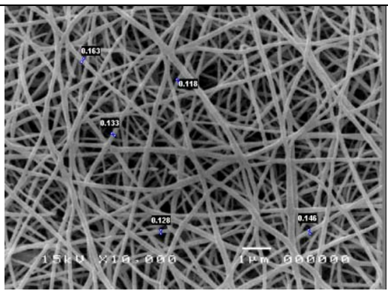
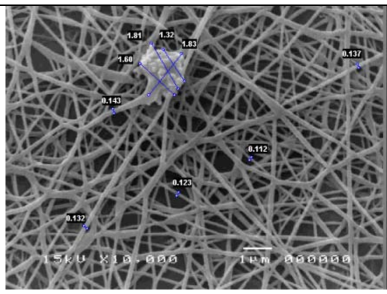
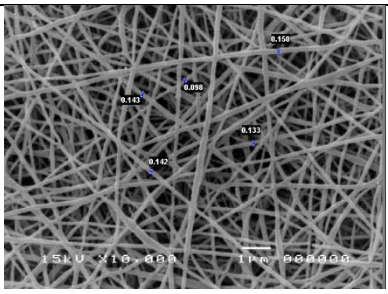
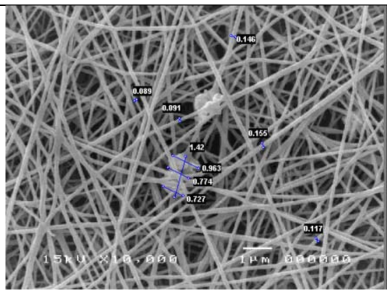
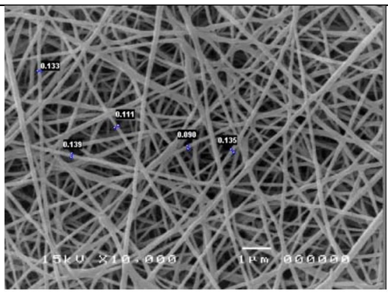
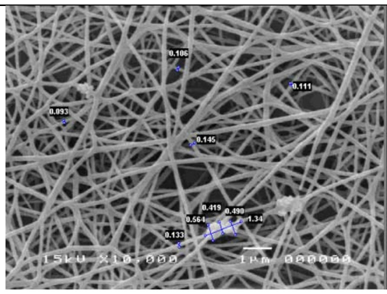
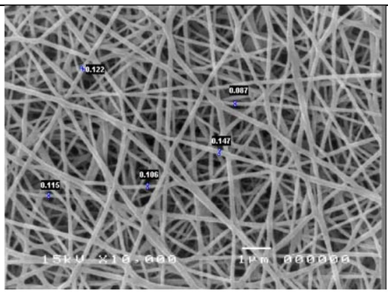
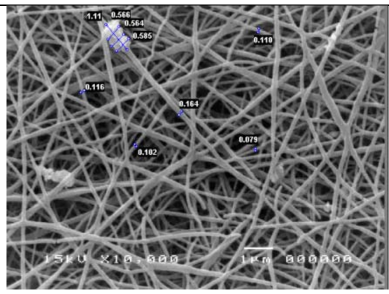
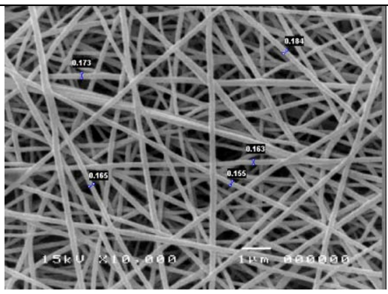
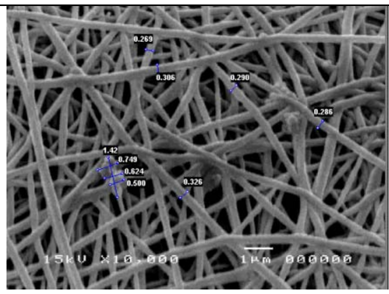
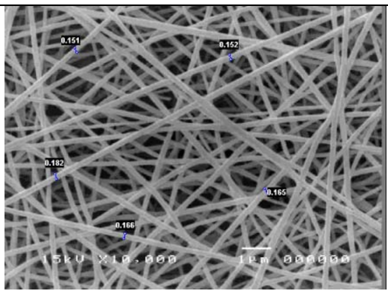
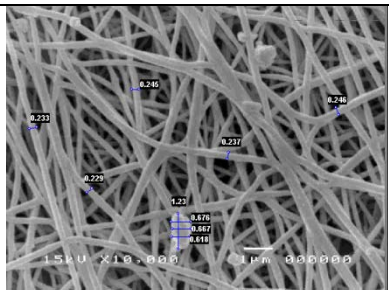
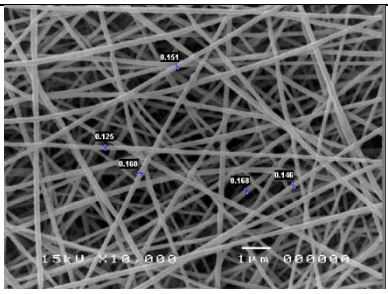
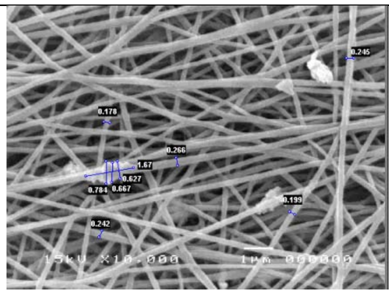
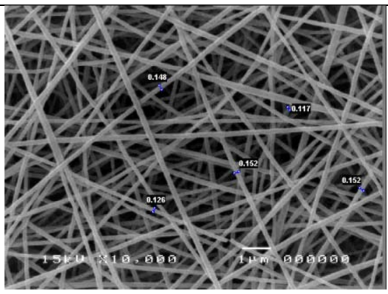
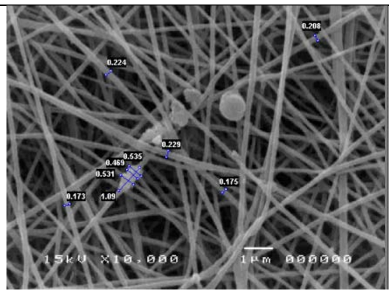
APPENDICES

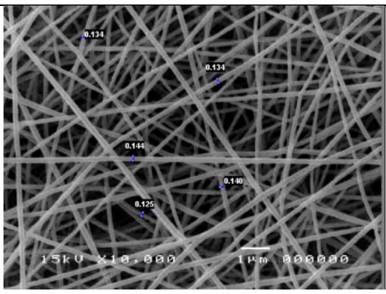
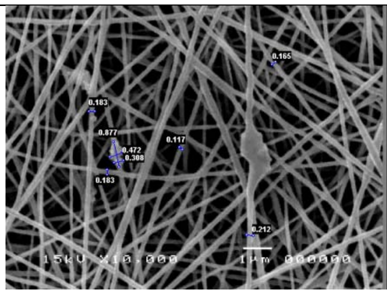
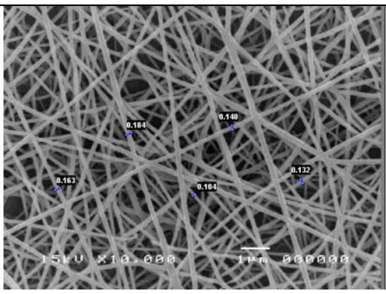
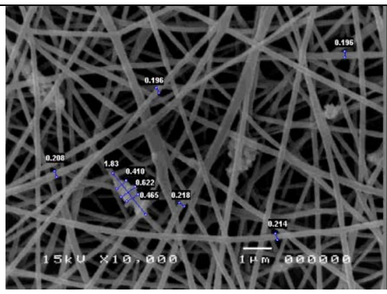
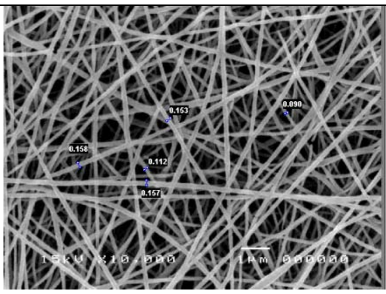
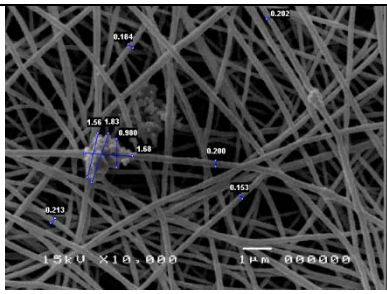
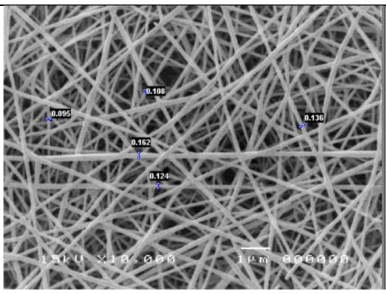
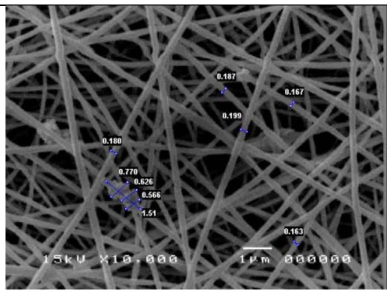
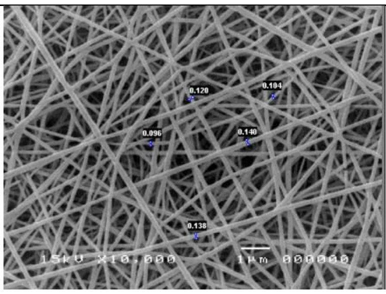
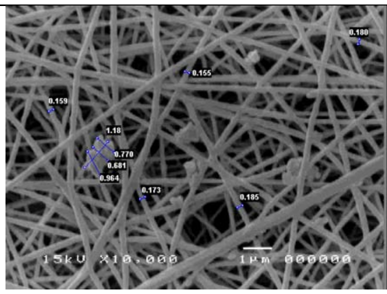
Appendix A Tables of Characterization Results of Randomized Fibers

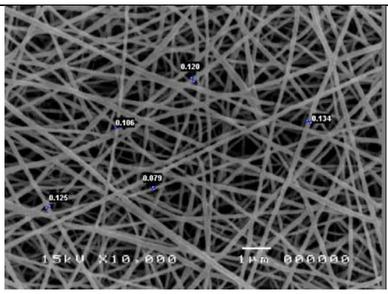
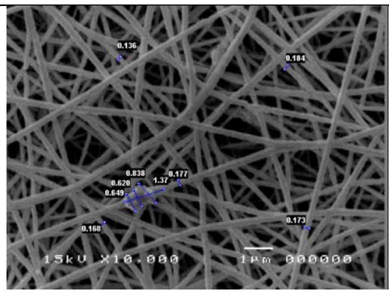
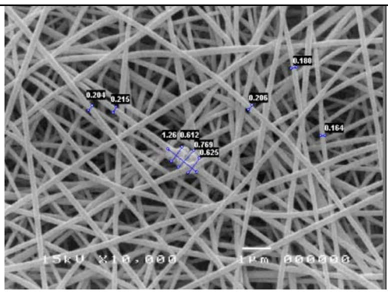
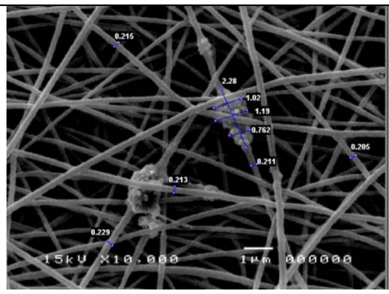
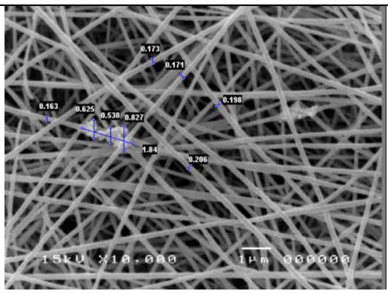
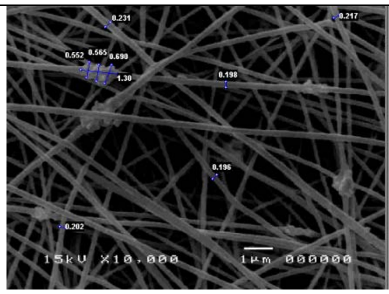
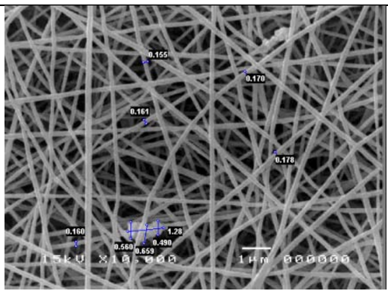
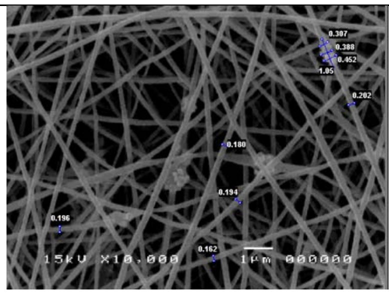
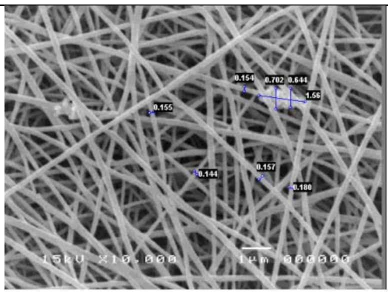
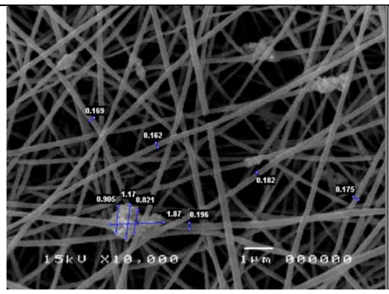
1. Illustrated the randomized fiber images by SEM

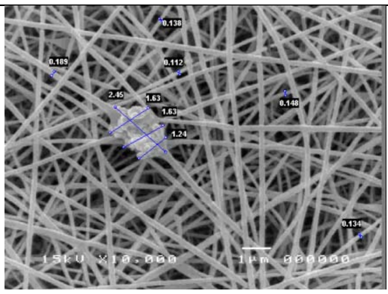
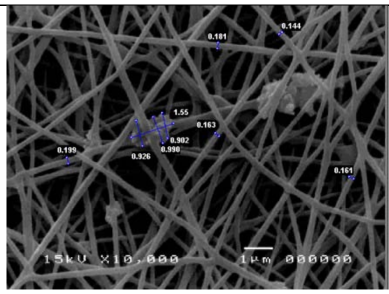
1. PVA 10%, 12.5 kV		26. PVA10%: AgNPs 0.5%, 12.5 kV	
2. PVA 10%, 15 kV		27. PVA10%: AgNPs 0.5%, 15 kV	
3. PVA 10%, 17.5 kV		28. PVA10%: AgNPs 0.5%, 17.5 kV	
4. PVA 10%, 20 kV		29. PVA10%: AgNPs 0.5%, 20 kV	

5. PVA 10%, 22.5 kV		30. PVA10%: AgNPs 0.5%, 22.5 kV	
6. PVA 10%: PEDOT 0.052%, 12.5 kV		31. PVA10%: AgNPs 0.75%, 12.5 kV	
7. PVA 10%: PEDOT 0.052%, 15 kV		32. PVA10%: AgNPs 0.75%, 15 kV	
8. PVA 10%: PEDOT 0.052%, 17.5 kV		33. PVA10%: AgNPs 0.75%, 17.5 kV	
9. PVA 10%: PEDOT 0.052%, 20 kV		34. PVA10%: AgNPs 0.75%, 20 kV	

10. PVA 10%: PEDOT 0.052%, 22.5 kV		35. PVA10%: AgNPs 0.75%, 22.5 kV	
11. PVA 10%: PEDOT 0.084%, 12.5 kV		36. PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%, 12.5 kV	
12. PVA 10%: PEDOT 0.084%, 15 kV		37. PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%, 15 kV	
13. PVA 10%: PEDOT 0.084%, 17.5 kV		38. PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%, 17.5 kV	
14. PVA 10%: PEDOT 0.084%, 20 kV		39. PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%, 20 kV	

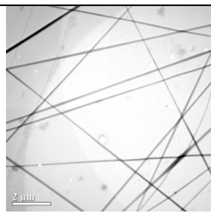
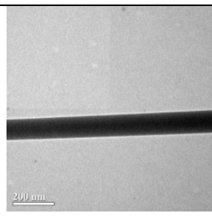
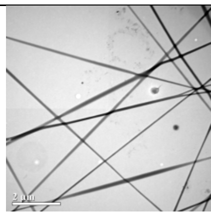
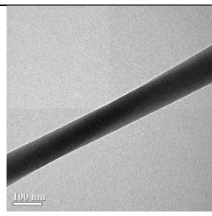
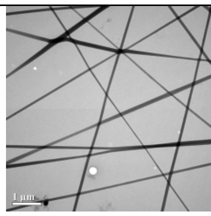
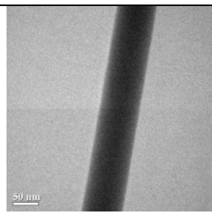
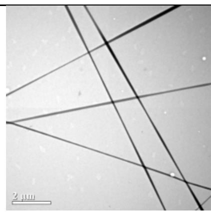
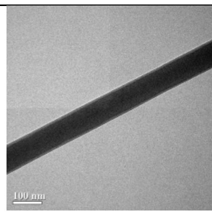
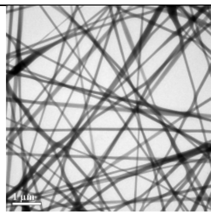
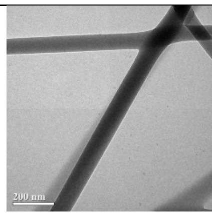
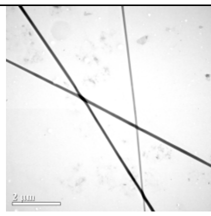
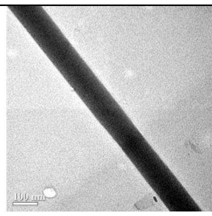
15. PVA 10%: PEDOT 0.084%, 22.5 kV		40. PVA10%: AgNPs 0.25%: PEDOT/PSS 0.084%, 22.5 kV	
16. PVA 10%: PEDOT 0.1%, 12.5 kV		41. PVA10%: AgNPs 0.5%: PEDOT/PSS 0.084%, 12.5 kV	
17. PVA 10%: PEDOT 0.1%, 15 kV		42. PVA10%: AgNPs 0.5%: PEDOT/PSS 0.084%, 15 kV	
18. PVA 10%: PEDOT 0.1%, 17.5 kV		43. PVA10%: AgNPs 0.5%: PEDOT/PSS 0.084%, 17.5 kV	
19. PVA 10%: PEDOT 0.1%, 20 kV		44. PVA10%: AgNPs 0.5%: PEDOT/PSS 0.084%, 20 kV	

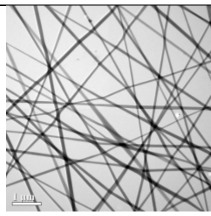
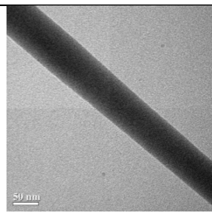
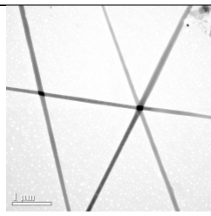
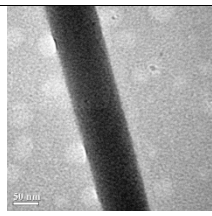
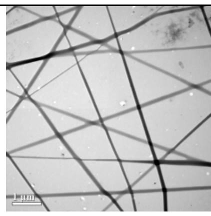
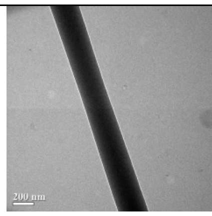
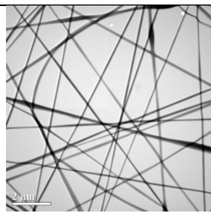
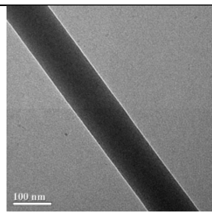
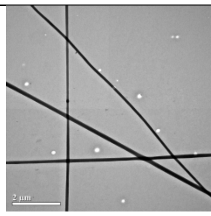
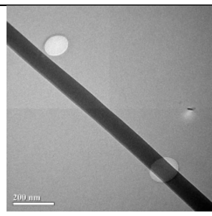
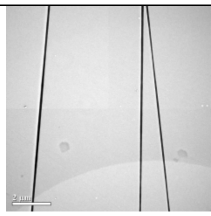
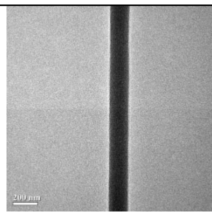
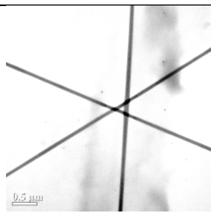
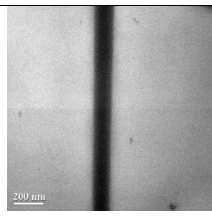
20. PVA 10%: PEDOT 0.1%, 22.5 kV		45. PVA10%: AgNPs 0.5%: PEDOT/PSS 0.084%, 22.5 kV	
21. PVA 10%: AgNPs 0.25%, 12.5 kV		46. PVA10%: AgNPs 0.75%: PEDOT/PSS 0.084%, 12.5 kV	
22. PVA 10%: AgNPs 0.25%, 15 kV		47. PVA10%: AgNPs 0.75%: PEDOT/PSS 0.084%, 15 kV	
23. PVA 10%: AgNPs 0.25%, 17.5 kV		48. PVA10%: AgNPs 0.75%: PEDOT/PSS 0.084%, 17.5 kV	
24. PVA 10%: AgNPs 0.25%, 20 kV		49. PVA10%: AgNPs 0.75%: PEDOT/PSS 0.084%, 20 kV	

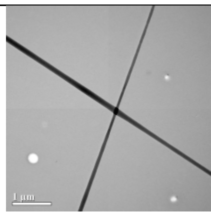
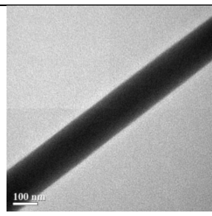
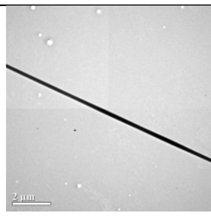
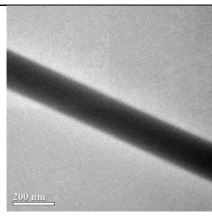
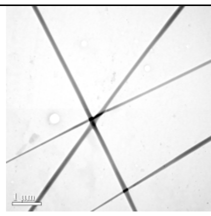
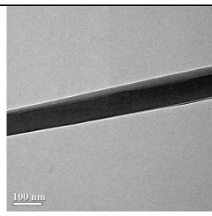
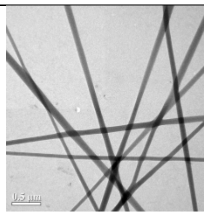
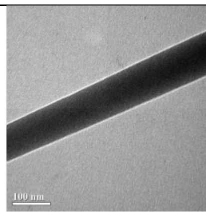
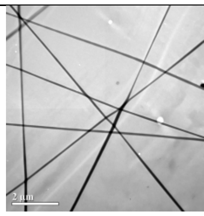
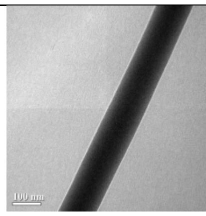
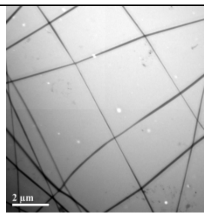
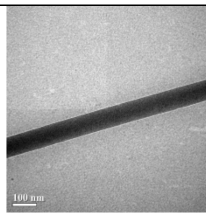
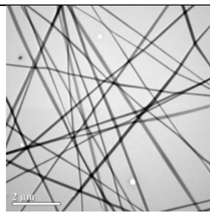
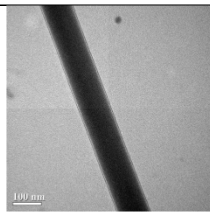
25. PVA 10%: AgNPs 0.25%, 22.5 kV		50. PVA10%: AgNPs 0.75%: PEDOT/PSS 0.084%, 22.5 kV	

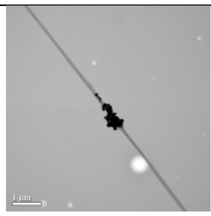
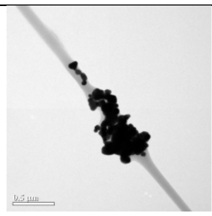
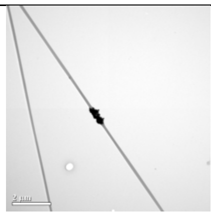
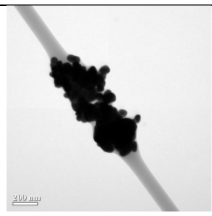
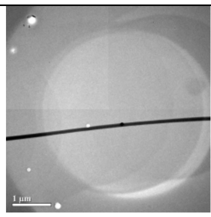
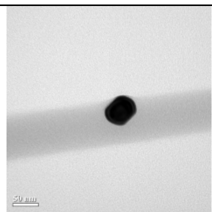
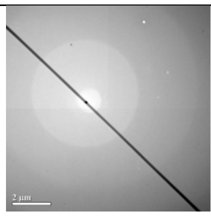
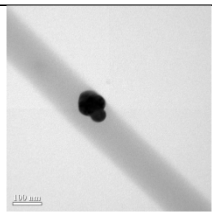
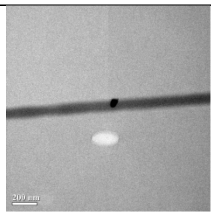
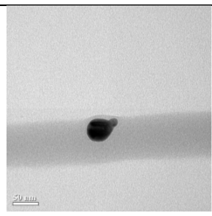
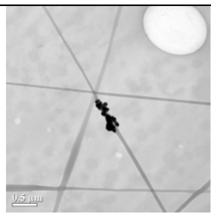
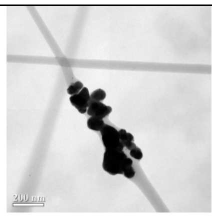
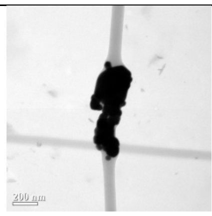
2. Illustrated the randomized fiber images by TEM

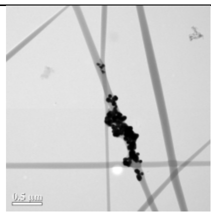
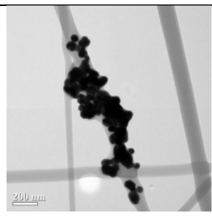
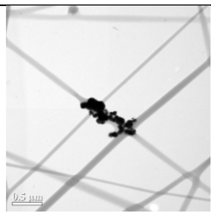
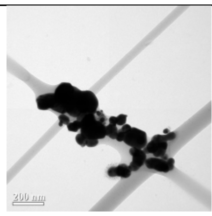
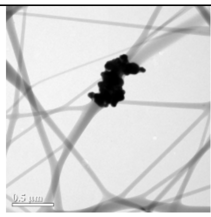
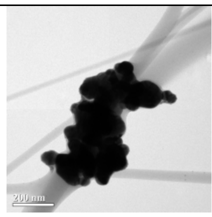
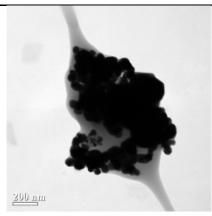
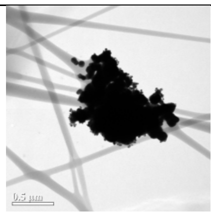
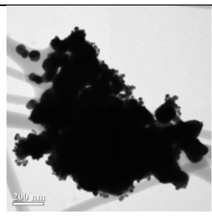
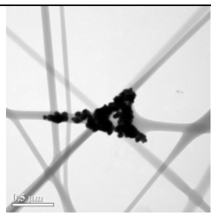
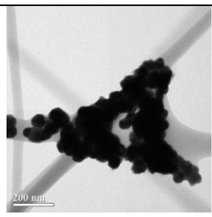
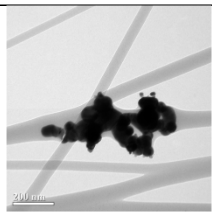
TEM Magnification: 2μm and 200 nm.

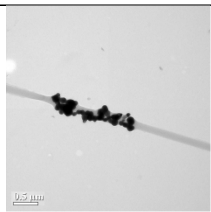
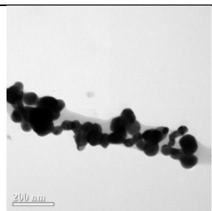
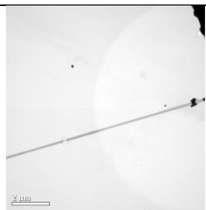
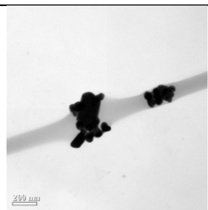
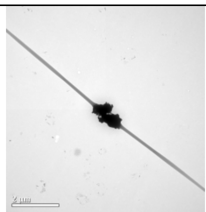
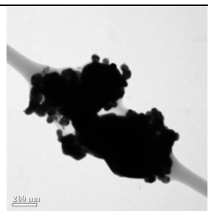
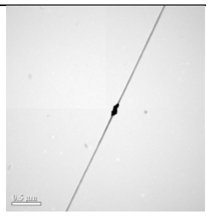
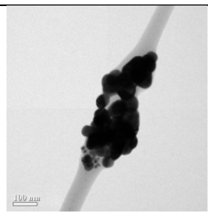
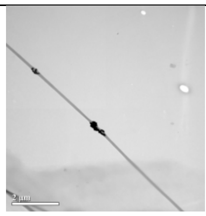
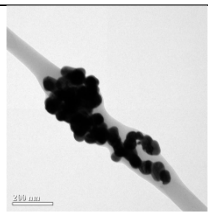
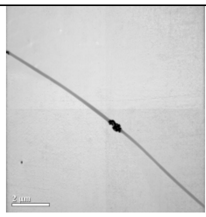
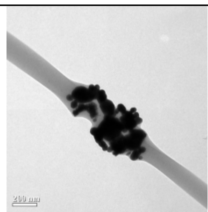
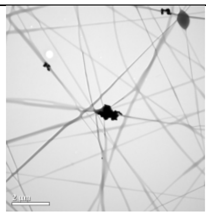
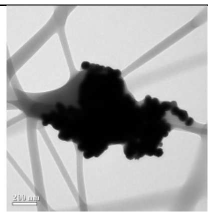
	Chemical Concentration Ratios (w/v)	Voltages (kV)	Low Mag.: ~2μm	High Mag.: ~200 nm.
1	PVA10%	12.5		
2	PVA10%	15		
3	PVA10%	17.5		
4	PVA10%	20		
5	PVA10%	22.5		
6	PVA 10%: PEDOT/PSS 0.052%	12.5		

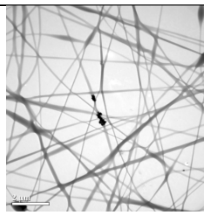
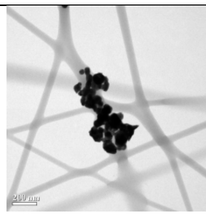
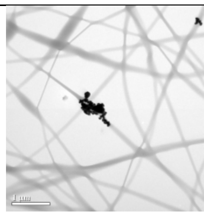
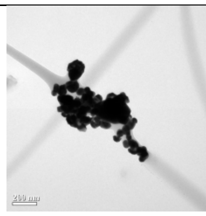
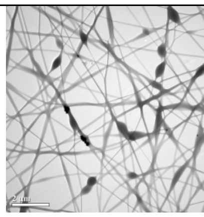
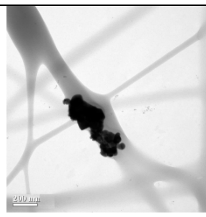
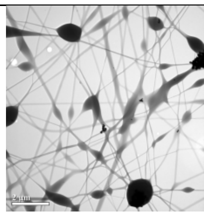
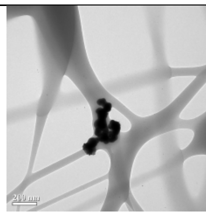
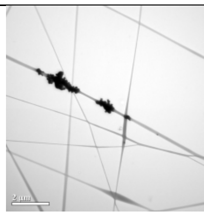
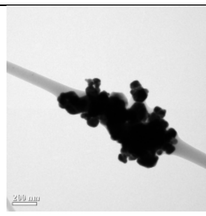
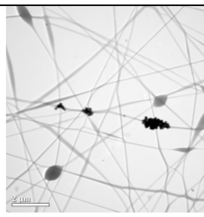
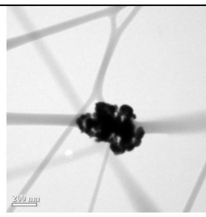
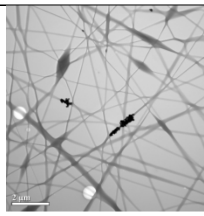
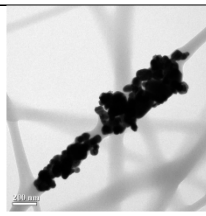
7	PVA 10%: PEDOT/PSS 0.052%	15		
8	PVA 10%: PEDOT/PSS 0.052%	17.5		
9	PVA 10%: PEDOT/PSS 0.052%	20		
10	PVA 10%: PEDOT/PSS 0.052%	22.5		
11	PVA 10%: PEDOT 0.084%	12.5		
12	PVA 10%: PEDOT 0.084%	15		
13	PVA 10%: PEDOT 0.084%	17.5		

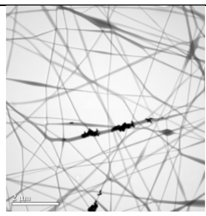
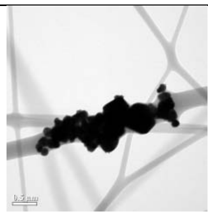
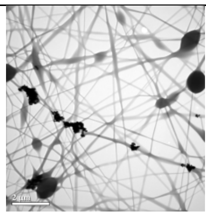
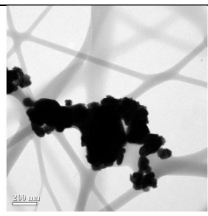
14	PVA 10%: PEDOT 0.084%	20		
15	PVA 10%: PEDOT 0.084%	22.5		
16	PVA 10%: PEDOT 0.1%	12.5		
17	PVA 10%: PEDOT 0.1%	15		
18	PVA 10%: PEDOT 0.1%	17.5		
19	PVA 10%: PEDOT 0.1%	20		
20	PVA 10%: PEDOT 0.1%	22.5		

21	PVA 10% + AgNPs 0.25%	12.5		
22	PVA 10% + AgNPs 0.25%	15		
23	PVA 10% + AgNPs 0.25%	17.5		
24	PVA 10% + AgNPs 0.25%	20		
25	PVA 10% + AgNPs 0.25%	22.5		
26	PVA10% +AgNPs 0.5%	12.5		
27	PVA10% +AgNPs 0.5%	15		

28	PVA10% +AgNPs 0.5%	17.5		
29	PVA10% +AgNPs 0.5%	20		
30	PVA10% +AgNPs 0.5%	22.5		
31	PVA10% +AgNPs 0.75%	12.5		
32	PVA10% +AgNPs 0.75%	15		
33	PVA10% +AgNPs 0.75%	17.5		
34	PVA10% +AgNPs 0.75%	20		

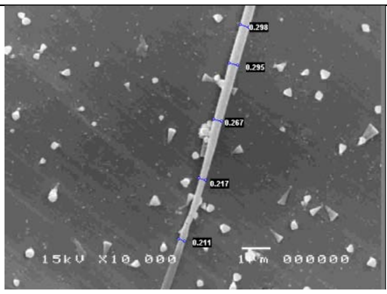
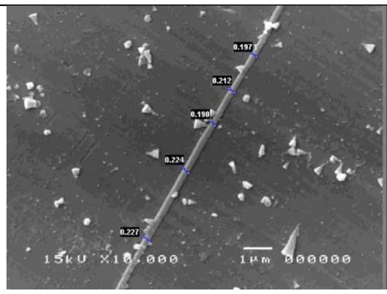
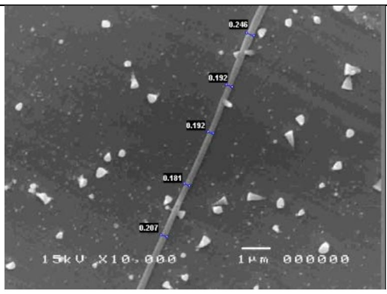
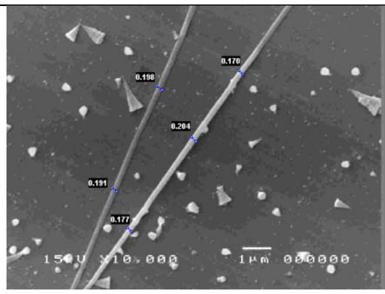
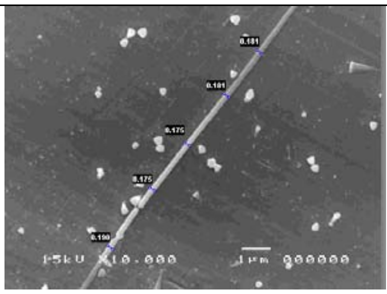
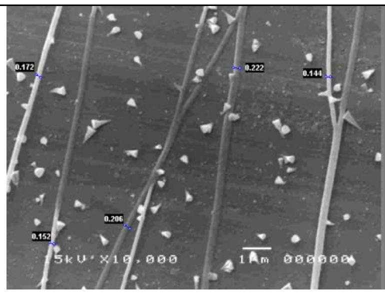
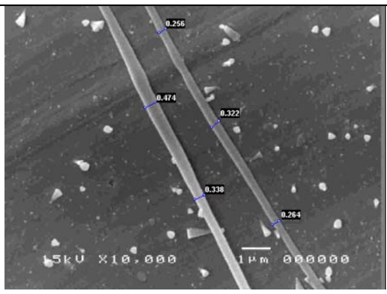
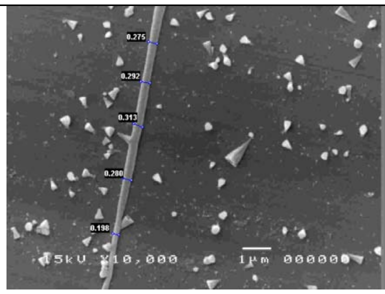
35	PVA10% +AgNPs 0.75%	22.5		
36	PVA10%+AgNPs 0.25% + PEDOT/PSS 0.084%	12.5		
37	PVA10%+AgNPs 0.25% + PEDOT/PSS 0.084%	15		
38	PVA10%+AgNPs 0.25% + PEDOT/PSS 0.084%	17.5		
39	PVA10%+AgNPs 0.25% + PEDOT/PSS 0.084%	20		
40	PVA10%+AgNPs 0.25% + PEDOT/PSS 0.084%	22.5		
41	PVA10%+AgNPs 0.5%+ PEDOT/PSS 0.084%	12.5		

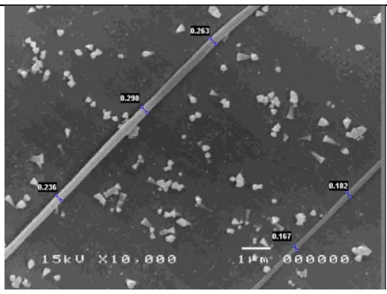
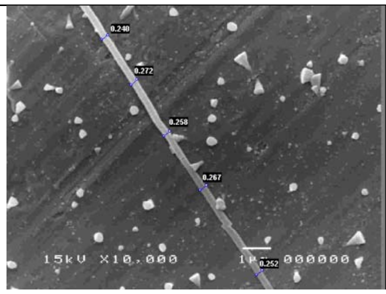
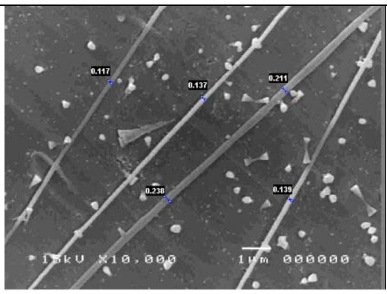
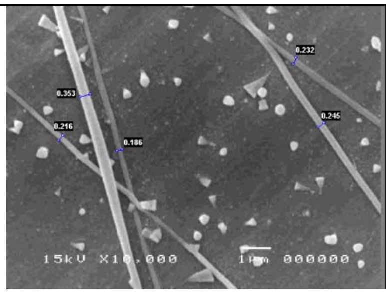
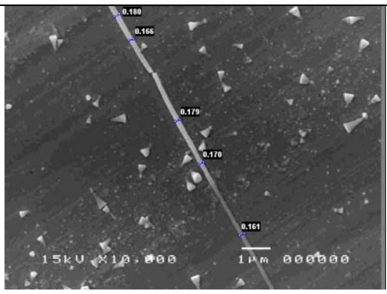
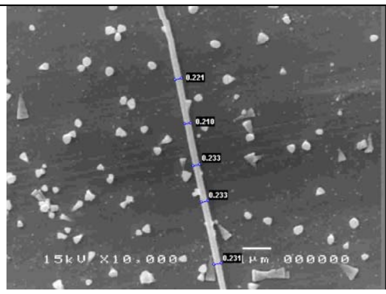
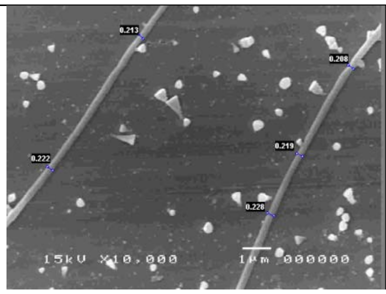
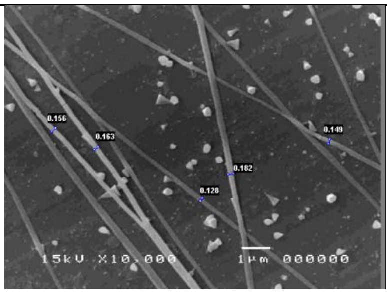
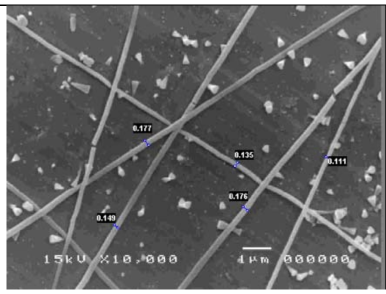
42	PVA10%+AgNPs 0.5%+ PEDOT/PSS 0.084%	15		
43	PVA10%+AgNPs 0.5%+ PEDOT/PSS 0.084%	17.5		
44	PVA10%+AgNPs 0.5%+ PEDOT/PSS 0.084%	20		
45	PVA10%+AgNPs 0.5%+ PEDOT/PSS 0.084%	22.5		
46	PVA10%+AgNPs 0.75%+ PEDOT/PSS 0.084%	12.5		
47	PVA10%+AgNPs 0.75%+ PEDOT/PSS 0.084%	15		
48	PVA10%+AgNPs 0.75%+ PEDOT/PSS 0.084%	17.5		

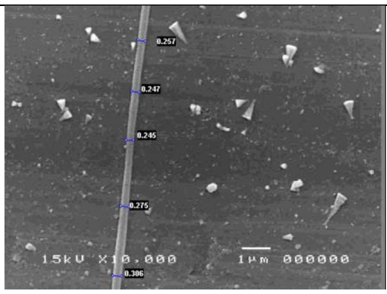
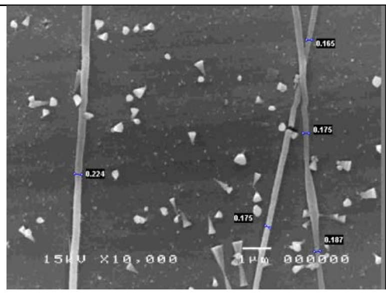
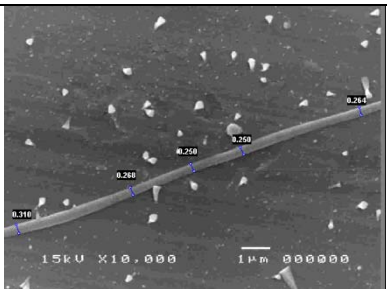
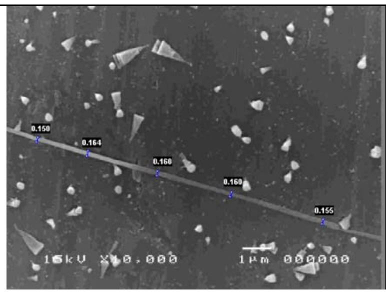
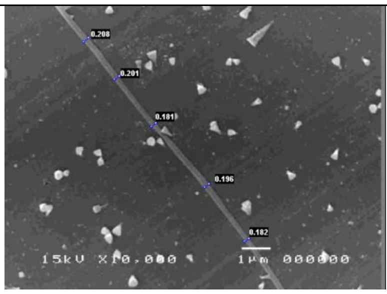
49	PVA10%+AgNPs 0.75%+ PEDOT/PSS 0.084%	20		
50	PVA10%+AgNPs 0.75%+ PEDOT/PSS 0.084%	22.5		

Appendix B Tables of Characterization Results of Aligned fibers

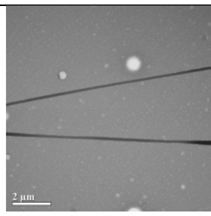
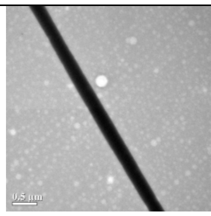
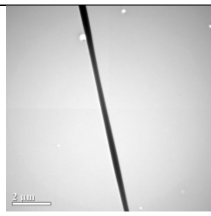
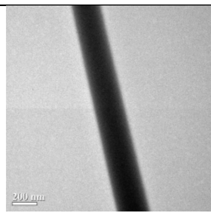
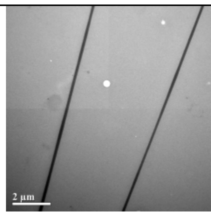
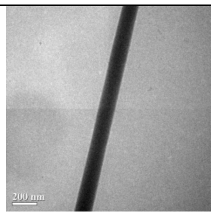
1. Illustrated the aligned single fiber images by SEM

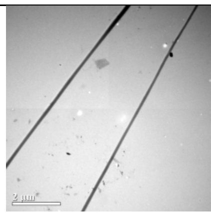
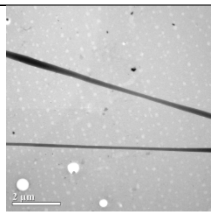
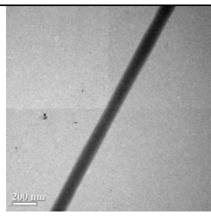
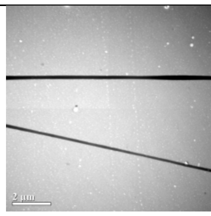
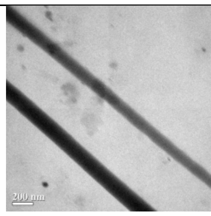
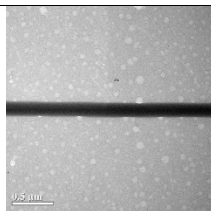
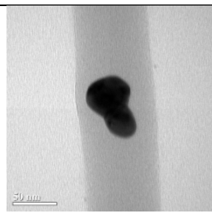
1. PVA 10%, 12.5 kV		13. PVA 10%: AgNPs 0.25%, 12.5 kV	
2. PVA 10%, 15 kV		14. PVA 10%: AgNPs 0.25%, 15 kV	
3. PVA 10%, 17.5 kV		15. PVA 10%: AgNPs 0.25%, 17.5 kV	
4. PVA 10%: PEDOT 0.052%, 12.5 kV		16. PVA10%: AgNPs 0.5%, 12.5 kV	

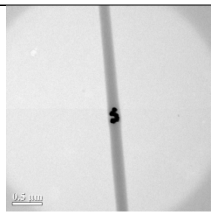
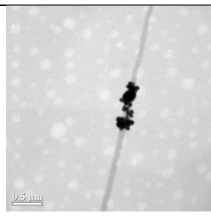
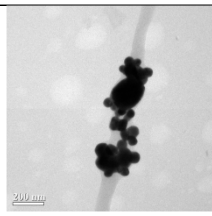
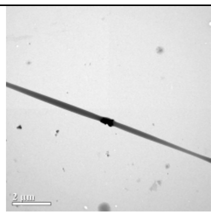
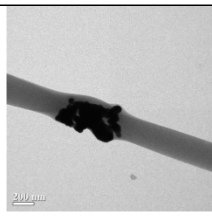
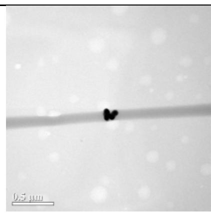
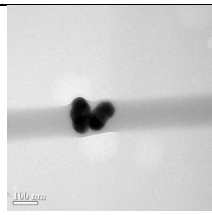
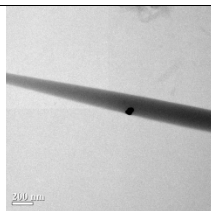
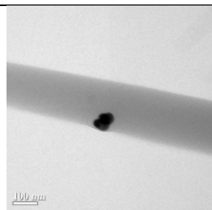
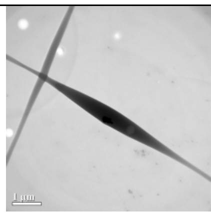
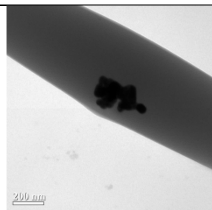
5. PVA 10%: PEDOT 0.052%, 15 kV		17. PVA10%: AgNPs 0.5%, 15 kV	
6. PVA 10%: PEDOT 0.052%, 17.5 kV		18. PVA10%: AgNPs 0.5%, 17.5 kV	
7. PVA 10%: PEDOT 0.084%, 12.5 kV		19. PVA10%: AgNPs 0.75%, 12.5 kV	
8. PVA 10%: PEDOT 0.084%, 15 kV		20. PVA10%: AgNPs 0.75%, 15 kV	
9. PVA 10%: PEDOT 0.084%, 17.5 kV		21. PVA10%: AgNPs 0.75%, 17.5 kV	

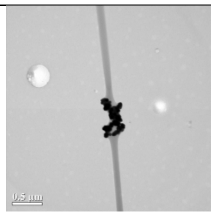
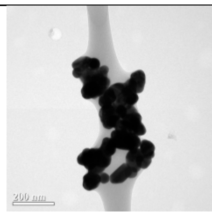
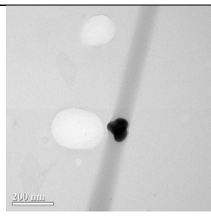
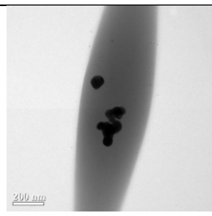
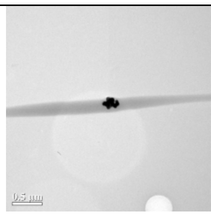
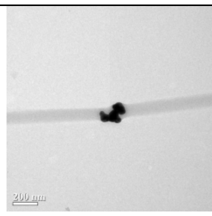
10. PVA 10%: PEDOT 0.1%, 12.5 kV		22. PVA10% : AgNPs 0.25%: PEDOT/PSS 0.084%, 17.5 kV, 30 min.	
11. PVA 10%: PEDOT 0.1%, 15 kV		23. PVA10% : AgNPs 0.25%: PEDOT/PSS 0.084%, 17.5 kV, 45 min.	
12. PVA 10%: PEDOT 0.1%, 17.5 kV			

2. Illustrated the aligned single fiber images by TEM

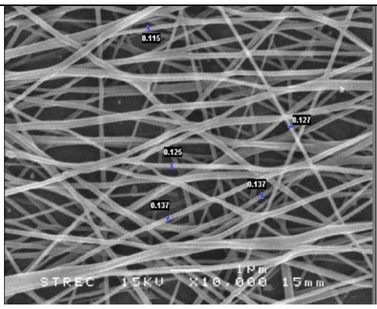
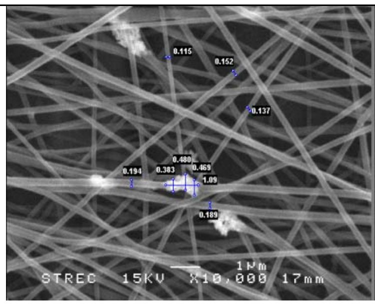
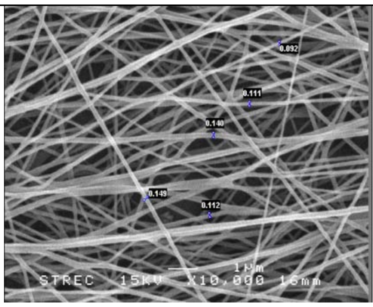
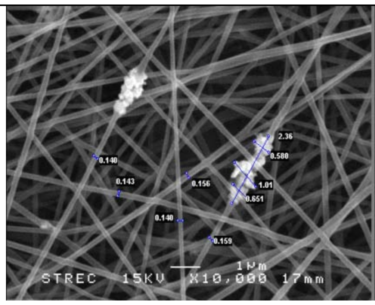
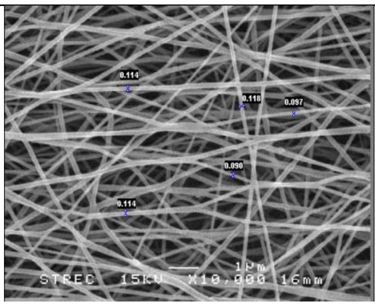
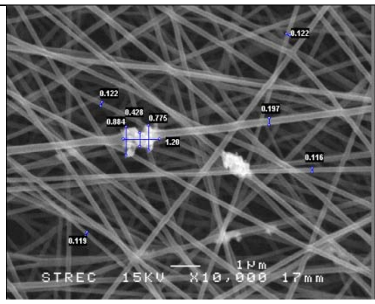
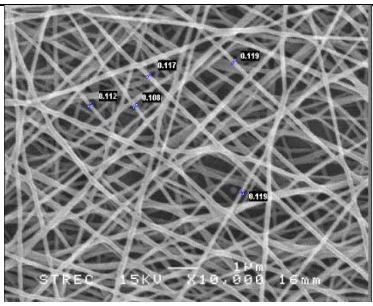
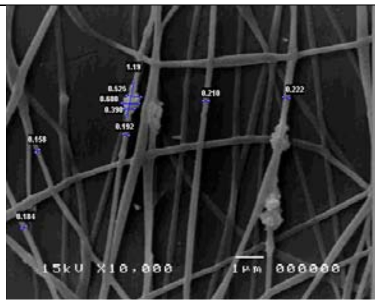
	Chemical Concentration Ratios (w/v)	Voltages (kV)	Low Magnification	High Magnification
1	PVA10%	12.5		
2	PVA10%	15		
3	PVA10%	17.5		
4	PVA 10%: PEDOT/PSS 0.052%	12.5		
5	PVA 10%: PEDOT/PSS 0.052%	15		
6	PVA 10%: PEDOT/PSS 0.052%	17.5		

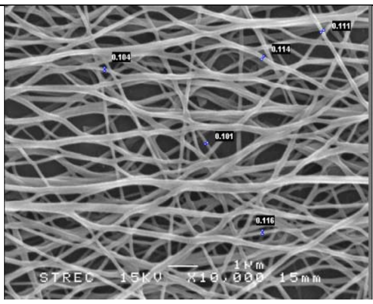
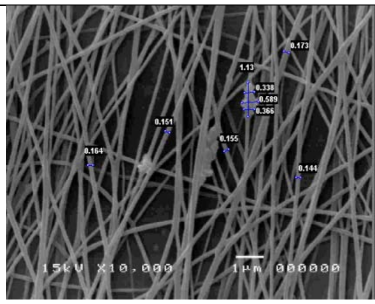
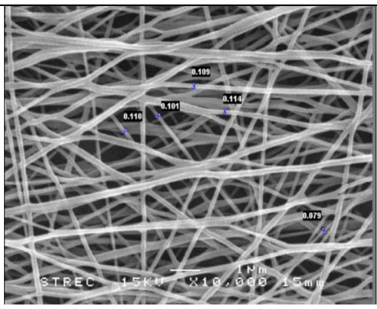
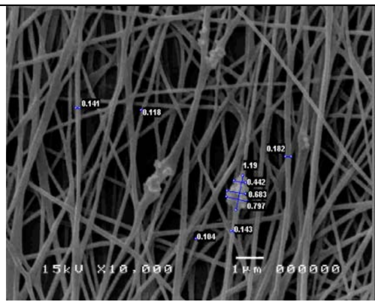
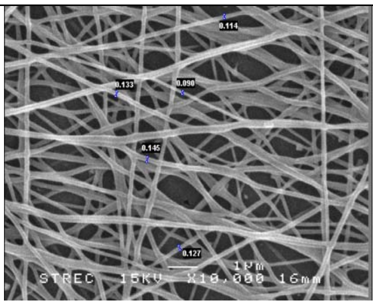
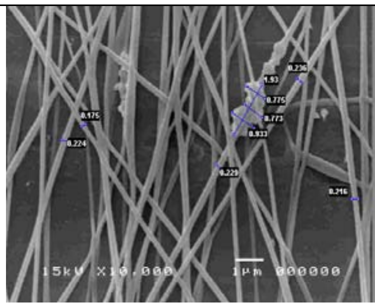
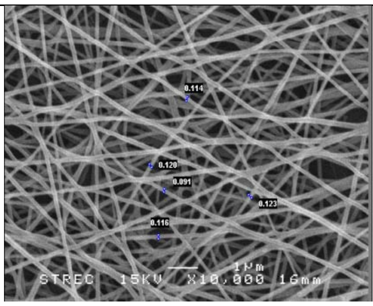
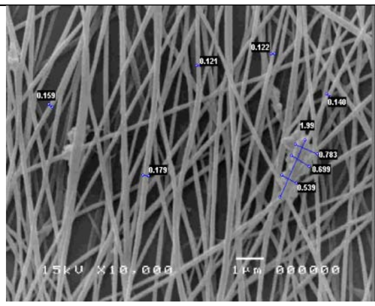
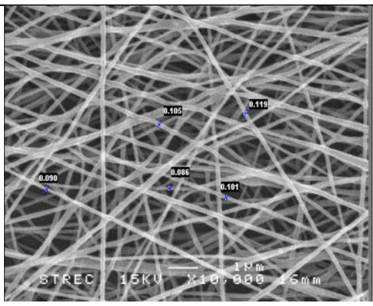
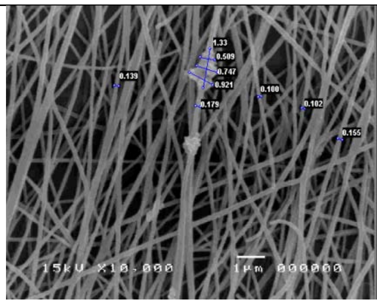
7	PVA 10%: PEDOT 0.084%	12.5		
8	PVA 10%: PEDOT 0.084%	15		
9	PVA 10%: PEDOT 0.084%	17.5		
10	PVA 10%: PEDOT 0.1%	12.5		
11	PVA 10%: PEDOT 0.1%	15		
12	PVA 10%: PEDOT 0.1%	17.5		
13	PVA 10% + AgNPs 0.25%	12.5		

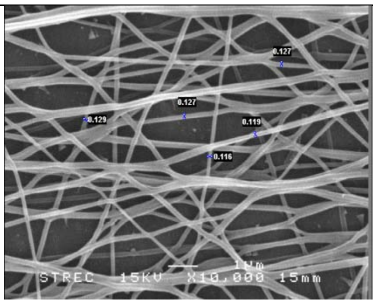
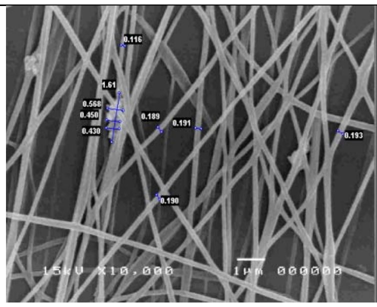
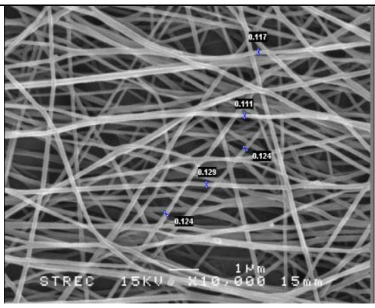
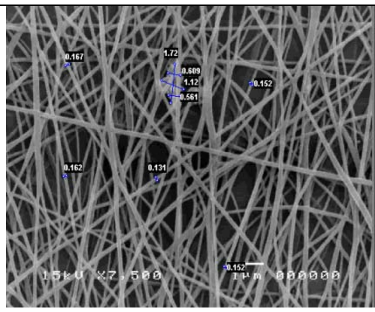
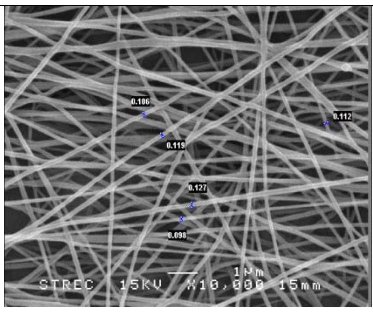
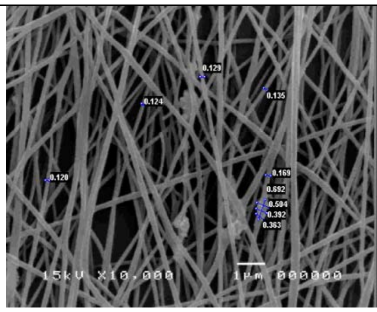
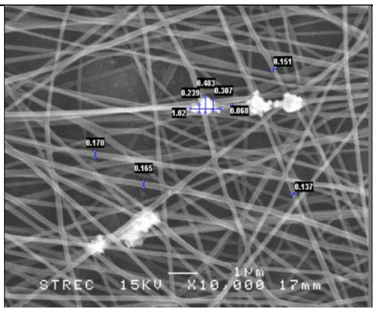
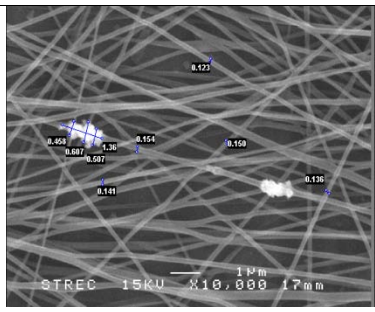
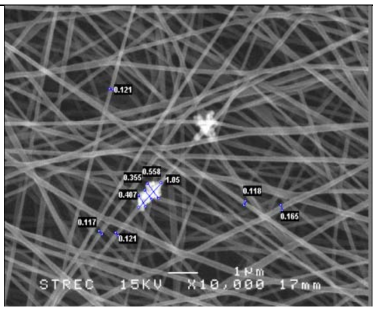
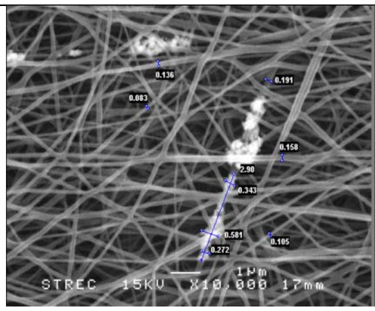
14	PVA 10% + AgNPs 0.25%	15		
15	PVA 10% + AgNPs 0.25%	17.5		
16	PVA10% +AgNPs 0.5%	12.5		
17	PVA10% +AgNPs 0.5%	15		
18	PVA10% +AgNPs 0.5%	17.5		
19	PVA10% +AgNPs 0.75%	12.5		
20	PVA10% +AgNPs 0.75%	15		

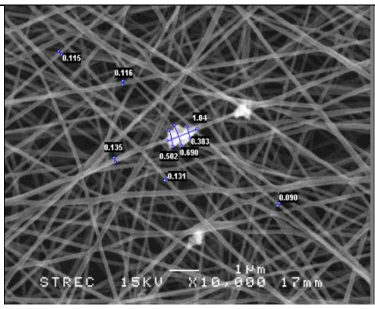
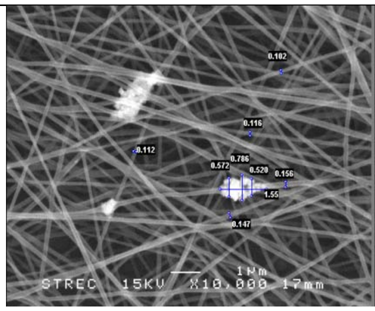
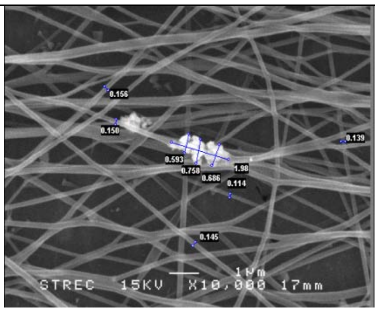
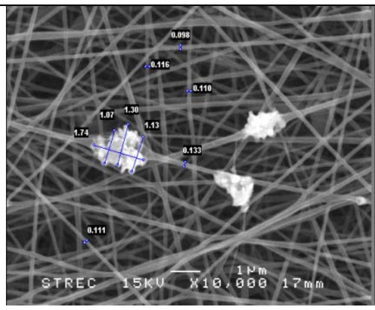
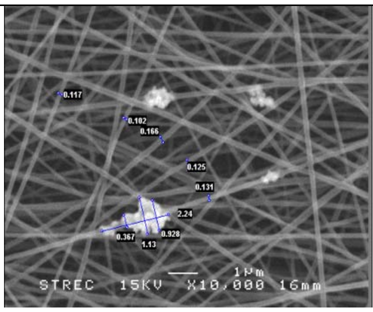
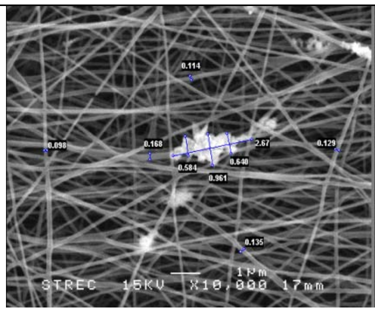
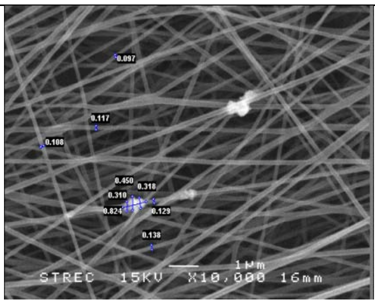
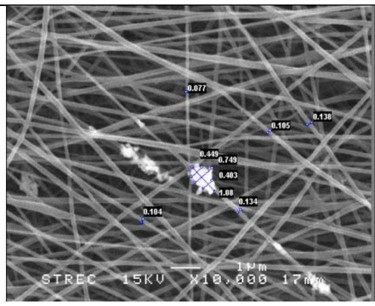
21	PVA10% +AgNPs 0.75%	17.5		
22	PVA10%+AgNPs 0.25% + PEDOT/PSS 0.084%	17.5, 30 min.		
23	PVA10%+AgNPs 0.25% + PEDOT/PSS 0.084%	17.5, 45 min.		

3. Illustrated the aligned fiber mat images by SEM

1. PVA 10%, 12.5 kV		19. PVA10%: AgNPs 0.75%, 12.5 kV	
2. PVA 10%, 15 kV		20. PVA10%: AgNPs 0.75%, 15 kV	
3. PVA 10%, 17.5 kV		21. PVA10%: AgNPs 0.75%, 17.5 kV	
4. PVA 10%: PEDOT 0.052%, 12.5 kV		22. PVA10% : AgNPs 0.25%: PEDOT/PSS 0.084%, 12.5 kV	

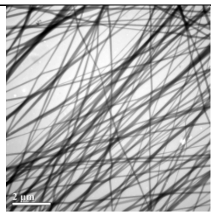
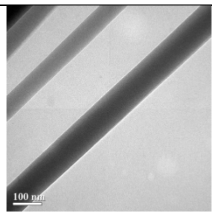
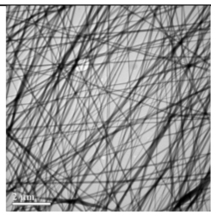
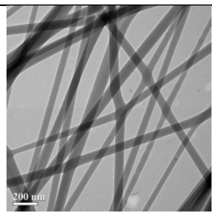
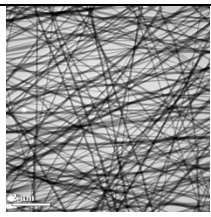
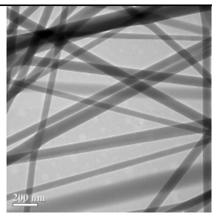
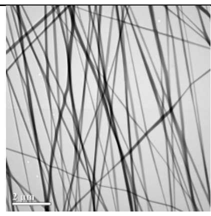
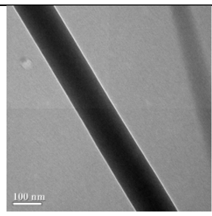
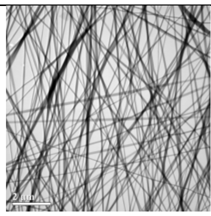
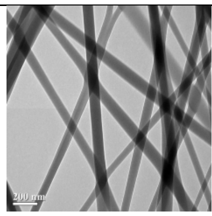
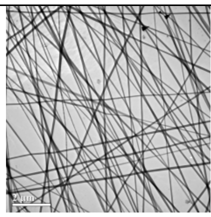
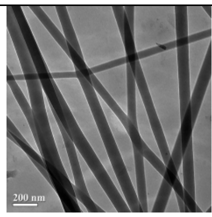
5. PVA 10%: PEDOT 0.052%, 15 kV		23. PVA10% : AgNPs 0.25%: PEDOT/PSS 0.084%, 15 kV	
6. PVA 10%: PEDOT 0.052%, 17.5 kV		24. PVA10% : AgNPs 0.25%: PEDOT/PSS 0.084%, 17.5 kV	
7. PVA 10%: PEDOT 0.084%, 12.5 kV		25. PVA10% +AgNPs 0.5%+ PEDOT/PSS 0.084%, 12.5 kV	
8. PVA 10%: PEDOT 0.084%, 15 kV		26. PVA10% +AgNPs 0.5%+ PEDOT/PSS 0.084%, 15 kV	
9. PVA 10%: PEDOT 0.084%, 17.5 kV		27. PVA10% +AgNPs 0.5%+ PEDOT/PSS 0.084%, 17.5 kV	

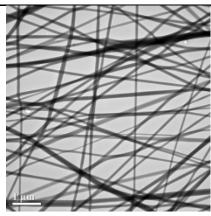
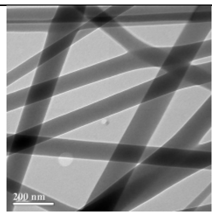
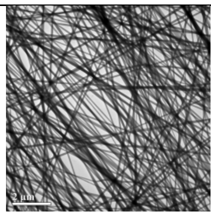
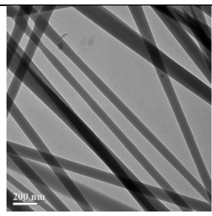
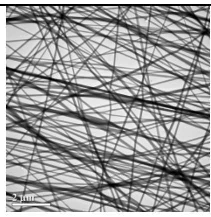
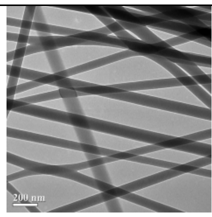
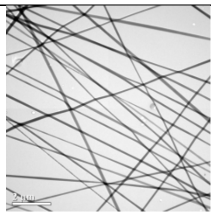
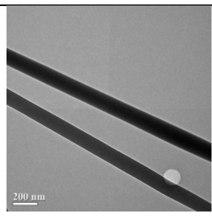
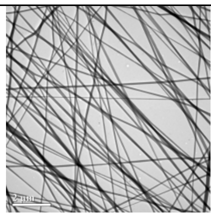
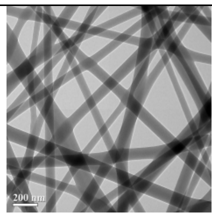
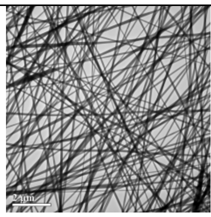
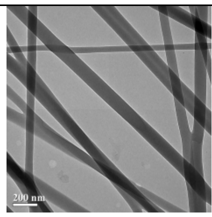
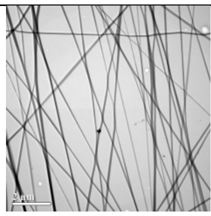
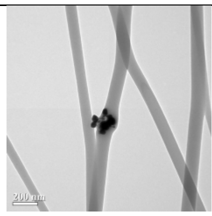
10. PVA 10%: PEDOT 0.1%, 12.5 kV		28. PVA10% +AgNPs 0.75%+ PEDOT/PSS 0.084%, 12.5 kV	
11. PVA 10%: PEDOT 0.1%, 15 kV		29. PVA10% +AgNPs 0.75%+ PEDOT/PSS 0.084%, 15 kV	
12. PVA 10%: PEDOT 0.1%, 17.5 kV		30. PVA10% +AgNPs 0.75%+ PEDOT/PSS 0.084%, 17.5 kV	
13. PVA 10%: AgNPs 0.25%, 12.5 kV		31. PVA10% : AgNPs 0.25%: PEDOT/PSS 0.084%, 12.5 kV, 30 min.	
14. PVA 10%: AgNPs 0.25%, 15 kV		32. PVA10% : AgNPs 0.25%: PEDOT/PSS 0.084%, 15 kV, 30 min.	

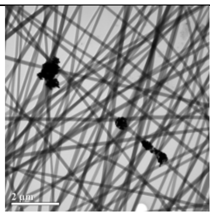
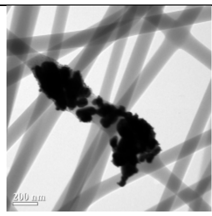
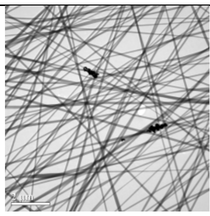
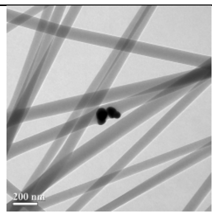
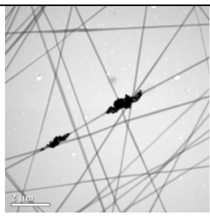
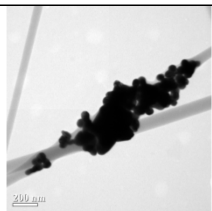
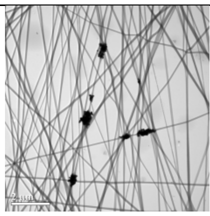
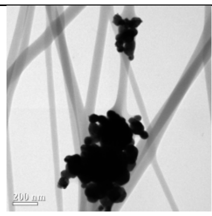
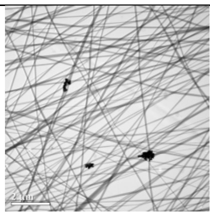
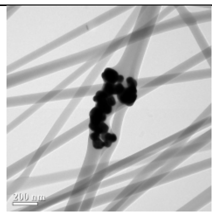
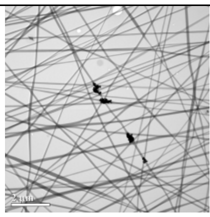
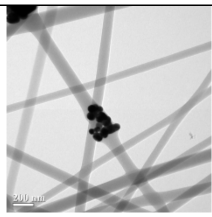
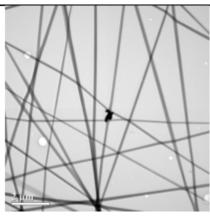
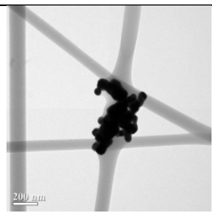
15. PVA 10%: AgNPs 0.25%, 17.5 kV		33. PVA10% : AgNPs 0.25%: PEDOT/PSS 0.084%, 12.5 kV, 45 min.	
16. PVA10%: AgNPs 0.5%, 12.5 kV		34. PVA10% : AgNPs 0.25%: PEDOT/PSS 0.084%, 15 kV, 45 min.	
17. PVA10%: AgNPs 0.5%, 15 kV		35 PVA10% : AgNPs 0.25%: PEDOT/PSS 0.084%, 17.5 kV, 30 min.	
18. PVA10%: AgNPs 0.5%, 17.5 kV		36. PVA10% : AgNPs 0.25%: PEDOT/PSS 0.084%, 17.5 kV, 45 min.	

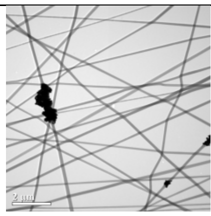
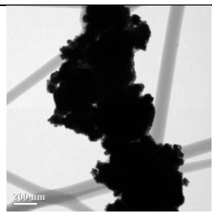
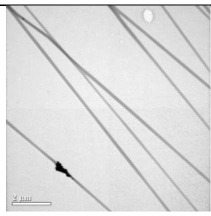
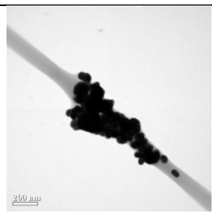
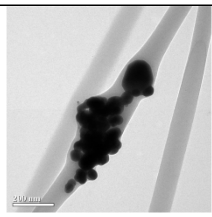
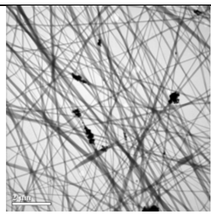
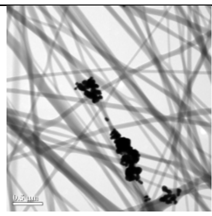
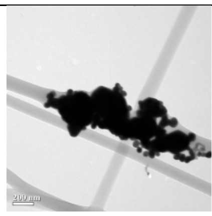
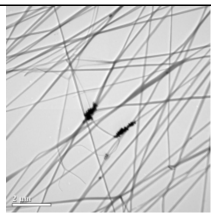
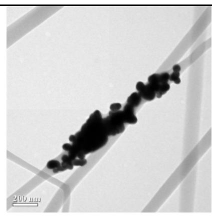
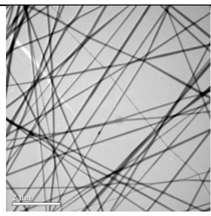
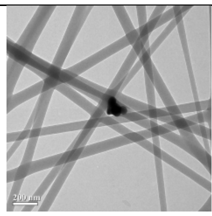
4. Illustrated the aligned fiber mat images by TEM

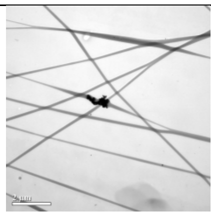
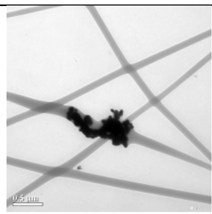
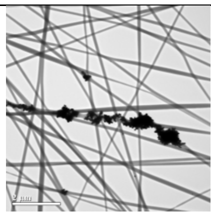
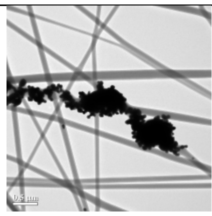
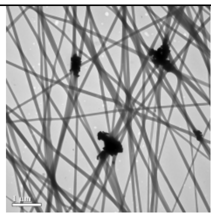
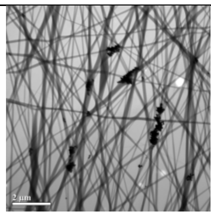
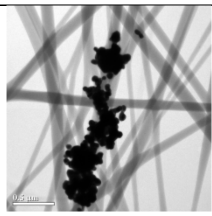
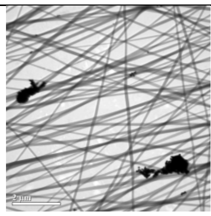
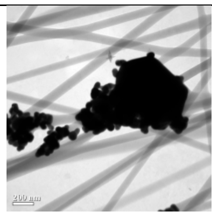
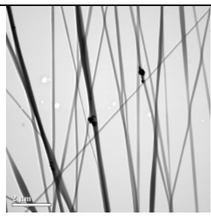
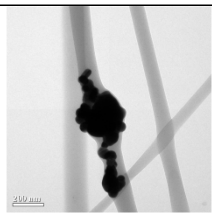
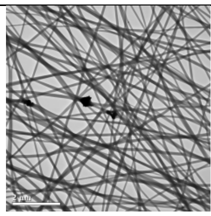
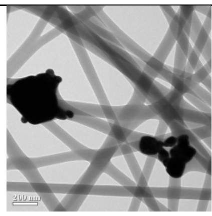
TEM Magnification: 2μm and 200 nm.

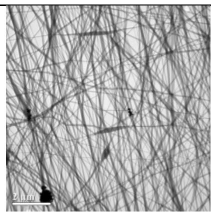
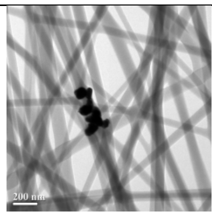
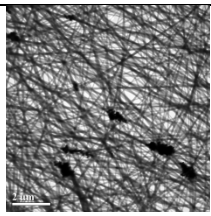
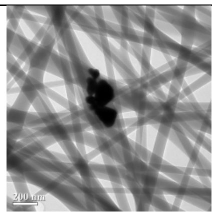
	Chemical Concentration Ratios (w/v)	Voltages (kV)	Mag.: ~2μm	Mag.: ~200 nm.
1	PVA10%	12.5		
2	PVA10%	15		
3	PVA10%	17.5		
4	PVA 10%: PEDOT/PSS 0.052%	12.5		
5	PVA 10%: PEDOT/PSS 0.052%	15		
6	PVA 10%: PEDOT/PSS 0.052%	17.5		

7	PVA 10%: PEDOT 0.084%	12.5		
8	PVA 10%: PEDOT 0.084%	15		
9	PVA 10%: PEDOT 0.084%	17.5		
10	PVA 10%: PEDOT 0.1%	12.5		
11	PVA 10%: PEDOT 0.1%	15		
12	PVA 10%: PEDOT 0.1%	17.5		
13	PVA 10% + AgNPs 0.25%	12.5		

14	PVA 10% + AgNPs 0.25%	15		
15	PVA 10% + AgNPs 0.25%	17.5		
16	PVA10% +AgNPs 0.5%	12.5		
17	PVA10% +AgNPs 0.5%	15		
18	PVA10% +AgNPs 0.5%	17.5		
19	PVA10% +AgNPs 0.75%	12.5		
20	PVA10% +AgNPs 0.75%	15		

21	PVA10% +AgNPs 0.75%	17.5		
22	PVA10% : AgNPs 0.25%: PEDOT/PSS 0.084%	12.5		
23	PVA10% : AgNPs 0.25%: PEDOT/PSS 0.084%	15		
24	PVA10% : AgNPs 0.25%: PEDOT/PSS 0.084%	17.5		
25	PVA10% +AgNPs 0.5%+ PEDOT/PSS 0.084%	12.5		
26	PVA10% +AgNPs 0.5%+ PEDOT/PSS 0.084%	15		
27	PVA10% +AgNPs 0.5%+ PEDOT/PSS 0.084%	17.5		

28	PVA10% +AgNPs 0.75%+ PEDOT/PSS 0.084%	12.5		
29	PVA10% +AgNPs 0.75%+ PEDOT/PSS 0.084%	15		
30	PVA10% +AgNPs 0.75%+ PEDOT/PSS 0.084%	17.5		
31	PVA10% : AgNPs 0.25%: PEDOT/PSS 0.084%	12.5 kV, 30 min.		
32	PVA10% : AgNPs 0.25%: PEDOT/PSS 0.084%	15 kV, 30 min.		
33	PVA10% : AgNPs 0.25%: PEDOT/PSS 0.084%	12.5 kV, 45 min.		
34	PVA10% : AgNPs 0.25%: PEDOT/PSS 0.084%	15 kV, 45 min.		

35	PVA10% : AgNPs 0.25%: PEDOT/PSS 0.084%	17.5 kV, 30 min.		
36	PVA10% : AgNPs 0.25%: PEDOT/PSS 0.084%	17.5 kV, 45 min.		

Appendix C Table of Electrical Conductivity Measurement Result of Randomized Fibers by Using The 4-probe Technique

Fiber Layer Thickness (D) = 6.69 μm

1. PVA 10%, 12.5 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
-5.148E+16	3.940E-01	3.077E+02	-1.212E+02	-2.788E+02	3.631E+01	-3.444E+13	3.249E-03	3.013E+02	-9.933E-01

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	6253.060	-1897.180	-317.966	-5439.670	-3738.620	-957.161	-1286.520	-1765.250	-2302.830	-2074.080
-I:	-1268.570	1747.340	-3287.570	-4903.470	-4119.270	-658.683	2582.600	3642.430	-2545.080	-2435.740

2. PVA 10%, 15.0 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
-3.652E+16	6.482E+00	2.637E+01	-1.709E+02	-3.756E+02	3.367E+01	-2.443E+13	3.792E-02	2.835E+02	-1.220E+00

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	6732.960	-1842.540	-488.699	-5499.440	-3096.750	-999.460	-1074.870	-1716.330	-2346.870	-2174.870
-I:	-1700.760	1520.200	-3592.940	-5065.620	-3897.940	-736.671	2845.660	3525.840	-2603.880	-2542.610

3. PVA 10%, 1.75 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
2.910E+16	1.778E+01	1.207E+01	2.145E+02	4.695E+02	-4.039E+01	1.947E+13	8.288E-02	2.588E+02	-1.487E+00

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	6759.030	-1683.870	-843.893	-2139.050	-5634.380	-999.247	-959.414	-1731.170	-1964.000	-2688.940
-I:	-2340.940	1425.490	-3719.370	-3325.880	-5277.370	-1172.380	2727.670	3151.740	-2288.800	-2880.920

4. PVA 10%, 20.0 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
1.576E+17	2.413E+00	1.641E+01	3.960E+01	8.928E+01	-1.007E+01	1.054E+14	6.094E-02	2.501E+02	-1.464E+00

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	7033.450	-2095.730	-228.089	-2872.470	-3653.820	-999.460	-948.275	-1058.640	-2027.160	-2193.400
-I:	-2841.590	1373.890	-3579.450	-3764.810	-4252.560	-1333.930	3140.240	3029.870	-2392.140	-2525.250

5. PVA 10%, 22.5 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
-1.873E+17	2.529E+00	1.318E+01	-3.334E+01	-9.658E+01	2.991E+01	-1.253E+14	7.588E-02	2.757E+02	-1.358E+00

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	6368.210	-1225.260	-152.554	-3055.610	-2767.720	-959.137	-999.460	-1000.520	-2472.620	-2445.250
-I:	-1745.810	1695.920	-2912.590	-3700.740	-3730.460	-717.972	2946.030	3320.170	-2650.600	-2721.590

6. PVA 10%+PEDOT/PSS 0.084%, 12.5 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
3.095E+16	2.997E+01	6.728E+00	2.017E+02	4.256E+02	-2.224E+01	2.071E+13	1.486E-01	2.888E+02	-1.233E+00

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	6582.090	-2130.610	-625.020	-2651.920	-5853.510	-999.460	-1023.980	-1679.840	-2396.490	-2918.770
-I:	-2021.500	1434.160	-4163.670	-3676.370	-5478.490	-1192.420	2691.020	3152.160	-2666.750	-3115.900

7. PVA 10% + PEDOT/PSS 0.084%, 15.0 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
6.196E+16	7.705E+00	1.307E+01	1.007E+02	1.775E+02	2.402E+01	4.145E+13	7.649E-02	3.099E+02	-1.193E+00

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	6780.460	-2204.220	-549.091	-4467.490	-5825.400	-999.460	-1054.220	-1688.350	-2525.070	-2405.510
-I:	-1904.850	1465.350	-3963.140	-4656.590	-5430.910	-1065.270	2565.120	3160.640	-2799.220	-2758.650

8. PVA 10% + PEDOT/PSS 0.084%, 17.5 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
-1.829E+17	3.130E+01	1.091E+00	-3.413E+01	-6.045E+01	-7.815E+00	-1.223E+14	9.169E-01	2.165E+02	-5.466E-01

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	6975.720	-3235.090	-978.957	-2236.880	-2230.000	-1382.160	-2059.320	-1489.990	-1894.770	-2406.300
-I:	-300.333	3226.630	-2264.170	-3296.340	-3488.250	-1219.430	2902.420	3165.630	-2207.880	-2693.710

9. PVA 10% + PEDOT/PSS 0.084%, 20.0 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
-5.154E+17	1.121E+01	1.080E+00	-1.211E+01	-2.902E+01	4.799E+00	-3.448E+14	9.255E-01	2.448E+02	-8.086E-01

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	7181.740	-1376.910	93.728	-2141.000	-2235.150	-1285.470	-2193.960	-1409.920	-2017.760	-2229.960
-I:	-286.689	3226.940	-2115.150	-3285.300	-3474.890	-1257.660	3245.410	3064.500	-2352.110	-2580.090

10. PVA 10% + PEDOT/PSS 0.084%, 22.5 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
-1.279E+17	9.151E+01	5.335E-01	-4.881E+01	-1.039E+02	6.222E+00	-8.555E+13	1.875E+00	2.458E+02	-5.915E-01

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	6809.350	-2735.310	-905.324	-3336.300	-2731.740	-1353.370	-1987.350	-1519.650	-2135.570	-2134.060
-I:	-118.906	2909.740	-2541.690	-4035.560	-3772.510	-1151.650	2571.540	3240.600	-2477.600	-2496.550

11. PVA 10% + PEDOT/PSS 0.052%, 12.5 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
-7.096E+16	8.076E-01	1.089E+02	-8.796E+01	-1.782E+02	2.241E+00	-4.747E+13	9.181E-03	1.944E+02	-8.330E-01

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	6814.510	-3194.340	-1015.710	-2990.450	-1701.360	-1037.300	-2088.300	-1428.590	-2085.540	-2012.770
-I:	-1816.360	2104.370	-3256.750	-3852.730	-3149.540	-1233.730	3202.660	3074.150	-2431.070	-2365.670

12. PVA 10% + PEDOT/PSS 0.052%, 15.0 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
-1.065E+17	1.387E+02	4.226E-01	-5.863E+01	-1.236E+02	6.313E+00	-7.122E+13	2.366E+00	2.389E+02	-7.573E-01

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	6608.470	-1474.960	-36.145	-2751.550	-2090.430	-1195.640	-2128.640	-1476.660	-2132.690	-2259.320
-I:	-140.344	2938.540	-2567.990	-3586.520	-3331.790	-1123.800	2802.340	3103.730	-2383.430	-2530.820

13. PVA 10% + PEDOT/PSS 0.052%, 17.5 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
4.399E+16	1.473E+01	9.634E+00	1.419E+02	2.437E+02	4.008E+01	2.943E+13	1.038E-01	2.785E+02	-1.128E+00

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	6962.370	-3204.190	-896.287	-2908.760	-5037.180	-999.460	-999.460	-1013.990	-2677.360	-2574.300
-I:	-3030.050	1380.010	-4142.980	-3636.110	-4963.040	-1308.620	3033.760	2982.680	-2792.640	-2821.370

14. PVA 10% + PEDOT/PSS 0.052%, 20.0 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
1.152E+17	5.633E+00	9.621E+00	5.419E+01	1.107E+02	-2.287E+00	7.706E+13	1.039E-01	2.605E+02	-5.936E-01

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	6371.940	-2123.060	-916.941	-2833.720	-3815.780	-1229.140	-1983.650	-1461.230	-2257.600	-2564.520
-I:	174.478	2801.030	-2734.820	-3612.600	-4230.740	-900.377	2621.770	3221.320	-2505.370	-2804.770

15. PVA 10% + PEDOT/PSS 0.052%, 22.5 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
-4.148E+16	2.360E+01	6.378E+00	-1.505E+02	-3.012E+02	1.794E-01	-2.775E+13	1.568E-01	2.232E+02	-1.315E+00

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	6835.760	-1789.440	-303.652	-3934.350	-2043.330	-989.229	-1110.600	-1776.070	-1948.750	-2106.950
-I:	-1900.900	1613.100	-3735.360	-4188.560	-3287.900	-1234.090	2803.810	3186.360	-2274.260	-2433.050

16. PVA 10% + PEDOT/PSS 0.1%, 12.5 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
9.504E+16	1.045E+01	6.283E+00	6.568E+01	1.131E+02	1.823E+01	6.358E+13	1.592E-01	2.603E+02	-5.976E-01

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	6445.710	-2222.350	-1244.910	-3105.130	-4125.980	-1365.710	-1942.880	-1451.720	-2083.710	-2208.050
-I:	-230.622	2990.350	-2510.430	-3832.640	-4481.460	-977.308	2592.370	3188.850	-2418.280	-2602.560

17. PVA 10% + PEDOT/PSS 0.1%, 15.0 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
2.704E+17	6.219E+00	3.712E+00	2.308E+01	4.735E+01	-1.180E+00	1.809E+14	2.694E-01	2.347E+02	-1.423E+00

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	6991.870	-2239.920	-633.312	-2359.780	-3049.260	-999.460	-999.460	-1030.510	-2063.030	-2475.450
-I:	-2842.430	1340.020	-4021.370	-3385.510	-3919.290	-1399.690	3008.500	3165.850	-2338.230	-2746.770

18. PVA 10% + PEDOT/PSS 0.1%, 17.5 kV

```
  DATE       User_Name   Sample_Name
02-09-2012     User_1       Sample_1
------------------------------------------------------------------------------------------------------------------------
  I(mA)     B       D       D_T      MN     T(K)
  10.000   0.550   6.690   0.100    1000    300
------------------------------------------------------------------------------------------------------------------------
    Nb          u          rho         RH          RHA         RHB         NS         SIGMA       DELTA      ALPHA
 4.182E+17  3.393E+00  4.399E+00  1.493E+01  2.209E+01  7.767E+00  2.797E+14  2.273E-01  2.228E+02  -1.272E+00
------------------------------------------------------------------------------------------------------------------------
  Vab       Vbc       Vac       Vmac      V-mac      Vcd       Vda       Vbd       Vmbd      V-mbd
+I:
 7277.680 -3064.990  -820.724 -2557.860  -2980.040  -999.460   -999.460 -1067.070 -1819.620 -2026.160
-I:
 -3327.890  1296.300 -4354.190 -3503.670 -3853.210 -1472.780  3206.630  3171.760 -2144.160 -2376.240
```

19. PVA 10% + PEDOT/PSS 0.1%, 20.0 kV

```
  DATE       User_Name   Sample_Name
02-09-2012     User_1       Sample_1
------------------------------------------------------------------------------------------------------------------------
  I(mA)     B       D       D_T      MN     T(K)
  10.000   0.550   6.690   0.100    1000    300
------------------------------------------------------------------------------------------------------------------------
    Nb          u          rho         RH          RHA         RHB         NS         SIGMA       DELTA      ALPHA
 4.038E+16  4.586E+02  3.371E-01  1.546E+02  2.967E+02  1.252E+01  2.701E+13  2.966E+00  2.670E+02  -5.058E-01
------------------------------------------------------------------------------------------------------------------------
  Vab       Vbc       Vac       Vmac      V-mac      Vcd       Vda       Vbd       Vmbd      V-mbd
+I:
 6735.000 -2446.480 -1007.090 -2403.040 -4801.590 -1398.790 -2114.920 -1625.620 -1834.070 -2148.280
-I:
  99.937   3722.570  -1930.120  -3303.980 -4726.910 -1108.440  2419.750  3326.870 -2127.500 -2482.880
```

20. PVA 10% + PEDOT/PSS 0.1%, 22.5 kV

```
  DATE       User_Name   Sample_Name
02-09-2012     User_1       Sample_1
------------------------------------------------------------------------------------------------------------------------
  I(mA)     B       D       D_T      MN     T(K)
  10.000   0.550   6.690   0.100    1000    300
------------------------------------------------------------------------------------------------------------------------
    Nb          u          rho         RH          RHA         RHB         NS         SIGMA       DELTA      ALPHA
 1.232E+17  1.420E+01  3.569E+00  5.066E+01  8.967E+01  1.165E+01  8.243E+13  2.802E-01  2.249E+02  -1.211E+00
------------------------------------------------------------------------------------------------------------------------
  Vab       Vbc       Vac       Vmac      V-mac      Vcd       Vda       Vbd       Vmbd      V-mbd
+I:
 6616.650 -2107.920  -531.316  -2780.260 -3714.410   -999.460 -1262.550 -1794.410 -2003.480 -2211.190
-I:
 -1991.450  1600.060 -4280.950 -3624.140 -4263.410 -1388.270  2621.970  3184.590 -2323.470 -2569.500
```

21. PVA 10% +Ag0.25%, 12.5 kV

```
   DATE       User_Name    Sample_Name
02-09-2012       User_1        Sample_1
-------------------------------------------------------------------------------------------------------
   I(mA)      B        D       D_T      MN      T(K)
   10.000    0.550    6.690    0.100    1000     300
-------------------------------------------------------------------------------------------------------
     Nb            u            rho          RH          RHA          RHB          NS          SIGMA        DELTA       ALPHA
 -5.405E+16  4.367E+00  2.644E+01  -1.155E+02  -1.948E+02  -3.619E+01  -3.616E+13  3.782E-02  3.093E+02  -5.123E-01
-------------------------------------------------------------------------------------------------------
   Vab        Vbc        Vac       Vmac      V-mac      Vcd        Vda        Vbd       Vmbd      V-mbd
+I:
 6897.740 -3267.980 -1048.250 -4743.060 -3377.050 -1315.840 -1982.480 -1403.200 -2592.410 -3069.440
-I:
 -214.819  3119.830  -2270.250  -4742.760 -4017.310  -903.406  2657.590  2817.920 -2824.650  -3182.660
```

22. PVA 10% +Ag0.25%, 15.0 kV

```
   DATE       User_Name    Sample_Name
02-09-2012       User_1        Sample_1
-------------------------------------------------------------------------------------------------------
   I(mA)      B        D       D_T      MN      T(K)
   10.000    0.550    6.690    0.100    1000     300
-------------------------------------------------------------------------------------------------------
     Nb            u            rho          RH          RHA          RHB          NS          SIGMA        DELTA       ALPHA
  2.708E+17  2.272E+00  1.014E+01  2.305E+01  -2.380E+01  6.990E+01  1.812E+14  9.857E-02  3.896E+02  -1.289E+00
-------------------------------------------------------------------------------------------------------
   Vab        Vbc        Vac       Vmac      V-mac      Vcd        Vda        Vbd       Vmbd      V-mbd
+I:
 6455.100 -1582.030  -146.281  -6003.800 -6111.500  -968.305  -947.650  -1710.100 -3396.670 -2747.180
-I:
 -1664.170  1667.660 -3578.490 -5468.500 -5654.450 -1261.160  2724.120  3108.850 -3428.030 -3008.390
```

23. PVA 10% +Ag0.25%, 17.5 kV

```
   DATE       User_Name    Sample_Name
02-09-2012       User_1        Sample_1
-------------------------------------------------------------------------------------------------------
   I(mA)      B        D       D_T      MN      T(K)
   10.000    0.550    6.690    0.100    1000     300
-------------------------------------------------------------------------------------------------------
     Nb            u            rho          RH          RHA          RHB          NS          SIGMA        DELTA       ALPHA
  1.108E+17  4.446E+01  1.267E+00  5.635E+01  1.115E+02  1.150E+00  7.411E+13  7.891E-01  2.301E+02  -1.083E+00
-------------------------------------------------------------------------------------------------------
   Vab        Vbc        Vac       Vmac      V-mac      Vcd        Vda        Vbd       Vmbd      V-mbd
+I:
 7327.230 -3813.970  -632.005 -1495.110  -2743.450  -923.228 -2102.770 -1370.940 -1976.580 -2253.030
-I:
 -3296.830  1312.210 -4623.050 -2882.080 -3763.590 -1443.820  3500.450  3180.430 -2351.140 -2631.370
```

24. PVA 10% +Ag0.25%, 20.0 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
8.066E+16	1.687E+01	4.589E+00	7.739E+01	1.651E+02	-1.034E+01	5.396E+13	2.179E-01	2.559E+02	-1.178E+00

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	7329.500	-4022.720	-786.481	-2675.660	-4171.710	-999.460	-924.158	-1060.170	-1988.340	-2305.630
-I:	-3968.810	1104.810	-4925.600	-3634.520	-4587.550	-1679.720	3537.270	3176.710	-2379.580	-2662.860

25. PVA 10% +Ag0.25%, 22.5 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
7.902E+16	4.207E+00	1.878E+01	7.900E+01	1.506E+02	7.411E+00	5.286E+13	5.326E-02	2.162E+02	-1.086E+00

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	6496.820	-2126.520	-492.575	-2014.190	-3249.400	-982.760	-1268.690	-1728.440	-2086.510	-2268.580
-I:	-1567.590	1603.930	-3958.150	-3297.270	-4037.290	-1026.230	2637.290	3152.810	-2434.590	-2641.030

26. PVA 10% +Ag0.5%, 12.5 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
-4.285E+17	7.347E+01	1.983E-01	-1.457E+01	-3.542E+01	6.282E+00	-2.867E+14	5.044E+00	2.257E+02	-3.580E-01

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	4238.870	-1838.020	-122.457	-2883.820	-2797.860	-715.593	-1680.950	-1422.620	-2164.380	-2197.900
-I:	263.223	1654.330	-2657.100	-3601.940	-3632.450	797.398	1901.020	1995.030	-2569.270	-2623.450

27. PVA 10% +Ag0.5%, 15.0 kV

```
  DATE      User_Name   Sample_Name
02-09-2012    User_1      Sample_1
--------------------------------------------------------------------------------
  I(mA)    B      D     D_T    MN    T(K)
  10.000  0.550  6.690  0.100  1000   300
--------------------------------------------------------------------------------
    Nb          u          rho         RH          RHA         RHB         NS         SIGMA       DELTA       ALPHA
 -2.313E+16  2.158E+03  1.251E-01  -2.699E+02  -5.415E+02  1.721E+00  -1.547E+13  7.996E+00  2.664E+02  -4.400E-01
--------------------------------------------------------------------------------
  Vab       Vbc       Vac       Vmac      V-mac     Vcd      Vda       Vbd       Vmbd      V-mbd
+I:
 4503.960 -2234.320  -374.897 -5219.300 -2275.440  -851.137 -1476.330 -1426.250 -2409.970 -2247.100
-I:
 -264.833  1487.550 -3210.540 -4661.780 -3498.520   727.401  2458.270  2849.590  -2742.010 -2584.800
```

28. PVA 10% +Ag0.5%, 17.5 kV

```
  DATE      User_Name   Sample_Name
02-09-2012    User_1      Sample_1
--------------------------------------------------------------------------------
  I(mA)    B      D     D_T    MN    T(K)
  10.000  0.550  6.690  0.100  1000   300
--------------------------------------------------------------------------------
    Nb          u          rho         RH          RHA         RHB         NS         SIGMA       DELTA       ALPHA
 -3.188E+17  9.260E-01  2.114E+01  -1.958E+01  -4.503E+01  5.869E+00  -2.133E+14  4.730E-02  2.217E+02  -1.095E+00
--------------------------------------------------------------------------------
  Vab       Vbc       Vac       Vmac      V-mac     Vcd      Vda       Vbd       Vmbd      V-mbd
+I:
 7149.510 -3185.250  -814.770 -2276.370  -2065.760  -999.460  -984.533 -1035.930 -2155.820 -2104.600
-I:
-2994.610  1432.340 -4154.670 -3436.120 -3373.580  -963.284  3688.220  3205.280 -2478.550 -2446.630
```

29. PVA 10% +Ag0.5%, 20.0 kV

```
  DATE      User_Name   Sample_Name
02-09-2012    User_1      Sample_1
--------------------------------------------------------------------------------
  I(mA)    B      D     D_T    MN    T(K)
  10.000  0.550  6.690  0.100  1000   300
--------------------------------------------------------------------------------
    Nb          u          rho         RH          RHA         RHB         NS         SIGMA       DELTA       ALPHA
  1.349E+17  2.342E+00  1.976E+01  4.628E+01  9.124E+01  1.329E+00  9.023E+13  5.061E-02  2.509E+02  -9.386E-01
--------------------------------------------------------------------------------
  Vab       Vbc       Vac       Vmac      V-mac     Vcd      Vda       Vbd       Vmbd      V-mbd
+I:
 6016.480 -2057.140  -410.625 -2527.600 -3338.320  -977.557 -1070.210 -1670.020 -2330.470 -2544.950
-I:
-1512.670  1650.810 -3426.850 -3573.840 -4084.530  -302.981  3328.470  3672.470 -2559.970 -2778.820
```

30. PVA 10% +Ag0.5%, 22.5 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
1.341E+17	1.435E+02	3.244E-01	4.655E+01	8.588E+01	7.228E+00	8.971E+13	3.083E+00	2.666E+02	-4.574E-01

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	6546.720	-2803.900	-945.424	-2462.460	-3185.660	-999.460	-1010.430	-1650.220	-2262.380	-2317.080
-I:	99.095	3357.850	-1756.910	-3545.430	-3986.230	-450.249	3160.930	3558.410	-2541.030	-2619.500

31. PVA 10% +Ag0.75%, 12.5 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
2.227E+17	1.841E+02	1.523E-01	2.803E+01	4.182E+01	1.425E+01	1.490E+14	6.565E+00	2.854E+02	-5.731E-01

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	5633.370	-999.460	-1750.400	-2757.110	-3200.020	-999.460	-1318.730	-1602.980	-2278.910	-2379.640
-I:	99.937	3234.130	-660.132	-3683.830	-3989.210	-333.346	2820.400	3672.870	-2536.590	-2684.170

32. PVA 10% +Ag0.75%, 15.0 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
1.617E+17	1.163E+00	3.317E+01	3.859E+01	6.633E+01	1.086E+01	1.082E+14	3.014E-02	2.308E+02	-7.103E-01

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	6667.700	-2811.380	-1191.250	-2355.620	-3117.270	-993.261	-2045.830	-1440.880	-1994.140	-2157.150
-I:	-1022.550	2475.570	-2804.650	-3381.640	-3925.170	-790.926	3902.750	3810.140	-2294.200	-2492.910

33. PVA 10% +Ag0.75%, 17.5 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
-1.064E+17	2.805E+00	2.092E+01	-5.869E+01	-1.191E+02	1.721E+00	-7.116E+13	4.780E-02	2.945E+02	-1.045E+00

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	6660.620	-2040.170	-211.359	-4318.350	-3600.970	-981.912	-1042.260	-1645.650	-2313.600	-2299.750
-I:	-1448.270	1610.760	-3289.160	-4510.700	-4184.960	-454.271	3000.330	3688.960	-2625.250	-2617.060

34. PVA 10% +Ag0.75%, 20.0 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
8.314E+16	5.051E+00	1.486E+01	7.508E+01	1.405E+02	9.609E+00	5.562E+13	6.728E-02	3.113E+02	-1.288E+00

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	6893.800	-1358.880	135.836	-2981.110	-4083.610	-989.021	-999.460	-1003.600	-2187.010	-2224.730
-I:	-1577.460	1811.850	-2713.530	-3826.200	-4466.520	-558.330	3498.890	3646.920	-2467.190	-2536.510

35. PVA 10% +Ag0.75%, 22.5 kV

DATE	User_Name	Sample_Name
02-09-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
10.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
-5.212E+16	2.872E+00	4.169E+01	-1.198E+02	-2.402E+02	6.843E-01	-3.487E+13	2.399E-02	2.614E+02	-1.342E+00

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	6830.650	-2004.640	-143.279	-4201.150	-2500.490	-999.460	-999.460	-1098.530	-2072.600	-2081.920
-I:	-2366.510	1530.320	-3766.740	-4508.350	-3597.600	-1357.700	3408.800	3376.710	-2430.990	-2442.560

36. PVA 10%+Ag0.25%+PEDOT/PSS 0.084%, 12.5 kV

DATE	User_Name	Sample_Name
01-06-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
20.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
2.499E+16	6.865E+02	3.639E-01	2.498E+02	4.111E+02	8.850E+01	1.672E+13	2.748E+00	1.182E+02	9.331E-02

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	2370.460	-5752.910	-317.273	3723.170	348.640	-934.693	-6193.010	-1400.210	1508.090	4386.310
-I:	1790.790	4738.590	-2187.350	-999.460	-1670.240	1833.450	5251.810	2068.010	-979.443	1316.740

37. PVA 10%+Ag0.25%+PEDOT/PSS 0.084%, 15.0 kV

DATE	User_Name	Sample_Name
01-06-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
20.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
-1.545E+17	1.167E+02	3.463E-01	-4.041E+01	-8.014E+01	-6.842E-01	-1.033E+14	2.888E+00	1.181E+02	5.042E-02

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	2983.090	-5764.470	-346.771	1894.470	2943.480	-999.460	-4666.380	-1056.040	4514.260	4496.360
-I:	1971.020	4965.660	-1814.660	-1460.340	-938.407	912.737	5131.610	2045.760	1543.140	1529.740

38. PVA 10%+Ag0.25%+PEDOT/PSS 0.084%, 1.75 kV

DATE	User_Name	Sample_Name
01-06-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
20.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
6.395E+16	2.903E+02	3.362E-01	9.761E+01	1.487E+02	4.653E+01	4.278E+13	2.974E+00	1.300E+02	7.436E-02

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	2700.410	-5584.889	-418.155	3829.670	2208.990	-999.460	-4664.540	-1127.610	2506.890	4567.850
-I:	2021.350	4838.720	-1967.220	-826.259	-1468.970	1100.160	5153.200	2120.620	-238.084	1516.880

39. PVA 10%+Ag0.25%+PEDOT/PSS 0.084%, 20.0K

DATE	User_Name	Sample_Name
01-06-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
20.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
2.727E+16	6.146E+02	3.724E-01	2.289E+02	3.916E+02	6.618E+01	1.824E+13	2.685E+00	1.112E+02	1.968E-01

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	2847.130	-5542.190	99.937	3715.890	-99.946	-999.460	-4688.610	-1003.070	2142.890	4804.030
-I:	4117.690	5008.450	-2015.390	-999.460	-2239.750	1670.590	5084.370	2043.420	-960.172	1265.720

40. PVA 10%+Ag0.25%+PEDOT/PSS 0.084%, 22.5 kV

DATE	User_Name	Sample_Name
01-06-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
20.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
5.933E+18	3.119E+00	3.373E-01	1.052E+00	-1.732E+00	3.837E+00	3.969E+15	2.964E+00	1.363E+02	2.097E-02

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	3010.510	-5208.540	-616.985	3622.640	3625.440	-999.460	-4344.020	-1026.210	2036.700	2046.530
-I:	1649.200	4881.780	-1982.300	-990.866	-999.460	733.450	5454.800	2071.080	-526.785	-542.188

41. PVA 10%+Ag0.50%+ PEDOT/PSS 0.084%, 12.5 kV

DATE	User_Name	Sample_Name
01-06-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
20.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
-5.189E+16	3.575E+02	3.365E-01	-1.203E+02	-2.060E+02	-3.465E+01	-3.471E+13	2.972E+00	1.171E+02	1.940E-02

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	2610.220	-6049.310	-711.176	1262.630	3572.240	-999.460	-4215.690	-1104.560	4390.960	2378.140
-I:	1449.170	4952.180	-1740.950	-1771.020	-816.014	398.638	5470.920	2019.920	1641.940	-142.980

42. PVA 10%+Ag0.50%+ PEDOT/PSS 0.084%, 15.0 kV

DATE	User_Name	Sample_Name
01-06-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
20.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
-1.157E+18	1.636E+01	3.299E-01	-5.396E+00	-1.022E+01	-5.719E-01	-7.738E+14	3.031E+00	1.349E+02	5.481E-03

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	3018.660	-5599.220	-745.144	3567.430	3657.580	-999.460	-4277.220	-1051.180	1851.790	1856.060
-I:	1536.310	4901.640	-1902.120	-956.146	-933.220	480.120	5448.770	2044.810	-534.622	-526.591

43. PVA 10%+Ag0.50%+ PEDOT/PSS 0.084%, 17.5 kV

DATE	User_Name	Sample_Name
01-06-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
20.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
-9.214E+17	2.198E+01	3.082E-01	-6.775E+00	9.665E+00	-2.321E+01	-6.164E+14	3.244E+00	1.289E+02	2.390E-03

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	2546.290	-6104.280	-913.819	3496.700	3578.880	-999.460	-4410.960	-549.211	2407.090	2212.160
-I:	1379.150	4995.330	-1741.240	-945.304	-799.561	65.242	5274.250	2008.870	-99.946	-142.200

44. PVA 10%+Ag0.50%+ PEDOT/PSS 0.084%, 20.0 kV

DATE	User_Name	Sample_Name
01-06-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
20.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
8.717E+17	1.150E+01	6.227E-01	7.161E+00	-1.683E+01	3.115E+01	5.832E+14	1.606E+00	1.284E+02	1.064E-01

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	2738.650	-6175.350	-1058.240	3364.080	3467.600	-1050.510	-6511.730	-1219.140	3125.080	2814.530
-I:	4037.830	6001.840	-108.734	-529.864	-537.016	227.870	5546.000	1960.740	1033.390	517.974

45. PVA 10%+Ag0.50%+ PEDOT/PSS 0.084%, 22.5 kV

DATE	User_Name	Sample_Name
01-06-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
20.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
3.752E+18	5.497E+00	3.026E-01	1.664E+00	-4.217E+00	7.544E+00	2.510E+15	3.304E+00	1.329E+02	7.744E-02

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	3282.020	-4178.290	-1432.880	3547.510	3443.710	-981.889	-6649.650	-1226.810	3798.030	3922.460
-I:	4031.400	6187.280	139.352	-157.896	-289.434	15.497	5428.260	1964.350	1674.940	1749.750

46. PVA 10%+Ag0.75%+ PEDOT/PSS 0.084%, 12.5 kV

DATE	User_Name	Sample_Name
01-06-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
20.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
8.254E+16	2.732E+02	2.768E-01	7.562E+01	1.274E+02	2.384E+01	5.522E+13	3.613E+00	1.267E+02	8.360E-02

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	3183.820	-4626.630	-1412.420	3467.310	1648.840	-998.447	-6573.390	-1221.680	3431.380	4114.850
-I:	4068.800	6121.330	119.646	-261.345	-1241.860	19.183	5418.560	1922.040	1358.030	1884.720

47. PVA 10%+Ag0.75%+ PEDOT/PSS 0.084%, 15.0 kV

DATE	User_Name	Sample_Name
01-06-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
20.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
-6.249E+17	6.441E+01	1.551E-01	-9.989E+00	-2.448E+01	4.507E+00	-4.181E+14	6.448E+00	1.293E+02	6.050E-02

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	3306.070	-6084.690	-1122.590	3334.150	3531.310	-937.667	-6700.300	-1241.750	3763.970	3786.960
-I:	3947.840	6250.310	325.216	-189.661	-153.533	-94.503	5523.760	1962.610	1692.220	1685.570

48. PVA 10%+Ag0.75%+ PEDOT/PSS 0.084%, 17.5 kV

DATE	User_Name	Sample_Name
01-06-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
20.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
-1.421E+18	4.052E+01	1.084E-01	-4.394E+00	-2.547E+01	1.669E+01	-9.505E+14	9.222E+00	1.288E+02	6.511E-02

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	3300.000	-6178.880	-1144.290	3342.190	3550.360	-963.067	-6638.130	-1228.180	3503.700	3881.550
-I:	4009.510	6175.300	194.860	-259.347	-218.722	-87.689	5389.050	1952.230	1462.100	1730.200

49. PVA 10%+Ag0.75%+ PEDOT/PSS 0.084%, 20.0 kV

DATE	User_Name	Sample_Name
01-06-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
20.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
-8.838E+16	6.468E+02	1.092E-01	-7.063E+01	-1.299E+02	-1.135E+01	-5.912E+13	9.157E+00	1.242E+02	6.715E-02

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	3317.040	-6215.450	-1170.080	1853.590	3350.330	-1028.980	-6576.770	-1233.380	3979.250	3479.610
-I:	3995.620	6134.740	121.167	-1061.550	-419.271	-73.988	5457.070	1920.900	1796.620	1371.620

50. PVA 10%+Ag0.75%+ PEDOT/PSS 0.084%, 22.5 kV

DATE	User_Name	Sample_Name
01-06-2012	User_1	Sample_1

I(mA)	B	D	D_T	MN	T(K)
20.000	0.550	6.690	0.100	1000	300

Nb	u	rho	RH	RHA	RHB	NS	SIGMA	DELTA	ALPHA
-1.122E+18	7.049E+01	7.894E-02	-5.565E+00	-2.957E+01	1.844E+01	-7.504E+14	1.267E+01	1.256E+02	2.378E-02

	Vab	Vbc	Vac	Vmac	V-mac	Vcd	Vda	Vbd	Vmbd	V-mbd
+I:	3303.660	-4689.540	-1701.890	3380.250	3340.030	-999.460	-4491.620	-446.622	3690.770	3798.530
-I:	3867.740	6379.680	614.199	134.725	-99.946	-1032.170	5109.800	1934.450	1742.840	1729.350

Appendix D Table of Electrical Conductivity Measurement Result of Aligned Single Fibers by Using The 2-probe Technique

1) PVA10%, 12.5 kV, 20 min (R_0=4.06 MΩ)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at $R_0//R_1$	I (μA) at $R_0//R_1$	I (μA) at $R_0//R_1$	I (μA) at $R_0//R_1$	Voltage (V)	R_o*I (μA) at $R_0//R_1$	R_0*V	R_1=(V*R_0)/(I*R_0-V) Mohm	abs R_1=(V*R_0)/(I*R_0-V) Mohm
0.234	0.2344	0.234	0.234133333	1	0.950581333	4.06	-82.15519102	82.16
0.4785	0.4795	0.4798	0.479266667	2	1.945822667	8.12	-149.8781778	149.88
0.7397	0.7399	0.7397	0.739766667	3	3.003452667	12.18	3527.708052	3527.71
0.9847	0.9847	0.98469	0.984696667	4	3.997868467	16.24	-7618.928471	7618.93
1.2192	1.2196	1.221	1.219933333	5	4.952929333	20.3	-431.2664646	431.27
1.4675	1.4678	1.4687	1.468	6	5.96008	24.36	-610.2204409	610.22
1.7157	1.7158	1.7165	1.716	7	6.96696	28.42	-860.1694915	860.17
1.9634	1.9633	1.9637	1.963466667	8	7.971674667	32.48	-1146.676709	1146.68
								1803.38

2) PVA10%, 15.0 kV, 20 min (R_0=4.06 MΩ)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at $R_0//R_1$	I (μA) at $R_0//R_1$	I (μA) at $R_0//R_1$	I (μA) at $R_0//R_1$	Voltage (V)	R_o*I (μA) at $R_0//R_1$	R_0*V	R_1=(V*R_0)/(I*R_0-V) Mohm	abs R_1=(V*R_0)/(I*R_0-V) Mohm
0.2441	0.244	0.2439	0.244	1	0.99064	4.06	-433.7606838	433.76
0.49	0.4902	0.489	0.489733333	2	1.988317333	8.12	-695.046793	695.05
0.7404	0.7404	0.7403	0.740366667	3	3.005888667	12.18	2068.379939	2068.38
0.9848	0.98478	0.98475	0.984776667	4	3.998193267	16.24	-8988.598207	8988.60
1.2379	1.2384	1.2378	1.238033333	5	5.026415333	20.3	768.493047	768.49
1.4878	1.4886	1.4882	1.4882	6	6.042092	24.36	578.7323007	578.73
1.7382	1.7383	1.7382	1.738233333	7	7.057227333	28.42	496.6158363	496.62
1.9875	1.9876	1.9876	1.987566667	8	8.069520667	32.48	467.1992022	467.20
								2228.00

3) PVA10%, 17.5 kV, 20 min (R_0=4.06 MΩ)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at $R_0//R_1$	I (μA) at $R_0//R_1$	I (μA) at $R_0//R_1$	I (μA) at $R_0//R_1$	Voltage (V)	R_o*I (μA) at $R_0//R_1$	R_0*V	R_1=(V*R_0)/(I*R_0-V) Mohm	abs R_1=(V*R_0)/(I*R_0-V) Mohm
0.2465	0.2452	0.2447	0.245466667	1	0.996594667	4.06	-1192.247455	1192.25
0.4937	0.4925	0.4924	0.492866667	2	2.001038667	8.12	7817.715019	7817.72
0.742	0.7413	0.7411	0.741466667	3	3.010354667	12.18	1176.281226	1176.28
0.9859	0.9859	0.9857	0.985833333	4	4.002483333	16.24	6539.597315	6539.60
1.2394	1.2389	1.2389	1.239066667	5	5.030610667	20.3	663.1675233	663.17
1.4892	1.4886	1.4889	1.4889	6	6.044934	24.36	542.1284551	542.13
1.7392	1.738	1.7383	1.7385	7	7.05831	28.42	487.394958	487.40
1.988	1.9866	1.9876	1.9874	8	8.068844	32.48	471.7912963	471.79
								2361.29

4) PVA10%+PEDOT/PSS 0.052%, 12.5 kV, 20 min (R_0=4.06 MΩ)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2465	0.2452	0.2447	0.245466667	1	0.996594667	4.06	-1192.247455	1192.25
0.4937	0.4925	0.4924	0.492866667	2	2.001038667	8.12	7817.715019	7817.72
0.742	0.7413	0.7411	0.741466667	3	3.010354667	12.18	1176.281226	1176.28
0.9904	0.9891	0.9894	0.989633333	4	4.017911333	16.24	906.6885026	906.69
1.2394	1.2389	1.2389	1.239066667	5	5.030610667	20.3	663.1675233	663.17
1.4892	1.4886	1.4889	1.4889	6	6.044934	24.36	542.1284551	542.13
1.7392	1.738	1.7384	1.738533333	7	7.058445333	28.42	486.2663686	486.27
1.988	1.9876	1.9866	1.9874	8	8.068844	32.48	471.7912963	471.79
								1657.04

5) PVA10%+PEDOT/PSS 0.052%, 15.0 kV, 20 min (R_0=4.06 MΩ)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.246	0.2461	0.2461	0.246066667	1	0.999030667	4.06	-4188.445667	4188.45
0.4944	0.4944	0.4945	0.494433333	2	2.007399333	8.12	1097.396162	1097.40
0.7437	0.7438	0.7438	0.743766667	3	3.019692667	12.18	618.5043502	618.50
0.9926	0.9928	0.9927	0.9927	4	4.030362	16.24	534.8791252	534.88
1.2427	1.2428	1.2426	1.2427	5	5.045362	20.3	447.5111327	447.51
1.4929	1.4932	1.4928	1.492966667	6	6.061444667	24.36	396.4542624	396.45
1.743	1.7437	1.7431	1.743266667	7	7.077662667	28.42	365.9415936	365.94
1.9932	1.9933	1.9929	1.993133333	8	8.092121333	32.48	352.5784834	352.58
								1000.21

6) PVA10%+PEDOT/PSS 0.052%, 17.5 kV, 20 min (R_0=4.06 MΩ)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2469	0.2465	0.2468	0.246733333	1	1.001737333	4.06	2336.914812	2336.92
0.4952	0.495	0.495	0.495066667	2	2.009970667	8.12	814.388874	814.39
0.7445	0.7443	0.7443	0.744366667	3	3.022128667	12.18	550.4172567	550.42
0.9934	0.9935	0.9933	0.9934	4	4.033204	16.24	489.0976991	489.10
1.2434	1.2437	1.2436	1.243566667	5	5.048880667	20.3	415.2971182	415.30
1.4937	1.4939	1.4938	1.4938	6	6.064828	24.36	375.763559	375.76
1.7444	1.7444	1.7442	1.744333333	7	7.081993333	28.42	346.6135458	346.61
1.9944	1.994	1.9945	1.9943	8	8.096858	32.48	335.3362655	335.34
								707.98

7) PVA10%+PEDOT/PSS 0.084%, 12.5 kV, 20 min (R_0=4.06 MΩ)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2348	0.2348	0.2349	0.234833333	1	0.953423333	4.06	-87.16810993	87.17
0.48	0.4808	0.4808	0.480533333	2	1.950965333	8.12	-165.5971286	165.60
0.727	0.7278	0.7284	0.727733333	3	2.954597333	12.18	-268.2661811	268.27
0.9775	0.9774	0.9774	0.977433333	4	3.968379333	16.24	-513.5881596	513.59
1.23	1.231	1.23	1.230333333	5	4.995153333	20.3	-4188.445667	4188.45
1.469	1.4698	1.4702	1.469666667	6	5.966846667	24.36	-734.7677458	734.77
1.7174	1.7173	1.7183	1.717666667	7	6.973726667	28.42	-1081.705151	1081.71
1.9645	1.965	1.9653	1.964933333	8	7.977629333	32.48	-1451.901299	1451.90
								1061.43

8) PVA10%+PEDOT/PSS 0.084%, 15.0 kV, 20 min (R_0=4.06 MΩ)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2473	0.247	0.2463	0.246866667	1	1.002278667	4.06	1781.74371	1781.74
0.4956	0.4994	0.4947	0.496566667	2	2.016060667	8.12	505.5829978	505.58
0.7451	0.7448	0.7442	0.7447	3	3.023482	12.18	518.6951708	518.70
0.9942	0.9937	0.9936	0.993833333	4	4.034963333	16.24	464.486605	464.49
1.234	1.2336	1.2336	1.233733333	5	5.008957333	20.3	2266.299494	2266.30
1.4942	1.4938	1.4942	1.494066667	6	6.065910667	24.36	369.5911638	369.59
1.7446	1.7445	1.7441	1.7444	7	7.082264	28.42	345.473111	345.47
1.9942	1.9936	1.9932	1.993666667	8	8.094286667	32.48	344.4813689	344.48
								824.54

9) PVA10%+PEDOT/PSS 0.084%, 17.5 kV, 20 min (R_0=4.06 MΩ)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.247	0.2466	0.2466	0.246733333	1	1.001737333	4.06	2336.914812	2336.92
0.4957	0.4955	0.4951	0.495433333	2	2.011459333	8.12	708.5927046	708.59
0.7454	0.7451	0.7447	0.745066667	3	3.024970667	12.18	487.7723195	487.77
0.9946	0.9945	0.9946	0.994566667	4	4.037940667	16.24	428.0367592	428.04
1.2448	1.2446	1.2449	1.244766667	5	5.053752667	20.3	377.6556822	377.66
1.4957	1.4952	1.4951	1.495333333	6	6.071053333	24.36	342.8410584	342.84
1.7458	1.746	1.746	1.745933333	7	7.088489333	28.42	321.1686531	321.17
1.9956	1.9959	1.996	1.995833333	8	8.103083333	32.48	315.0848828	315.08
								664.76

10) PVA10%+PEDOT/PSS 0.1%, 12.5 kV, 20 min (R_0=4.06 MΩ)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2467	0.2468	0.2468	0.246766667	1	1.001872667	4.06	2168.031328	2168.03
0.4954	0.4953	0.4954	0.495366667	2	2.011188667	8.12	725.7343741	725.73
0.745	0.7449	0.7452	0.745033333	3	3.024835333	12.18	490.4303009	490.43
0.994	0.9944	0.9945	0.9943	4	4.036858	16.24	440.6099083	440.61
1.2444	1.2446	1.2444	1.244466667	5	5.052534667	20.3	386.4115124	386.41
1.4947	1.4952	1.4953	1.495066667	6	6.069970667	24.36	348.1458897	348.15
1.7456	1.7462	1.746	1.745933333	7	7.088489333	28.42	321.1686531	321.17
1.9952	1.996	1.9959	1.9957	8	8.102542	32.48	316.7482592	316.75
								649.66

11) PVA10%+PEDOT/PSS 0.1%, 15.0 kV, 20 min (R_0=4.06 MΩ)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.247	0.2472	0.247	0.247066667	1	1.003090667	4.06	1313.632442	1313.63
0.4957	0.4961	0.4959	0.4959	2	2.013354	8.12	608.0575109	608.06
0.7458	0.7456	0.7456	0.745666667	3	3.027406667	12.18	444.4174167	444.42
0.9947	0.9952	0.9948	0.9949	4	4.039294	16.24	413.2946506	413.29
1.2449	1.2455	1.2453	1.245233333	5	5.055647333	20.3	364.7973548	364.80
1.4954	1.4958	1.4959	1.4957	6	6.072542	24.36	335.8054644	335.81
1.7462	1.7465	1.7467	1.746466667	7	7.090654667	28.42	313.4973747	313.50
1.9968	1.9966	1.9967	1.9967	8	8.106602	32.48	304.6847151	304.68
								512.27

12) PVA10%+PEDOT/PSS 0.1%, 17.5 kV, 20 min (R_0=4.06 MΩ)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2476	0.2476	0.2474	0.247533333	1	1.004985333	4.06	814.388874	284.82
0.4965	0.4964	0.4961	0.496333333	2	2.015113333	8.12	537.2739303	584.47
0.7462	0.746	0.746	0.746066667	3	3.029030667	12.18	419.5563312	849.16
0.9958	0.9953	0.9954	0.9955	4	4.04173	16.24	389.1684639	1040.62
1.246	1.2458	1.2454	1.245733333	5	5.057677333	20.3	351.9580193	1009.12
1.4964	1.4964	1.4966	1.496466667	6	6.075654667	24.36	321.9893904	927.96
1.7474	1.7473	1.7473	1.747333333	7	7.094173333	28.42	301.7839445	888.69
1.9976	1.9976	1.9977	1.997633333	8	8.110391333	32.48	294.225996	1512.95
								887.22

13) PVA10%+AgNPs 0.25%, 12.5 kV, 20 min (R_0=3.959 MΩ)

I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2561	1	1.0138999	3.959	284.822193	284.82
0.5086	2	2.0135474	7.918	584.4663921	584.47
0.7613	3	3.0139867	11.877	849.1638485	849.16
1.0142	4	4.0152178	15.836	1040.62348	1040.62
1.2679	5	5.0196161	19.795	1009.12006	1009.12
1.522	6	6.025598	23.754	927.9631221	927.96
1.776	7	7.031184	27.713	888.6929194	888.69
2.026	8	8.020934	31.672	1512.945448	1512.95
					887.22

14) PVA10%+AgNPs 0.25%, 15.0 kV, 20 min (R_0=3.959 MΩ)

I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2548	1	1.0087532	3.959	452.2917333	452.29
0.5075	2	2.0091925	7.918	861.354365	861.35
0.7611	3	3.0131949	11.877	900.1205011	900.12
1.0144	4	4.0160096	15.836	989.1565061	989.16
1.2683	5	5.0211997	19.795	933.7396284	933.74
1.5228	6	6.0287652	23.754	825.7894956	825.79
1.7771	7	7.0355389	27.713	779.7934095	779.79
2.028	8	8.028852	31.672	1097.740191	1097.74
					855.00

15) PVA10%+AgNPs 0.25%, 17.5 kV, 20 min (R_0=3.959 MΩ)

I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.255	1	1.009545	3.959	414.772132	414.77
0.5078	2	2.0103802	7.918	762.7984047	762.80
0.7612	3	3.0135908	11.877	873.8999912	873.90
1.0143	4	4.0156137	15.836	1014.237497	1014.24
1.268	5	5.020012	19.795	989.1565061	989.16
1.5225	6	6.0275775	23.754	861.354365	861.35
1.7772	7	7.0359348	27.713	771.2022886	771.20
2.028	8	8.028852	31.672	1097.740191	1097.74
					848.15

16) PVA10%+AgNPs 0.5%, 12.5 kV, 20 min (R_0=3.959 MΩ)

I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2567	1	1.0162753	3.959	243.2520445	243.25
0.5084	2	2.0127556	7.918	620.746966	620.75
0.7615	3	3.0147785	11.877	803.6674899	803.67
1.0143	4	4.0156137	15.836	1014.237497	1014.24
1.268	5	5.020012	19.795	989.1565061	989.16
1.5222	6	6.0263898	23.754	900.1205011	900.12
1.7759	7	7.0307881	27.713	900.1205011	900.12
2.026	8	8.020934	31.672	1512.945448	1512.95
					873.03

17) PVA10%+AgNPs 0.5%, 15.0 kV, 20 min (R_0=3.959 MΩ)

I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2549	1	1.0091491	3.959	432.7201583	432.72
0.508	2	2.011172	7.918	708.736126	708.74
0.7612	3	3.0135908	11.877	873.8999912	873.90
1.0145	4	4.0164055	15.836	965.2860321	965.29
1.2684	5	5.0215956	19.795	916.6219045	916.62
1.5229	6	6.0291611	23.754	814.5783252	814.58
1.7772	7	7.0359348	27.713	771.2022886	771.20
2.028	8	8.028852	31.672	1097.740191	1097.74
					822.60

18) PVA10%+AgNPs 0.5%, 17.5 kV, 20 min (R_0=3.959 MΩ)

I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.256	1	1.013504	3.959	293.1723934	293.17
0.5085	2	2.0131515	7.918	602.0606015	602.06
0.7615	3	3.0147785	11.877	803.6674899	803.67
1.0144	4	4.0160096	15.836	989.1565061	989.16
1.267	5	5.016053	19.795	1233.102847	1233.10
1.5226	6	6.0279734	23.754	849.1638485	849.16
1.7775	7	7.0371225	27.713	746.5283857	746.53
2.029	8	8.032811	31.672	965.2860321	965.29
					810.27

19) PVA10%+AgNPs 0.75%, 12.5 kV, 20 min (R_0=3.959 MΩ)

I (µA) at R_0//R1	Voltage (V)	R_o*I (µA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2614	1	1.0348826	3.959	113.4949803	113.49
0.5107	2	2.0218613	7.918	362.1925503	362.19
0.763	3	3.020717	11.877	573.2972921	573.30
1.0149	4	4.0179891	15.836	880.3108549	880.31
1.2679	5	5.0196161	19.795	1009.12006	1009.12
1.5213	6	6.0228267	23.754	1040.62348	1040.62
1.7749	7	7.0268291	27.713	1032.94557	1032.95
2.025	8	8.016975	31.672	1865.802651	1865.80
					859.72

20) PVA10%+AgNPs 0.75%, 15.0 kV, 20 min (R_0=3.959 MΩ)

I (µA) at R_0//R1	Voltage (V)	R_o*I (µA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2536	1	1.0040024	3.959	989.1565061	989.16
0.507	2	2.007213	7.918	1097.740191	1097.74
0.7613	3	3.0139867	11.877	849.1638485	849.16
1.015	4	4.018385	15.836	861.354365	861.35
1.2697	5	5.0267423	19.795	740.2130707	740.21
1.5236	6	6.0319324	23.754	743.8839549	743.88
1.7802	7	7.0478118	27.713	579.6267867	579.63
2.033	8	8.048647	31.672	651.0576192	651.06
					814.02

21) PVA10%+AgNPs 0.75%, 17.5 kV, 20 min (R_0=3.959 MΩ)

I (µA) at R_0//R1	Voltage (V)	R_o*I (µA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2309	1	0.9141331	3.959	-46.10624117	46.11
0.4834	2	1.9137806	7.918	-91.83548018	91.84
0.7223	3	2.8595857	11.877	-84.58540191	84.59
0.9792	4	3.8766528	15.836	-128.3855653	128.39
1.224	5	4.845816	19.795	-128.3855653	128.39
1.5103	6	5.9792777	23.754	-1146.301328	1146.30
1.7636	7	6.9820924	27.713	-1547.555228	1547.56
2.018	8	7.989262	31.672	-2949.525051	2949.53
					765.33

22) PVA10%+AgNPs 0.25% +PEDOT/PSS 0.084%, 17.5 kV, 30 min (R_0=3.959 MΩ)

I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2573	1	1.0186507	3.959	212.2708531	212.27
0.5108	2	2.0222572	7.918	355.7500494	355.75
0.7655	3	3.0306145	11.877	387.9534208	387.95
1.0181	4	4.0306579	15.836	516.5389671	516.54
1.2722	5	5.0366398	19.795	540.2594992	540.26
1.5273	6	6.0465807	23.754	509.9536933	509.95
1.7823	7	7.0561257	27.713	493.7666702	493.77
2.036	8	8.060524	31.672	523.2965435	523.30
					442.47

23) PVA10%+AgNPs 0.25% +PEDOT/PSS 0.084%, 17.5 kV, 45 min (R_0=3.959 MΩ)

I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2577	1	1.0202343	3.959	195.6578681	195.66
0.5118	2	2.0262162	7.918	302.0269909	302.03
0.7668	3	3.0357612	11.877	332.1197275	332.12
1.0212	4	4.0429308	15.836	368.8726975	368.87
1.2764	5	5.0532676	19.795	371.6142646	371.61
1.5325	6	6.0671675	23.754	353.6531805	353.65
1.7902	7	7.0874018	27.713	317.0758497	317.08
2.04	8	8.07636	31.672	414.772132	414.77
					331.97

Appendix E Table of Electrical Conductivity Measurement Result of Aligned Fiber Mat by Using The 2-probe Technique

1) PVA10%, 12.5 kV, 20 min (R_0=3.9232)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2539	0.2539	0.2539	0.2539	1	0.99610048	3.9232	-1006.072542	1006.07
0.5088	0.5087	0.5087	0.508733333	2	1.995862613	7.8464	-1896.462824	1896.46
0.7647	0.7646	0.7646	0.764633333	3	2.999809493	11.7696	-61780.51512	61780.52
1.0197	1.0198	1.0198	1.019766667	4	4.000748587	15.6928	20963.23739	20963.24
1.2755	1.2755	1.2754	1.275466667	5	5.003910827	19.616	5015.819332	5015.82
1.5313	1.5313	1.5312	1.531266667	6	6.007465387	23.5392	3153.111962	3153.11
1.7871	1.787	1.787	1.787033333	7	7.010889173	27.4624	2521.991262	2521.99
2.038	2.038	2.038	2.038	8	7.9954816	31.3856	-6946.175637	6946.18
								12910.42

2) PVA10%, 15 kV, 20 min (R_0=3.9232)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2543	0.2541	0.2548	0.25445	1	0.99825824	3.9232	-2252.434319	2252.43
0.5093	0.5089	0.5091	0.509	2	1.9969088	7.8464	-2538.302277	2538.30
0.765	0.7646	0.7645	0.76455	3	2.99948256	11.7696	-22745.8256	22745.83
1.02	1.0196	1.0194	1.0195	4	3.9997024	15.6928	-52731.1828	52731.18
1.2758	1.2752	1.2748	1.275	5	5.00208	19.616	9430.769231	9430.77
1.5318	1.5309	1.5304	1.53065	6	6.00504608	23.5392	4664.848754	4664.85
1.7881	1.7867	1.786	1.78635	7	7.00820832	27.4624	3345.678531	3345.68
2.04	2.039	2.037	2.038	8	7.9954816	31.3856	-6946.175637	6946.18
								13081.90

3) PVA10%, 17.5 kV, 20 min (R_0=3.9232)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2543	0.254	0.254	0.2541	1	0.99688512	3.9232	-1259.502774	1259.50
0.5088	0.5089	0.5089	0.508866667	2	1.996385707	7.8464	-2170.936135	2170.94
0.7645	0.7647	0.7646	0.7646	3	2.99967872	11.7696	-36633.46614	36633.47
1.0193	1.0197	1.0195	1.0195	4	3.9997024	15.6928	-52731.1828	52731.18
1.2749	1.2753	1.2752	1.275133333	5	5.002603093	19.616	7535.649893	7535.65
1.5307	1.5311	1.5309	1.5309	6	6.00602688	23.5392	3905.702453	3905.70
1.7864	1.787	1.7869	1.786766667	7	7.009842987	27.4624	2790.047465	2790.05
2.038	2.039	2.039	2.038666667	8	7.998097067	31.3856	-16493.27354	16493.27
								15439.97

4) PVA10%+PEDOT/PSS 0.052%, 12.5 kV, 20 min (R_0=3.9232)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2538	0.254	0.254	0.253933333	1	0.996231253	3.9232	-1040.982679	1040.98
0.509	0.5091	0.5092	0.5091	2	1.99730112	7.8464	-2907.280057	2907.28
0.7649	0.7649	0.7648	0.764866667	3	3.000724907	11.7696	16236.02119	16236.02
1.0199	1.02	1.0199	1.019933333	4	4.001402453	15.6928	11189.53453	11189.53
1.2756	1.2757	1.2757	1.275666667	5	5.004695467	19.616	4177.646524	4177.65
1.5315	1.5315	1.5314	1.531466667	6	6.008250027	23.5392	2853.227141	2853.23
1.7864	1.7865	1.7865	1.786466667	7	7.008666027	27.4624	3168.972478	3168.97
2.039	2.039	2.039	2.039	8	7.9994048	31.3856	-52731.1828	52731.18
								11788.11

5) PVA10%+PEDOT/PSS 0.052%, 15 kV, 20 min (R_0=3.9232)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.254	0.254	0.2539	0.253966667	1	0.996362027	3.9232	-1078.402627	1078.40
0.5092	0.5092	0.5091	0.509166667	2	1.997562667	7.8464	-3219.256018	3219.26
0.7651	0.7651	0.7651	0.7651	3	3.00164032	11.7696	7175.18533	7175.19
1.0201	1.0199	1.0198	1.019933333	4	4.001402453	15.6928	11189.53453	11189.53
1.2757	1.2756	1.2756	1.275633333	5	5.004564693	19.616	4297.331402	4297.33
1.5318	1.5317	1.5318	1.531766667	6	6.009426987	23.5392	2497.001516	2497.00
1.7867	1.7867	1.7866	1.786666667	7	7.009450667	27.4624	2905.869074	2905.87
2.039	2.039	2.039	2.039	8	7.9994048	31.3856	-52731.1828	52731.18
								10636.72

6) PVA10%+PEDOT/PSS 0.052%, 17.5 kV, 20 min (R_0=3.9232)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.254	0.254	0.2541	0.254033333	1	0.996623573	3.9232	-1161.93846	1161.94
0.5092	0.5093	0.5092	0.509233333	2	1.997824213	7.8464	-3606.235905	3606.24
0.7651	0.765	0.7649	0.765	3	3.001248	11.7696	9430.769231	9430.77
1.0201	1.0201	1.0201	1.0201	4	4.00205632	15.6928	7631.497043	7631.50
1.2759	1.2759	1.2758	1.275866667	5	5.005480107	19.616	3579.49237	3579.49
1.5318	1.5319	1.5318	1.531833333	6	6.009688533	23.5392	2429.593747	2429.59
1.7868	1.7867	1.7868	1.786766667	7	7.009842987	27.4624	2790.047465	2790.05
2.039	2.039	2.039	2.039	8	7.9994048	31.3856	-52731.1828	52731.18
								10420.09

7) PVA10%+PEDOT/PSS 0.084%, 12.5 kV, 20 min (R_0=3.9232)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.254	0.2539	0.2539	0.253933333	1	0.996231253	3.9232	-1040.982679	1040.98
0.5089	0.509	0.509	0.508966667	2	1.996778027	7.8464	-2435.277759	2435.28
0.7639	0.764	0.764	0.763966667	3	2.997194027	11.7696	-4194.480347	4194.48
1.0198	1.0198	1.0198	1.0198	4	4.00087936	15.6928	17845.70597	17845.71
1.2755	1.2755	1.2755	1.2755	5	5.0040416	19.616	4853.523357	4853.52
1.5305	1.5306	1.5306	1.530566667	6	6.004719147	23.5392	4988.020433	4988.02
1.7863	1.7863	1.7863	1.7863	7	7.00801216	27.4624	3427.590063	3427.59
2.039	2.039	2.039	2.039	8	7.9994048	31.3856	-52731.1828	52731.18
								11439.60

8) PVA10%+PEDOT/PSS 0.084%, 15 kV, 20 min (R_0=3.9232)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2539	0.2539	0.2539	0.2539	1	0.99610048	3.9232	-1006.072542	1006.07
0.509	0.5089	0.5089	0.508933333	2	1.996647253	7.8464	-2340.29015	2340.29
0.764	0.764	0.7639	0.763966667	3	2.997194027	11.7696	-4194.480347	4194.48
1.0199	1.0199	1.0199	1.0199	4	4.00127168	15.6928	12340.21137	12340.21
1.2756	1.2755	1.2756	1.275566667	5	5.004303147	19.616	4558.524615	4558.52
1.5307	1.5308	1.5308	1.530766667	6	6.005503787	23.5392	4276.909958	4276.91
1.7864	1.7864	1.7863	1.786366667	7	7.008273707	27.4624	3319.23781	3319.24
2.039	2.039	2.039	2.039	8	7.9994048	31.3856	-52731.1828	52731.18
								10595.86

9) PVA10%+PEDOT/PSS 0.084%, 17.5 kV, 20 min (R_0=3.9232)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2535	0.2542	0.2541	0.253933333	1	0.996231253	3.9232	-1040.982679	1040.98
0.5086	0.5091	0.5089	0.508866667	2	1.996385707	7.8464	-2170.936135	2170.94
0.7654	0.7654	0.7653	0.765366667	3	3.002686507	11.7696	4381.00532	4381.01
1.0198	1.0202	1.0199	1.019966667	4	4.001533227	15.6928	10235.14679	10235.15
1.2752	1.2755	1.2756	1.275433333	5	5.003780053	19.616	5189.344771	5189.34
1.531	1.5313	1.5312	1.531166667	6	6.007073067	23.5392	3328.004826	3328.00
1.7859	1.7861	1.7861	1.786033333	7	7.006965973	27.4624	3942.363642	3942.36
2.039	2.039	2.039	2.039	8	7.9994048	31.3856	-52731.1828	52731.18
								10377.37

10) PVA10%+PEDOT/PSS 0.1%, 12.5 kV, 20 min (R_0=3.9232)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.254	0.254	0.254	0.254	1	0.9964928	3.9232	-1118.613139	1118.61
0.5093	0.5092	0.5093	0.509266667	2	1.997954987	7.8464	-3836.8454	3836.85
0.7651	0.7651	0.7651	0.7651	3	3.00164032	11.7696	7175.18533	7175.19
1.0202	1.0202	1.0202	1.0202	4	4.00244864	15.6928	6408.782018	6408.78
1.276	1.2759	1.2759	1.275933333	5	5.005741653	19.616	3416.437542	3416.44
1.5319	1.5319	1.5319	1.5319	6	6.00995008	23.5392	2365.729723	2365.73
1.7868	1.7868	1.7868	1.7868	7	7.00997376	27.4624	2753.465092	2753.47
2.039	2.039	2.039	2.039	8	7.9994048	31.3856	-52731.1828	52731.18
								9975.78

11) PVA10%+PEDOT/PSS 0.1%, 15 kV, 20 min (R_0=3.9232)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.254	0.254	0.254	0.254	1	0.9964928	3.9232	-1118.613139	1118.61
0.5093	0.5093	0.5093	0.5093	2	1.99808576	7.8464	-4098.963557	4098.96
0.7651	0.7651	0.7651	0.7651	3	3.00164032	11.7696	7175.18533	7175.19
1.0202	1.0202	1.0202	1.0202	4	4.00244864	15.6928	6408.782018	6408.78
1.276	1.276	1.2761	1.276033333	5	5.006133973	19.616	3197.927173	3197.93
1.5319	1.5319	1.5319	1.5319	6	6.00995008	23.5392	2365.729723	2365.73
1.7869	1.7869	1.787	1.786933333	7	7.010496853	27.4624	2616.250711	2616.25
2.039	2.039	2.039	2.039	8	7.9994048	31.3856	-52731.1828	52731.18
								9964.08

12) PVA10%+PEDOT/PSS 0.1%, 17.5 kV, 20 min (R_0=3.9232)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.254	0.254	0.254	0.254	1	0.9964928	3.9232	-1118.613139	1118.61
0.5093	0.5093	0.5093	0.5093	2	1.99808576	7.8464	-4098.963557	4098.96
0.7651	0.7651	0.7651	0.7651	3	3.00164032	11.7696	7175.18533	7175.19
1.0202	1.0203	1.0202	1.020233333	4	4.002579413	15.6928	6083.864031	6083.86
1.276	1.276	1.276	1.276	5	5.0060032	19.616	3267.590618	3267.59
1.5319	1.5319	1.5319	1.5319	6	6.00995008	23.5392	2365.729723	2365.73
1.7869	1.7869	1.7869	1.7869	7	7.01036608	27.4624	2649.256035	2649.26
2.039	2.039	2.039	2.039	8	7.9994048	31.3856	-52731.1828	52731.18
								9936.30

13) PVA10%+AgNPs 0.25%, 12.5 kV, 20 min (R_0=3.9232)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2525	0.252	0.2519	0.252133333	1	0.989169493	3.9232	-362.2360542	362.24
0.5065	0.5067	0.5069	0.5067	2	1.98788544	7.8464	-647.6834487	647.68
0.7624	0.7625	0.7626	0.7625	3	2.99144	11.7696	-1374.953271	1374.95
1.0171	1.0173	1.0173	1.017233333	4	3.990809813	15.6928	-1707.560528	1707.56
1.2732	1.273	1.2729	1.273033333	5	4.994364373	19.616	-3480.713177	3480.71
1.5287	1.5287	1.5287	1.5287	6	5.99739584	23.5392	-9039.07594	9039.08
1.7843	1.7845	1.7845	1.784433333	7	7.000688853	27.4624	39866.83184	39866.83
2.036	2.036	2.036	2.036	8	7.9876352	31.3856	-2538.302277	2538.30
								9667.91

14) PVA10%+AgNPs 0.25%, 15 kV, 20 min (R_0=3.9232)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2599	0.2563	0.2551	0.2571	1	1.00865472	3.9232	453.3017821	453.30
0.508	0.5086	0.5084	0.508333333	2	1.994293333	7.8464	-1374.953271	1374.95
0.7637	0.7637	0.7636	0.763666667	3	2.996017067	11.7696	-2955.008034	2955.01
1.0181	1.0181	1.0184	1.0182	4	3.99460224	15.6928	-2907.280057	2907.28
1.2738	1.2737	1.2738	1.273766667	5	4.997241387	19.616	-7110.818962	7110.82
1.5297	1.5296	1.5296	1.529633333	6	6.001057493	23.5392	22259.43111	22259.43
1.7899	1.7899	1.7899	1.7899	7	7.02213568	27.4624	1240.639547	1240.64
2.039	2.039	2.038	2.038666667	8	7.998097067	31.3856	-16493.27354	16493.27
								6849.34

15) PVA10%+AgNPs 0.25%, 17.5 kV, 20 min (R_0=3.9232)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.25	0.2508	0.2513	0.2507	1	0.98354624	3.9232	-238.4379011	238.44
0.5066	0.5068	0.5069	0.506766667	2	1.988146987	7.8464	-661.9751264	661.98
0.7629	0.7629	0.7628	0.762866667	3	2.992878507	11.7696	-1652.687077	1652.69
1.0179	1.0179	1.0179	1.0179	4	3.99342528	15.6928	-2386.839287	2386.84
1.2739	1.2739	1.2739	1.2739	5	4.99776448	19.616	-8774.692242	8774.69
1.5297	1.5297	1.5298	1.529733333	6	6.001449813	23.5392	16236.02119	16236.02
1.7896	1.7896	1.7897	1.789633333	7	7.021089493	27.4624	1302.183963	1302.18
2.039	2.038	2.038	2.038333333	8	7.996789333	31.3856	-9775.415282	9775.42
								5128.53

16) PVA10%+AgNPs 0.5%, 12.5 kV, 20 min (R_0=3.9232)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2521	0.2525	0.2527	0.252433333	1	0.990346453	3.9232	-406.3998586	406.40
0.5077	0.5078	0.5079	0.5078	2	1.99220096	7.8464	-1006.072542	1006.07
0.7637	0.7637	0.7638	0.763733333	3	2.996278613	11.7696	-3162.692043	3162.69
1.0188	1.0189	1.0189	1.018866667	4	3.997217707	15.6928	-5640.239227	5640.24
1.2746	1.2746	1.2746	1.2746	5	5.00051072	19.616	38408.5213	38408.52
1.5305	1.5305	1.5307	1.530566667	6	6.004719147	23.5392	4988.020433	4988.02
1.7864	1.7864	1.7865	1.786433333	7	7.008535253	27.4624	3217.526057	3217.53
2.039	2.039	2.038	2.038666667	8	7.998097067	31.3856	-16493.27354	16493.27
								9165.34

17) PVA10%+AgNPs 0.5%, 15 kV, 20 min (R_0=3.9232)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2539	0.2538	0.2537	0.2538	1	0.99570816	3.9232	-914.1067701	914.11
0.5087	0.5086	0.5086	0.508633333	2	1.995470293	7.8464	-1732.209297	1732.21
0.7644	0.7644	0.7644	0.7644	3	2.99889408	11.7696	-10642.36111	10642.36
1.0194	1.0193	1.0193	1.019333333	4	3.999048533	15.6928	-16493.27354	16493.27
1.2738	1.274	1.274	1.273933333	5	4.997895253	19.616	-9319.886479	9319.89
1.532	1.5309	1.5301	1.531	6	6.0064192	23.5392	3666.999003	3667.00
1.7866	1.7857	1.7854	1.7859	7	7.00644288	27.4624	4262.441641	4262.44
2.038	2.037	2.037	2.037333333	8	7.992866133	31.3856	-4399.521531	4399.52
								6428.85

18) PVA10%+AgNPs 0.5%, 17.5 kV, 20 min (R_0=3.9232)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2532	0.2532	0.2532	0.2532	1	0.99335424	3.9232	-590.3312789	590.3312789
0.508	0.5081	0.5082	0.5081	2	1.99337792	7.8464	-1184.884508	1184.884508
0.7642	0.764	0.764	0.764066667	3	2.997586347	11.7696	-4876.259502	4876.259502
1.0191	1.0192	1.0191	1.019133333	4	3.998263893	15.6928	-9039.07594	9039.07594
1.275	1.2751	1.2749	1.275	5	5.00208	19.616	9430.769231	9430.769231
1.5305	1.5305	1.5305	1.5305	6	6.0044576	23.5392	5280.68916	5280.68916
1.7852	1.7853	1.7853	1.785266667	7	7.003958187	27.4624	6938.12655	6938.12655
2.036	2.036	2.036	2.036	8	7.9876352	31.3856	-2538.302277	2538.302277
								4984.804806

19) PVA10%+AgNPs 0.75%, 12.5 kV, 20 min (R_0=3.9232)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2526	0.253	0.2532	0.252933333	1	0.992308053	3.9232	-510.0399379	510.04
0.5081	0.5082	0.5082	0.508166667	2	1.993639467	7.8464	-1233.607245	1233.61
0.7638	0.7638	0.7639	0.763833333	3	2.996670933	11.7696	-3535.405319	3535.41
1.0188	1.0188	1.0188	1.0188	4	3.99695616	15.6928	-5155.592935	5155.59
1.2758	1.2751	1.2749	1.275266667	5	5.003126187	19.616	6274.737273	6274.74
1.5314	1.5308	1.5307	1.530966667	6	6.006288427	23.5392	3743.257455	3743.26
1.7874	1.7867	1.7865	1.786866667	7	7.010235307	27.4624	2683.104756	2683.10
2.04	2.039	2.039	2.039333333	8	8.000712533	31.3856	44047.90419	44047.90
								8397.96

20) PVA10%+AgNPs 0.75%, 15 kV, 20 min (R_0=3.9232)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2536	0.2536	0.2535	0.253566667	1	0.994792747	3.9232	-753.4106272	753.41
0.5088	0.5088	0.5088	0.5088	2	1.99612416	7.8464	-2024.438573	2024.44
0.7657	0.7656	0.7655	0.7656	3	3.00360192	11.7696	3267.590618	3267.59
1.0198	1.0198	1.0197	1.019766667	4	4.000748587	15.6928	20963.23739	20963.24
1.2754	1.2753	1.2753	1.275333333	5	5.003387733	19.616	5790.302267	5790.30
1.5312	1.5311	1.5311	1.531133333	6	6.006942293	23.5392	3390.695102	3390.70
1.7869	1.7869	1.7868	1.786866667	7	7.010235307	27.4624	2683.104756	2683.10
2.038	2.038	2.038	2.038	8	7.9954816	31.3856	-6946.175637	6946.18
								5727.37

21) PVA10%+AgNPs 0.75%, 17.5 kV, 20 min (R_0=3.9232)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2533	0.2533	0.2533	0.2533	1	0.99374656	3.9232	-627.3666974	627.37
0.5082	0.5081	0.5081	0.508133333	2	1.993508693	7.8464	-1208.755094	1208.76
0.7642	0.764	0.764	0.764066667	3	2.997586347	11.7696	-4876.259502	4876.26
1.0192	1.0192	1.0191	1.019166667	4	3.998394667	15.6928	-9775.415282	9775.42
1.2757	1.2756	1.2756	1.275633333	5	5.004564693	19.616	4297.331402	4297.33
1.5311	1.531	1.531	1.531033333	6	6.006549973	23.5392	3593.785624	3593.79
1.7853	1.7853	1.7852	1.785266667	7	7.003958187	27.4624	6938.12655	6938.13
2.037	2.038	2.038	2.037666667	8	7.994173867	31.3856	-5387.037715	5387.04
								4588.01

22) PVA10%+AgNPs 0.25% +PEDOT/PSS 0.084%, 12.5 kV, 20 min (R_0=4.346)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2291	0.2289	0.2289	0.228966667	1	0.995089133	4.346	-884.9761753	884.98
0.4591	0.459	0.4589	0.459	2	1.994814	8.692	-1676.050906	1676.05
0.6897	0.6896	0.6897	0.689666667	3	2.997291333	13.038	-4813.438346	4813.44
0.9196	0.9196	0.9195	0.919566667	4	3.996436733	17.384	-4878.669386	4878.67
1.1501	1.1502	1.1501	1.150133333	5	4.998479467	21.73	-14291.03823	14291.04
1.3809	1.3809	1.3809	1.3809	6	6.0013914	26.076	18740.83657	18740.84
1.6113	1.6114	1.6115	1.6114	7	7.0031444	30.422	9674.977738	9674.98
1.8411	1.8412	1.8413	1.8412	8	8.0018552	34.768	18740.83657	18740.84
								9212.60

23) PVA10%+AgNPs 0.25% +PEDOT/PSS 0.084%, 15.0 kV, 20 min (R_0=4.346)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.229	0.2291	0.2291	0.229066667	1	0.995523733	4.346	-970.8983677	970.90
0.4591	0.4591	0.4589	0.459033333	2	1.994958867	8.692	-1724.215454	1724.22
0.6898	0.6899	0.6899	0.689866667	3	2.998160533	13.038	-7087.924036	7087.92
0.9198	0.9198	0.9198	0.9198	4	3.9974508	17.384	-6819.39432	6819.39
1.1501	1.15	1.15	1.150033333	5	4.998044867	21.73	-11114.3315	11114.33
1.3812	1.3813	1.3813	1.381266667	6	6.002984933	26.076	8735.873498	8735.87
1.612	1.612	1.612	1.612	7	7.005752	30.422	5288.942976	5288.94
1.8419	1.8419	1.8419	1.8419	8	8.0048974	34.768	7099.277167	7099.28
								6105.11

24) PVA10%+AgNPs 0.25% +PEDOT/PSS 0.084%, 17.5 kV, 20 min (R_0=4.346)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.229	0.229	0.2291	0.229033333	1	0.995378867	4.346	-940.4619357	940.46
0.4592	0.4592	0.4592	0.4592	2	1.9956832	8.692	-2013.52854	2013.53
0.6898	0.69	0.6898	0.689866667	3	2.998160533	13.038	-7087.924036	7087.92
0.9198	0.9199	0.9199	0.919866667	4	3.997740533	17.384	-7693.851056	7693.85
1.1501	1.15	1.15	1.150033333	5	4.998044867	21.73	-11114.3315	11114.33
1.3829	1.3829	1.3829	1.3829	6	6.0100834	26.076	2586.032489	2586.03
1.615	1.614	1.614	1.614333333	7	7.015892667	30.422	1914.2162	1914.22
1.842	1.8419	1.842	1.841966667	8	8.005187133	34.768	6702.738828	6702.74
								5006.64

25) PVA10%+AgNPs 0.5% +PEDOT/PSS 0.084%, 12.5 kV, 20 min (R_0=4.346)

I: No.1	I: No.2	I: No.3	I: Average					
I (µA) at R_0//R1	I (µA) at R_0//R1	I (µA) at R_0//R1	I (µA) at R_0//R1	Voltage (V)	R_o*I (µA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2291	0.229	0.229	0.229033	1	0.995379	4.346	-940.4619357	940.46
0.4592	0.4591	0.4591	0.459133	2	1.995393	8.692	-1886.885293	1886.89
0.6899	0.6899	0.6899	0.6899	3	2.998305	13.038	-7693.851056	7693.85
0.9199	0.9198	0.9199	0.919867	4	3.997741	17.384	-7693.851056	7693.85
1.1503	1.1503	1.1503	1.1503	5	4.999204	21.73	-27292.13765	27292.14
1.3813	1.3813	1.3813	1.3813	6	6.00313	26.076	8331.522781	8331.52
1.612	1.612	1.612	1.612	7	7.005752	30.422	5288.942976	5288.94
1.8419	1.8419	1.8419	1.8419	8	8.004897	34.768	7099.277167	7099.28
								8278.37

26) PVA10%+AgNPs 0.5% +PEDOT/PSS 0.084%, 15.0 kV, 20 min (R_0=4.346)

I: No.1	I: No.2	I: No.3	I: Average					
I (µA) at R_0//R1	I (µA) at R_0//R1	I (µA) at R_0//R1	I (µA) at R_0//R1	Voltage (V)	R_o*I (µA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.229	0.229	0.229	0.229	1	0.995234	4.346	-911.8757868	911.88
0.4591	0.4591	0.4591	0.4591	2	1.995249	8.692	-1829.355558	1829.36
0.6899	0.6899	0.6899	0.6899	3	2.998305	13.038	-7693.851056	7693.85
0.9199	0.9199	0.9199	0.9199	4	3.997885	17.384	-8220.940131	8220.94
1.15	1.15	1.15	1.15	5	4.9979	21.73	-10347.61905	10347.62
1.3814	1.3814	1.3814	1.3814	6	6.003564	26.076	7315.677253	7315.68
1.6121	1.6121	1.6121	1.6121	7	7.006187	30.422	4917.402127	4917.40
1.842	1.842	1.842	1.842	8	8.005332	34.768	6520.630158	6520.63
								5969.67

27) PVA10%+AgNPs 0.5% +PEDOT/PSS 0.084%, 17.5 kV, 20 min (R_0=4.346)

I: No.1	I: No.2	I: No.3	I: Average					
I (µA) at R_0//R1	I (µA) at R_0//R1	I (µA) at R_0//R1	I (µA) at R_0//R1	Voltage (V)	R_o*I (µA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2291	0.2291	0.2291	0.2291	1	0.995669	4.346	-1003.370735	1003.37
0.4592	0.4592	0.4592	0.4592	2	1.995683	8.692	-2013.52854	2013.53
0.6899	0.6899	0.6899	0.6899	3	2.998305	13.038	-7693.851056	7693.85
0.9199	0.92	0.9199	0.919933	4	3.99803	17.384	-8825.560144	8825.56
1.1498	1.15	1.15	1.149933	5	4.99761	21.73	-9093.064777	9093.06
1.383	1.383	1.383	1.383	6	6.010518	26.076	2479.178551	2479.18
1.617	1.6171	1.6171	1.617067	7	7.027772	30.422	1095.430366	1095.43
1.842	1.842	1.842	1.842	8	8.005332	34.768	6520.630158	6520.63
								4840.58

28) PVA10%+AgNPs 0.75% +PEDOT/PSS 0.084%, 12.5 kV, 20 min (R_0=4.346)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2291	0.2291	0.2291	0.2291	1	0.995669	4.346	-1003.370735	1003.37
0.4592	0.4592	0.4592	0.4592	2	1.995683	8.692	-2013.52854	2013.53
0.6899	0.69	0.69	0.689967	3	2.998595	13.038	-9280.596023	9280.60
0.9199	0.9199	0.9199	0.9199	4	3.997885	17.384	-8220.940131	8220.94
1.1507	1.1507	1.1507	1.1507	5	5.000942	21.73	23063.04394	23063.04
1.3814	1.3814	1.3814	1.3814	6	6.003564	26.076	7315.677253	7315.68
1.6121	1.6121	1.6121	1.6121	7	7.006187	30.422	4917.402127	4917.40
1.842	1.842	1.842	1.842	8	8.005332	34.768	6520.630158	6520.63
								7791.90

29) PVA10%+AgNPs 0.75% +PEDOT/PSS 0.084%, 15.0 kV, 20 min (R_0=4.346)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2291	0.229	0.229	0.229033	1	0.995379	4.346	-940.4619357	940.46
0.4592	0.4592	0.4592	0.4592	2	1.995683	8.692	-2013.52854	2013.53
0.6899	0.6899	0.6899	0.6899	3	2.998305	13.038	-7693.851056	7693.85
0.9198	0.9198	0.9198	0.9198	4	3.997451	17.384	-6819.39432	6819.39
1.1509	1.1509	1.1509	1.1509	5	5.001811	21.73	11996.246	11996.25
1.3816	1.3816	1.3816	1.3816	6	6.004434	26.076	5881.45074	5881.45
1.6123	1.6123	1.6123	1.6123	7	7.007056	30.422	4311.630148	4311.63
1.842	1.843	1.842	1.842333	8	8.006781	34.768	5127.519418	5127.52
								5598.01

30) PVA10%+AgNPs 0.75% +PEDOT/PSS 0.084%, 17.5 kV, 20 min (R_0=4.346)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2291	0.229	0.2291	0.229067	1	0.995524	4.346	-970.8983677	970.90
0.4592	0.4592	0.4592	0.4592	2	1.995683	8.692	-2013.52854	2013.53
0.6895	0.6895	0.6895	0.6895	3	2.996567	13.038	-3797.844451	3797.84
0.9198	0.9198	0.9198	0.9198	4	3.997451	17.384	-6819.39432	6819.39
1.151	1.151	1.151	1.151	5	5.002246	21.73	9674.977738	9674.98
1.3818	1.3818	1.3818	1.3818	6	6.005303	26.076	4917.402127	4917.40
1.6125	1.6125	1.6125	1.6125	7	7.007925	30.422	3838.73817	3838.74
1.843	1.843	1.843	1.843	8	8.009678	34.768	3592.477785	3592.48
								4453.16

31) PVA10%+AgNPs 0.25% +PEDOT/PSS 0.084%, 12.5 kV, 30 min (R_0=4.353 MΩ)

I: No.1	I: No.2	I: No.3	I: Average					
I (µA) at R_0//R1	I (µA) at R_0//R1	I (µA) at R_0//R1	I (µA) at R_0//R1	Voltage (V)	R_o*I (µA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2299	0.2296	0.2299	0.2298	1	1.0003194	4.353	13628.67877	13628.68
0.4596	0.4591	0.4589	0.4592	2	1.9988976	8.706	-7897.314949	7897.31
0.6891	0.6888	0.6887	0.688866667	3	2.9986366	13.059	-9578.260232	9578.26
0.9182	0.918	0.9178	0.918	4	3.996054	17.412	-4412.569691	4412.57
1.1481	1.1478	1.1479	1.147933333	5	4.9969538	21.765	-7144.9675	7144.97
1.3782	1.378	1.378	1.378066667	6	5.9987242	26.118	-20471.86079	20471.86
1.6083	1.6082	1.6081	1.6082	7	7.0004946	30.471	61607.35948	61607.36
1.8376	1.8375	1.8374	1.8375	8	7.9986375	34.824	-25558.89908	25558.90
								18787.49

32) PVA10%+AgNPs 0.25% +PEDOT/PSS 0.084%, 12.5 kV, 45 min (R_0=4.353 MΩ)

I: No.1	I: No.2	I: No.3	I: Average					
I (µA) at R_0//R1	I (µA) at R_0//R1	I (µA) at R_0//R1	I (µA) at R_0//R1	Voltage (V)	R_o*I (µA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2298	0.2304	0.23	0.230066667	1	1.0014802	4.353	2940.818808	2940.82
0.4602	0.46	0.4598	0.46	2	2.00238	8.706	3657.983193	3657.98
0.6898	0.6899	0.6898	0.689833333	3	3.0028445	13.059	4590.96502	4590.97
0.9188	0.9189	0.9187	0.9188	4	3.9995364	17.412	-37558.23986	37558.24
1.1485	1.1485	1.1486	1.148533333	5	4.9995656	21.765	-50103.59116	50103.59
1.3792	1.3791	1.3793	1.3792	6	6.0036576	26.118	7140.748031	7140.75
1.6091	1.609	1.6089	1.609	7	7.003977	30.471	7661.805381	7661.81
1.838	1.8381	1.8381	1.838066667	8	8.0011042	34.824	31537.7649	31537.76
								18148.99

33) PVA10%+AgNPs 0.25% +PEDOT/PSS 0.084%, 15.0 kV, 30 min (R_0=4.353 MΩ)

I: No.1	I: No.2	I: No.3	I: Average					
I (µA) at R_0//R1	I (µA) at R_0//R1	I (µA) at R_0//R1	I (µA) at R_0//R1	Voltage (V)	R_o*I (µA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2304	0.2313	0.2307	0.2308	1	1.004442	4.352	979.8271	979.83
0.4593	0.4595	0.4595	0.459433	2	1.999454	8.704	-15937.5	15937.50
0.689	0.6893	0.689	0.6891	3	2.998963	13.056	-12592.6	12592.59
0.9191	0.9183	0.9181	0.9185	4	3.997312	17.408	-6476.19	6476.19
1.1488	1.148	1.1479	1.148233	5	4.997111	21.76	-7533.23	7533.24
1.3788	1.3779	1.3778	1.378167	6	5.997781	26.112	-11769.2	11769.23
1.6088	1.6089	1.6087	1.6088	7	7.001498	30.464	20341.88	20341.88
1.8383	1.8379	1.8381	1.8381	8	7.999411	34.816	-59130.4	59130.43
								16845.11

34) PVA10%+AgNPs 0.25% +PEDOT/PSS 0.084%, 15.0 kV, 45 min (R_0=4.353 MΩ)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2314	0.2318	0.2308	0.231333	1	1.006763	4.352	643.5331	643.53
0.4605	0.4606	0.4604	0.4605	2	2.004096	8.704	2125	2125.00
0.6903	0.6902	0.6989	0.693133	3	3.016516	13.056	790.4934	790.49
0.9194	0.9192	0.9191	0.919233	4	4.000503	17.408	34576.27	34576.27
1.1492	1.149	1.1491	1.1491	5	5.000883	21.76	24637.68	24637.68
1.3791	1.3789	1.379	1.379	6	6.001408	26.112	18545.45	18545.45
1.6093	1.6093	1.6092	1.609267	7	7.003529	30.464	8633.615	8633.62
1.8384	1.8384	1.8386	1.838467	8	8.001007	34.816	34576.27	34576.27
								15566.04

35) PVA10%+AgNPs 0.25% +PEDOT/PSS 0.084%, 17.5 kV, 30 min. (R_0=3.9232)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2544	0.2544	0.2543	0.254366667	1	0.997931307	3.9232	-1896.462824	1896.46
0.5091	0.509	0.509	0.509033333	2	1.997039573	7.8464	-2650.428767	2650.43
0.7652	0.7653	0.7653	0.765266667	3	3.002294187	11.7696	5130.184118	5130.18
1.0194	1.0193	1.0193	1.019333333	4	3.999048533	15.6928	-16493.27354	16493.27
1.2756	1.2756	1.2755	1.275566667	5	5.004303147	19.616	4558.524615	4558.52
1.5308	1.531	1.531	1.530933333	6	6.006157653	23.5392	3822.754989	3822.75
1.788	1.7873	1.7879	1.787733333	7	7.013635413	27.4624	2014.04969	2014.05
2.037	2.037	2.036	2.036666667	8	7.990250667	31.3856	-3219.256018	3219.26
								4973.12

36) PVA10%+AgNPs 0.25% +PEDOT/PSS 0.084%, 17.5 kV, 45 min (R_0=3.9232)

I: No.1	I: No.2	I: No.3	I: Average					
I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	I (μA) at R_0//R1	Voltage (V)	R_o*I (μA) at R_0//R1	R_0*V	R1=(V*R_0)/(I*R_0-V) Mohm	abs R1=(V*R_0)/(I*R_0-V) Mohm
0.2543	0.2544	0.2543	0.254333333	1	0.997800533	3.9232	-1783.705141	1783.71
0.509	0.509	0.508	0.508666667	2	1.995601067	7.8464	-1783.705141	1783.71
0.7658	0.7659	0.7658	0.765833333	3	3.004517333	11.7696	2605.430933	2605.43
1.02	1.021	1.02	1.020333333	4	4.002971733	15.6928	5280.68916	5280.69
1.275	1.2751	1.275	1.275033333	5	5.002210773	19.616	8872.913249	8872.91
1.5311	1.531	1.531	1.531033333	6	6.006549973	23.5392	3593.785624	3593.79
1.7868	1.7869	1.7864	1.7867	7	7.00958144	27.4624	2866.208002	2866.21
2.037	2.037	2.037	2.037	8	7.9915584	31.3856	-3717.968158	3717.97
								4489.50

Appendix F Table of AgNPs lattice structure

<table>
<tr><td>Ag

Silver</td><td>2th</td><td>i</td><td>h</td><td>k</td><td>l</td></tr>
<tr><td rowspan="3">Lattice:

Face -centered cubic

S.G. : Fm-3m (225)</td><td>37.934</td><td>100</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>44.142</td><td>80</td><td>2</td><td>0</td><td>0</td></tr>
<tr><td>64.678</td><td>80</td><td>2</td><td>2</td><td>0</td></tr>
<tr><td>a = 4.07900</td><td>77.549</td><td>90</td><td>3</td><td>1</td><td>1</td></tr>
<tr><td rowspan="7">Z = 4

Radiation = 1.540598</td><td>81.505</td><td>50</td><td>2</td><td>2</td><td>2</td></tr>
<tr><td>98.085</td><td>20</td><td>4</td><td>0</td><td>0</td></tr>
<tr><td>110.063</td><td>60</td><td>3</td><td>3</td><td>1</td></tr>
<tr><td>115.662</td><td>60</td><td>4</td><td>2</td><td>0</td></tr>
<tr><td>136.272</td><td>40</td><td>4</td><td>2</td><td>2</td></tr>
<tr><td>154.355</td><td>40</td><td>5</td><td>1</td><td>1</td></tr>
<tr><td></td><td>10</td><td>4</td><td>4</td><td>0</td></tr>
<tr><td>Mol. weight = 107.87

Volume [CD] = 67.87

Dx = 10.557

Dm = 10.490</td><td colspan="5">Davey., Phys. Rev., volume 25, page 753 (1925)</td></tr>
</table>

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1998-2001: Master's Degree in Telecommunications Management, College of Innovative Education, Thammasat University.

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- Develop and execute an IT strategy and master plan to offer high quality support to students, faculty, and staff.
- Monitor the college's QA based on MUQD (Quality Development, Mahidol University) and CHE (Commission on Higher Education – สกอ.).
- Implement MUQD's QA and organize the college's QA working group.
- Manage CMMU's QA database using MUFIS and QA software system.

2002 - 2003

Employer: College of Innovative Education, Thammasat University.

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- In charge of overall curriculums and planning for a Master of Science in Retail Technology Management.
- Devise a plan for Information and Communication Technology (ICT) to support education services and knowledge organizations, especially in e-Learning.
- Give lectures to graduate students.