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**APPENDICES**

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## APPENDIX A

**Table 1** K/S @510 nm of nylon multifilament as a function of the pH of Scarlet dye solution bath

pH	K/S of salt-free of dye solution	K/S of added salt 0.1M in dye solution	Normalized K/S of salt-free of dye solution	Normalized K/S of added salt 0.1 M of dye solution
3	10.44	6.84	1	1
5	4.82	4.15	0.461686	0.606725
7	3.41	3.28	0.326628	0.479532
9	0.79	2.07	0.07567	0.302632
11	0.59	1.01	0.056513	0.147661
12	0.47	1.14	0.045019	0.166667

**Table 2** K/S @ 510 nm as a function of the number of PDADMAC-Dye layer and the number of dye layer at non-dyeable condition: pH 11

Number of layers	K/S of dyed nylon	K/S of PEM on nylon
0	0.05	0.05
4	0.14	0.47
8	-	0.94
10	0.20	-
12	-	1.73
16	0.34	2.37
20	0.29	4.64
24	-	3.96
28	-	9.44
30	0.32	-
40	0.42	13.18
60	0.60	13.18
80	-	12.42

**Table 3** K/S @ 510 nm of nylon multifilament as a function of the deposition time.**Table 3a** K/S @ 510 nm of nylon multifilament as a function of same deposition time in PDADMAC and dye solution.

Deposition time (min)	K/S of same deposition time in PDADMAC and Dye solution
0.25	4.66
0.5	4.19
1	4.55
2	4.33
5	4.88

**Table 3b** K/S @ 510 nm of nylon multifilament as a function of fixed deposition time 5 minutes in Dye solution and varied deposition time in PDADMAC solution.

Deposition time in PDADMAC solution (min)	K/S of fixed deposition time 5 minutes in Dye solution				Average	SD
	No. 1	No. 2	No. 3	No. 4		
0.25	3.65	3.74	3.58	3.99	3.74	0.179072
0.5	4.19	4.02	4.15	4.29	4.1625	0.111766
1	3.44	3.65	3.72	3.61	3.605	0.119024
2	4.14	4.22	4.19	4.43	4.245	0.127671
5	3.62	3.64	3.47	3.74	3.6175	0.111467

**Table 3c** K/S @ 510 nm of nylon multifilament as a function of fixed deposition time 5 minutes in PDADMAC solution and varied deposition time in dye solution.

Deposition time in Dye solution (min)	K/S of fixed deposition time 5 minutes in PDADMAC solution				Average	SD
	No. 1	No. 2	No. 3	No. 4		
0.25	3.09	2.74	2.81	2.91	2.8875	0.151959
0.5	2.71	3.00	2.86	2.86	2.8575	0.118427
1	3.02	3.44	3.42	3.18	3.265	0.201577
2	5.01	5.10	5.13	5.15	5.0975	0.061847
5	3.38	3.14	3.26	3.40	3.295	0.120416

**Table 4** K/S @ 510 nm of nylon multifilament as a function of salt concentration

Salt concentration (M)	K/S@ 510 nm of PEM on nylon	Absorbance@507 nm of PEM on glass slide
0	2.63	0.024859
0.05	-	0.039270
0.1	3.81	0.054061
0.2	-	0.054524
0.3	4.16	0.067751
0.4	-	0.050078
0.5	4.21	0.084712
0.7	3.05	0.103762
0.75	-	0.029428
0.8	-	0.057572
0.9	-	-
1	2.01	0.019853

**Table 5** K/S @ 510 nm of nylon multifilament as a function of PDADMAC and Scarlet dye concentration

PDAD and Dye concentration (mM)	K/S @ 510 nm	PDAD concentration (mM) [Fixed dye conc.]	K/S @ 510 nm	Dye concentration (mM) [Fixed PDADMAC conc.]	K/S @ 510 nm
0	0.05	0	0.05	0	0.05
0.01	1.7	0.001	0.38	0.0005	0.1
0.1	4.04	0.01	0.5	0.005	0.49
1	5.07	0.1	1.69	0.05	1.86
10	2.67	1	3.07	0.5	3.68
20	2.67	10	2.09	5	3.73
	3.45	50	1.2	50	4.46

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## APPENDIX B

**Table 6** K/S @ 510 nm of dye loading on silk as a function of the exhaustion time

Exhaustion time (min)	K/S @ 510 nm of dyed silk
0.5	2.91
1	3.15
5	4.08
10	4.83
20	6.47
30	7.41
60	9.92

**Table 7** K/S @ 510 nm of dye loading on silk as a function of salt concentration and pH condition of acid dye solution

pH	Salt concentration (M)			
	0	0.1	0.3	1
3	8	9.57	10.41	3.82
6	5.06	7.12	6.65	4.66
9	2.45	5.81	5.64	4.38
12	0.99	1.99	2.95	7.2

**Table 8** Absorbance @ 525-565 nm of dye release from different length of silk

Length (m)	Absorbance@525 nm	Absorbance@565 nm	Absorbance@ 525-565 nm	Absorbance@ 525-565 nm added NaOH
0.5	0.08040	0.0288	0.05160	0.01470
1	0.13140	0.0312	0.10030	0.03040
1.5	0.17911	0.03942	0.13970	0.04221
2	0.22472	0.44850	0.17988	0.04856
3	0.28620	0.05400	0.23220	0.06620
4	0.45610	0.10157	0.35453	0.09557



**Table 9** Absorbance @ 525-650 nm of dye release adjusted pH of soaping solution at pH 6 and pH 9.78 as a function of time

Time (min)	Abs of pH 6 @ 525-650 nm	Abs of pH 9.78 @ 525-650 nm	Normalized Absorbance pH 6	Normalized Absorbance pH 9.78
1	0.073196	0.086707	0.514076	0.529675
2	-	0.107315	-	0.655565
3	0.087799	0.114569	0.616639	0.699877
4	-	0.120074	-	0.733502
5	-	0.122474	-	0.748163
6	0.098796	-	0.693878	-
7	-	0.130483	-	0.797089
9	0.11564	-	0.812176	-
12	0.119355	0.141222	0.838268	0.862695
15	0.118736	0.148566	0.833922	0.907553
20	0.126224	-	0.886515	-
30	0.142383	0.163699	1	1

**Table 10** Absorbance @ 510 nm of dye release in adjusted pH of soaping solution and K/S @ 510 nm of silk after wash as a function of adjusted pH of soaping solution

pH of Std detergent	K/S @ 510 nm	Absorbance @ 510 nm
4	10.9	0.058178
5	9.44	0.083362
6	2.85	0.142089
7	1.38	0.152652
8	0.88	0.164933
9	0.69	0.191800
10	0.93	0.135132

## APPENDIX C

**Table 11** The approximately thickness as the function of a number of layers of PEM between PDADMAC/Alginate and PDADMAC/PSS-co-MA

Number of layers	Approximately thickness (Å)	
	PDADMAC & PSS-co-MA	PDADMAC & Alginate
20	500	300
30	800	400
40	1000	500
50	1300	550



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## APPENDIX D

**Table 12** Absorbance @ 507 nm of dye release from coated dyed-silk by PDADMAC/PSS-co-MA at different salt concentration in solution pH 10.7

No. of layer	Raw absorbance			Normalized absorbance		
	Salt concentration (M)					
	0.3	1	2	0.3	1	2
0	0.095141	0.114554	0.078281	1.000001	1.000001	0.999994
10	0.088856	0.080275	0.084793	0.933937	0.70076	1.083186
20	0.069199	0.075908	0.069930	0.727329	0.662642	0.893325
30	0.079557	0.068770	0.066996	0.836205	0.600327	0.855836
60	0.062292	0.049685	0.040447	0.654734	0.433722	0.516692

**Table 13** Absorbance @ 507 nm of dye release from coated dyed silk with PDADMAC/PSS-co-MA in different of the number of layers.

Number of layers	Absorbance @ 507 nm	Normalized absorbance
0	0.305623	1
6	0.240402	0.786599
10	0.230082	0.752829
20	0.211216	0.691101
30	0.243095	0.795408
46	0.226453	0.740956
60	0.228010	0.746051

**Table 14** Absorbance @ 507 nm of dye release from coated dyed silk by PDADMAC/PSS at different salt concentration in solution pH 10.7

Number of layers	Salt concentration (M)		
	0.5	1	2
0	0.215286	0.211975	0.211975
8	-	-	0.152287
10	0.166925	0.175682	-
20	0.146338	0.146972	0.139740
30	0.139978	0.112562	0.124477

**Table 15** Absorbance @ 507 nm of dye release from coated dyed silk with PDADMAC/PSS which are varied type of top layer

Number of layers	Absorbance @ 507 nm
0	0.211975
10	0.175682
11	0.188366
20	0.146972
21	0.158034
30	0.112562
31	0.149681

**Table 16** Absorbance @ 507 nm of dye release comparison between uncoated dyed silk and PEM which are constructed from PDADMAC/PSS-co-MA and PDADMAC/PSS that top layer is PDADMAC and PSS, respectively on dyed silk.

Type of coating	Absorbance @ 507 nm	Normalized absorbance @ 507 nm
Uncoated dyed-silk	0.226524	1
PDAD/ PSS-co-MA	0.144650	0.638563
PDAD/PSS: top PDAD	0.140171	0.618790
PDAD/PSS: top PSS	0.121697	0.537235

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## Optical alcohol sensor based on dye–Chitosan polyelectrolyte multilayers

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### Abstract

The layer-by-layer deposition technique was used to prepare polyelectrolyte multilayer (PEM) thin films that are sensitive to ethanol content in water. Cationic Chitosan was assembled with anionic acid dye, (phenyl amino)-5-[[4-(3-sulphonatophenyl) azo]-(1-naphthalenyl) azo]-1-naphthalenesulfonic acid disodium salt (Nylosan) on glass slide and characterized using UV–vis spectroscopy. The layer-by-layer deposition of Chitosan–Nylosan into PEM was studied by monitoring the increase in absorbance in the visible region (500–600 nm). The typical linear relationship between increase in absorbance and number of layers was found. The PEM thin films responded to increasing concentrations of ethanol in water with a shift of maximum absorbance ( $\lambda_{\max}$ ) from 540 to 580 nm. This shift was also characterized by an increase in absorbance at 600 nm which was used to monitor the response of the thin film to ethanol content in water. The characteristic color shift of the Nylosan dye occurred at a higher ethanol concentration (from 10% to 45%) in the PEM compared to its usual shift in aqueous solution (from 0% to 30%). The Chitosan–Nylosan thin films response to ethanol content was found to be linear from 10% to 45% ethanol content, which renders them useful as ethanol sensing thin films.

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**Keywords:** Polyelectrolyte multilayer; Chitosan; Nylosan; Sensor

### 1. Introduction

The monitoring of alcohol content in water is a critical factor in many industrial as well as biotechnical applications [1–3]. For example, continuous measurement of ethyl alcohol concentration in culture broth is required in the fermentation industries. While most of the commercially available gas sensors are based on the electrical conduction modulation of metal oxide materials on gas absorption [4,5], other materials such as conducting polymers [6,7] (e.g. polyaniline, polypyrrole) or enzymes [8,9] (e.g. glucose oxydase) can be used for their alcohol sensing properties.

Recently, the solvatochromic properties of organic dye molecules have also been used for the preparation of

alcohol-sensing devices. The term solvatochromism is used to describe the shift of an UV or visible absorption band as a function of the polarity of the surrounding medium or solvent [10,11]. This effect results from the solute–solvent interactions (e.g. dipole–dipole, dipole–induced dipole and hydrogen bonding), which tend to perturb the electronic geometry and charge distribution of the absorbing species leading to a positive or negative shift in absorbance. For example, dye molecules such as Reichardt's betaine [12] or Brooker's merocyanine [13] present a strong solvatochromism when exposed to solvents of various polarities.

Several strategies can be used to immobilize dye molecules onto a surface and for example, sensing films can be prepared by direct blending of the dye molecules into a polymer matrix (e.g. PVC), which is subsequently cast and cured into active thin films [14]. Alcohol sensors can also be prepared by spin casting of a dye–polymer–solvent mixture

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onto a glass substrate [15]. Both techniques are commonly used but present certain limitations such as the curing time or the geometrical limitation to a flat substrate when using the spin casting technique. The novel technique presented in this article is based on the self-assembled polyelectrolyte multilayers (PEM) procedure which allows the facile preparation of ethanol sensing nano-thin films. This PEM technique presents the advantage of allowing the coating of virtually any surface by simple dipping in dilute polyelectrolyte solutions without the need for any further treatments. Developed by Decher and coworkers in the early 1990s, this technique has been the subject of an abundant literature [16–25] and can be summarized as follows. Oppositely charged polyelectrolytes (polyanions and polycations) can be assembled into thin films by sequential dipping of a substrate into polyelectrolyte solutions followed by a rinse step. The electrostatic interaction between the absorbed layer on the substrate and the oppositely charged polyelectrolytes in solution leads to the irreversible absorption of a polyelectrolyte layer and also to the reversal of the surface charge allowing the deposition of the next layer [26].

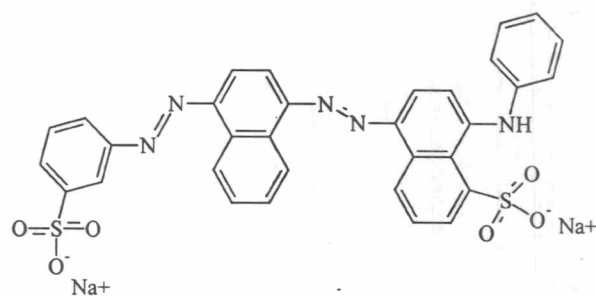
Interestingly, one of the two polyelectrolytes can be substituted with a variety of other charged materials (e.g. proteins, lipids, surfactants, DNA, magnetic particles, or inorganic crystals) leading to specific properties and applications [27–30]. Charged dye molecules have already been incorporated into PEM thin films for their non-linear optical properties [31] but to the knowledge of the authors, they have never been characterized for their ethanol sensing capabilities.

In this study, PEM were built from cationic Chitosan, which is a biopolymer derived from Chitin, as found in seashells, and the anionic acid dye, (phenyl amino)-5-[[4-(3-sulphonatophenyl) azo]-(1-naphthalenyl)azo]-1-naphthalenesulfonic acid disodium salt (Nylosan), as shown in Fig. 1. The Nylosan dye molecule contains two sulfonate groups, which can electrostatically interact with the positively charged Chitosan and therefore can be used to prepare polyelectrolyte multilayers. The layer-by-layer deposition of the Chitosan–Nylosan thin films was monitored using UV–vis spectroscopy as a function of the number of layers. In addition, the characteristic solvatochromism of the resulting thin film was investigated as a function of the ethanol concentration in water for its potential use as ethanol sensor.

## 2. Experimental

### 2.1. Chemicals and materials

The acid dye (phenyl amino)-5-[[4-(3-sulphonatophenyl) azo]-(1-naphthalenyl) azo]-1-naphthalenesulfonic acid disodium salt (Color index: acid blue 113) was provided by the Department of Materials Science, Chulalongkorn University, Bangkok, Thailand. Chitosan (MW = 800,000) with 84% deacetylation was purchased from Fluka. Solutions of various pH between 3 and 7 were prepared by mixing



(phenyl amino)-5-[[4-(3-sulphonatophenyl) azo]-(1-naphthalenyl) azo]-1-naphthalenesulfonic acid disodium salt, Nylosan.

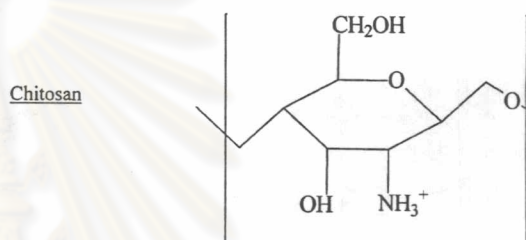


Fig. 1. Chemical structure of the Nylosan and Chitosan used in the preparation of the polyelectrolyte multilayer thin films.

the appropriate amount of acetic acid with sodium acetate salt and a 1 mM sodium hydroxide solution was used to adjust the pH to 11. Analytical grade ethanol, from Aldrich, was mixed with de-ionized water to prepare solutions with ethanol contents from 0% to 50%. Analytical grade sodium chloride residue less than 0.1% was purchased from Aldrich. All chemicals and solvents were used as received without any further purification. Glass slide substrates (4 cm × 1 cm) were purchased from Aldrich and cleaned using an oxidizing “piranha solution” which is described in the next section.

### 2.2. PEM technique

PEM with variable number of layers were assembled onto glass slide for UV–vis measurements. All PEMs were assembled by following the same procedure described hereafter. Before beginning the PEM deposition, glass slide substrates were cleaned from organic contaminants by a 15 min dipping in an oxidizing “piranha solution” prepared by mixing a 2:1 volume ratio of concentrated sulfuric acid with concentrated hydrogen peroxide (30%). The sample was then rinsed thoroughly with de-ionized water. This cleaning step resulted in a hydrophilic, organic free surface (Warning: piranha is a very oxidizing solution and should not be stored in a closed container).

For the PEM thin film buildup, the substrate was first immersed for 2 min in a solution containing 0.1% (w/w) of Chitosan and 0.1 M sodium chloride. The sample was then rinsed three times in de-ionized water for 1 min. The purpose of the rinse bath is to remove the excess and loosely bound

polyelectrolytes from the surface. These steps resulted in the deposition of a thin layer of Chitosan, which had for effect to reverse the charge at the surface of the sample from negative to positive. The surface with the Chitosan top layer was then immerse for 2 min in a solution containing 0.14 mM of Nylosan and 0.1 M sodium chloride followed by three rinses in water. The pH of the Nylosan dye, Chitosan and all rinse solutions was adjusted to pH 4 using acetic acid. These steps resulted in the deposition of a bi-layer of Chitosan–Nylosan and were repeated as many times as needed. When completed, the PEM thin film was dried with a stream of nitrogen and stored in a closed container. A homemade robot was used to improve reproducibility and to allow the facile deposition of up to 60 layers. All samples were spun with a homemade sample holder while in solution to accelerate the deposition process and render the PEM more uniform.

2.3. UV–vis measurements

The pre-cut glass slides were first coated with the Chitosan–Nylosan PEM and then analyzed using a single beam UV–vis spectrophotometer (Specords S 100, Analytik-Jena). Prior to any UV–vis measurements, a bare clean glass slide was first introduced in the UV–vis cuvette filled with pure water and recorded as a background. For the measurements, the PEM coated glass substrate was then inserted in a polystyrene cuvette and exposed to a range of ethanol-water mixtures. The absorbance of the thin film was measured in the 450–750 nm visible range, which includes the absorbance peak of the Nylosan dye. The  $\lambda_{max}$  absorbance of Nylosan dye varies from 520 to 580 nm as a function of the surrounding solvent.

3. Results and discussion

Polyelectrolyte multilayers assembled from cationic Chitosan and anionic Nylosan dye were deposited on glass slides and characterized using the UV–vis spectroscopic technique. It is important to note that when the Nylosan dye is assembled into a PEM, its characteristic absorbance is controlled by the electrostatic environment of the PEM and gives an absorbance peak at 540 nm. Therefore it is possible to monitor the layer-by-layer deposition of the PEM as a function of the number of layers. The expected linear relationship between the absorbance at 540 nm and the number of layers was confirmed with UV–vis measurements as shown in Fig. 2. Multilayers of up to 40 bi-layers of Chitosan and Nylosan were successfully deposited on glass slides.

Certain dye molecules are known to have solvatochromic properties depending on the ionic strength, pH or polarity of the surrounding solvent. This phenomenon is characterized by a shift of the  $\lambda_{max}$  value of the dye’s absorbance spectrum toward higher or lower wavelength. Before the buildup of Chitosan–Nylosan PEM, a study of the solvatochromic behavior of the Nylosan dye was conducted. Sample

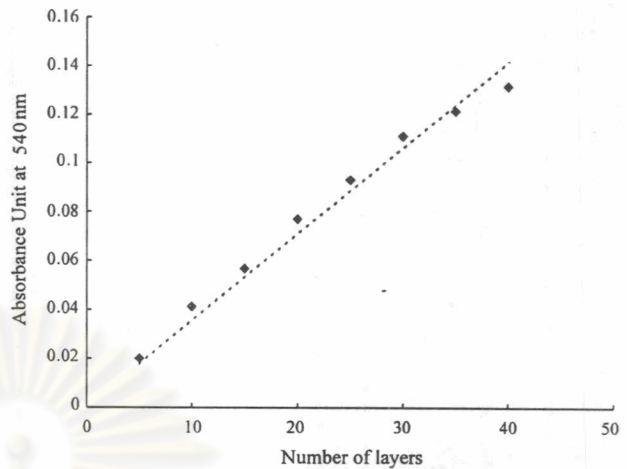


Fig. 2. Absorbance value at 540 nm of a Chitosan–Nylosan thin film as a function of the number of deposited layers.

solutions of the Nylosan dye as a function of increasing pH, ionic strength and ethanol content were prepared and measured using a UV–vis spectrophotometer. These results are reported in Fig. 3, and the different effects of the studied parameters on the  $\lambda_{max}$  absorbance of the dye can be clearly seen. An increase of both pH and ionic strength of the solution led to a shift of  $\lambda_{max}$  towards lower wavelengths respectively from 570 to 525 nm and from 570 to 565 nm. Contrarily, an increase in ethanol content resulted in a shift of the  $\lambda_{max}$  absorbance towards higher wavelengths from 570 to 580 nm. These observations confirm that any shift of the  $\lambda_{max}$  absorbance toward higher wavelength should be the result of the ethanol content in water rather than the pH or ionic strength of the solution.

As mentioned earlier, when Nylosan dye molecules are assembled into PEM, the absorbance spectrum of the thin film presents a maximum at 540 nm which gives a light purple color. This characteristic color of the dye in the PEM thin film also matches the color of the dye when dispersed

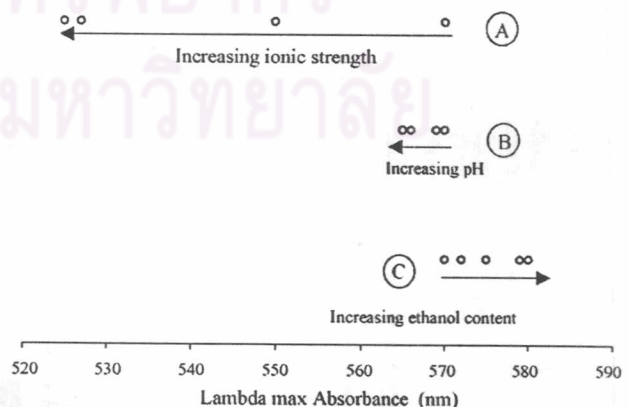


Fig. 3.  $\lambda_{max}$  absorbance values of the Nylosan dye in solution of (A) increasing ionic strength: 0, 0.1, 0.5 and 1 M NaCl; (B) increasing pH: 3, 4, 5 and 7; (C) increasing ethanol content in water: 0, 10, 20, 30 and 40%.

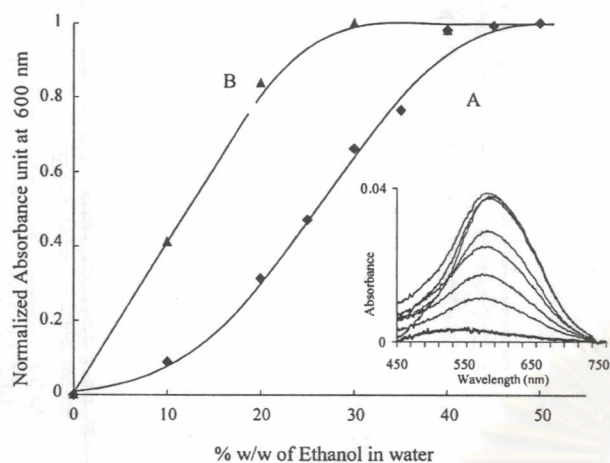


Fig. 4. Increase in absorbance at 600 nm of the Nylosan dye as a function of various environments. (A) Changes in absorbance when the dye is deposited into PEM. (B) Changes in absorbance when the Nylosan dye is dissolved in a water/ethanol mixture. Inset: UV-vis spectrum of the Chitosan-Nylosan thin film when exposed to increasing concentration of aqueous ethanol (10, 20, 25, 30, 35, 40, 45, 50 wt.%). The spectrum of the thin film initially dipped in water was subtracted and used as based line to improve the clarity of the graph.

in aqueous solutions of ionic strength equal to 0.1 M NaCl. This expected similarity in color of the dye when assembled into PEM is due to the electrostatic interactions between the sulfonate groups of the dye and the Chitosan's ammonium groups. These electrostatic interactions are also similar to those between Nylosan dyes and  $\text{Na}^+$  counter ion in solution both leading to a decrease in  $\lambda_{\text{max}}$  absorbance from 570 to 540 nm and giving a light purple color of the thin film. The following section is a study of the effect of increasing ethanol content in water on the absorbance response of a 40 layers Chitosan-Nylosan thin film.

It is important to note that in the next experiment, we chose to plot the changes in absorbance value at 600 nm as a characteristic of the film response to ethanol in solution instead of monitoring the shift of  $\lambda_{\text{max}}$  absorbance values. This choice is due to the fact that while  $\lambda_{\text{max}}$  varies from 540 to 580 nm, the absorbance at 600 nm increases nearly 50%, which makes it a better characteristic for sensor applications. In this experiment, 40 layers of Chitosan and Nylosan were deposited on pre-cut glass slides following the procedure already described in Section 2. The resulting PEM thin film was then introduced into a UV-vis cuvette and exposed to solutions of various ethanol contents. The change in absorbance of the PEM thin film as function of the ethanol content is represented by curve A in Fig. 4. No significant effect on the thin film's absorbance could be seen for ethanol content between 0% and 10%. At ethanol contents between 10% and 45%, a constant increase in absorbance was observed with a maximum at 45%. Further increase of the ethanol concentration to 50% content did not lead to any change in absorbance. Surprisingly, the changes in absorbance of the dye as a function of the ethanol content were different when the dye was dissolved

in aqueous solution as displayed by curve B in Fig. 4. In this case, the absorbance at 600 nm reached a plateau for ethanol content above 30%, while this plateau was reached for ethanol content above 45% in the Nylosan-Chitosan PEM.

We interpret the delayed shift of the dye's absorbance to be due to the electrostatic nature of the PEM. Firstly, this delay can be attributed to a lower ethanol content inside the PEM versus outside the PEM, in the surrounding solution. The ability of the PEM to separate organic solvent from water has already been reported [32–34] and for example when deposited onto porous alumina, PEM can be used to separate water from ethanol by permeation. The justification for this phenomenon lies in the highly ionic structure of the PEM, which promotes the diffusion of ions and water molecules, but limits the access to less polar solvent such as ethanol. A second argument for the delay in absorbance increase at 600 nm is the potentially competitive interaction between the ethanol-Nylosan system and the electrostatic interaction between the Nylosan-Chitosan complex. ATR-FT-IR studies are currently being pursued to characterize the amount of ethanol present in the Chitosan-Nylosan PEM as a function of the solution's ethanol content while monitoring the absorbance increase at 600 nm. It is also interesting to note that when testing thin films built from various number of layer (10, 20, 30 layers) the change in absorbance as a function of ethanol content was proportional to the initial absorbance of the thin film in water. These results suggest that this phenomenon is based on a bulk sensor effect and not limited to the surface of the film.

Lastly, the stability of the Chitosan-Nylosan PEM was studied. A PEM thin film was exposed to cycles of water and 50% ethanol content and the absorbance changes were monitored using UV-vis absorbance. After five cycles, the thin film had partially disappeared and released the Nylosan dye back into the solution. This decomposition is mostly due to the loss of electrostatic interactions between the Chitosan and the Nylosan, which are the structural binding forces of the PEM system. Consequently, this led to the slow release of the dye into the solution and to the decomposition of the film. Different strategies are being investigated to improve the stability of the dye in the PEM. Nevertheless, even considering the low cyclability of the Chitosan-Nylosan PEM, this system could be used as a disposable sensor tool for quick and inexpensive ethanol content measurements.

#### 4. Conclusion

This study demonstrates the potential use of Chitosan-Nylosan thin films as an alcohol sensor with a response in the range of 10–45% ethanol content in solution. The deposition of Nylosan and Chitosan into PEM displayed a linear growth as a function of the number of layers which is typical for such systems. We suggest that, due to electrostatic interactions, a lower ethanol content in the PEM leads to a delayed response of the Nylosan



dye to increasing ethanol content. Possibly, the response of the Nylosan can be tuned by controlling the structure and architecture of the thin film. The use of natural dye could also lead to the development of interesting biocompatible and inexpensive ethanol sensing thin films.

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