CHAPTER V

RESULTS AND DISCUSSION

The research has set its aim to prepare ZnO thin films using sol-gel process incorporating with dip coating technique for transparency and photoinduced hydrophilic properties. Effect of solvents on thin film preparation and the effect of thin film coating cycle on the improved hydrophilic property was investigated and reported in this chapter.

Part A: Investigation of effect of solvent types and preparing conditions on thin film appearance

First, it is required that ZnO thin flims to be prepared should exhibit a good appearance in their transparency because they are expected to use for glass coating which would not affect it visibility. Ohyama, Kozuka and Yoko (1997) suggested that 2-methoxyethanol was a good solvent for preparing ZnO precursor which could provide ZnO thin films with acceptable transparency. However, they made use of two-step heat treatment which would be suitable for practical use. Therefore, in this work some experimental trials were conducted to find out the optimal conditions which included types of solvents, concentration of precursor, withdrawal speed and calcination temperature on the appearance of the prepared ZnO thin films.

5.1 Effect of calcination temperature and withdrawal speed

Based on the experimental results of Ohyama, Yoko and Kozuka (1997), zinc acetate dihydrate was dispersed in 2-methoxyethanol before doping on the glass substrates. However, it is important to know the optimal conditions of calcination temperatures and withdrawal speed during the dip coating because these parameters could control the appearance of the prepared thin film. Experimental conditions for ZnO thin film preparation were listed in Table 4.1. The optimal condition for transparent thin film preparation was investigated. At the beginning the effect of the

calcination temperature was examined by varying in a range of 300 to 500°C with a constant withdrawal speed of 1.0 cm/min and then the withdraw speeds were varied in the range of 1.0 to 6.0 cm/min. The film appearances which were characterized by their transmittance are summarized in Table 5.1.

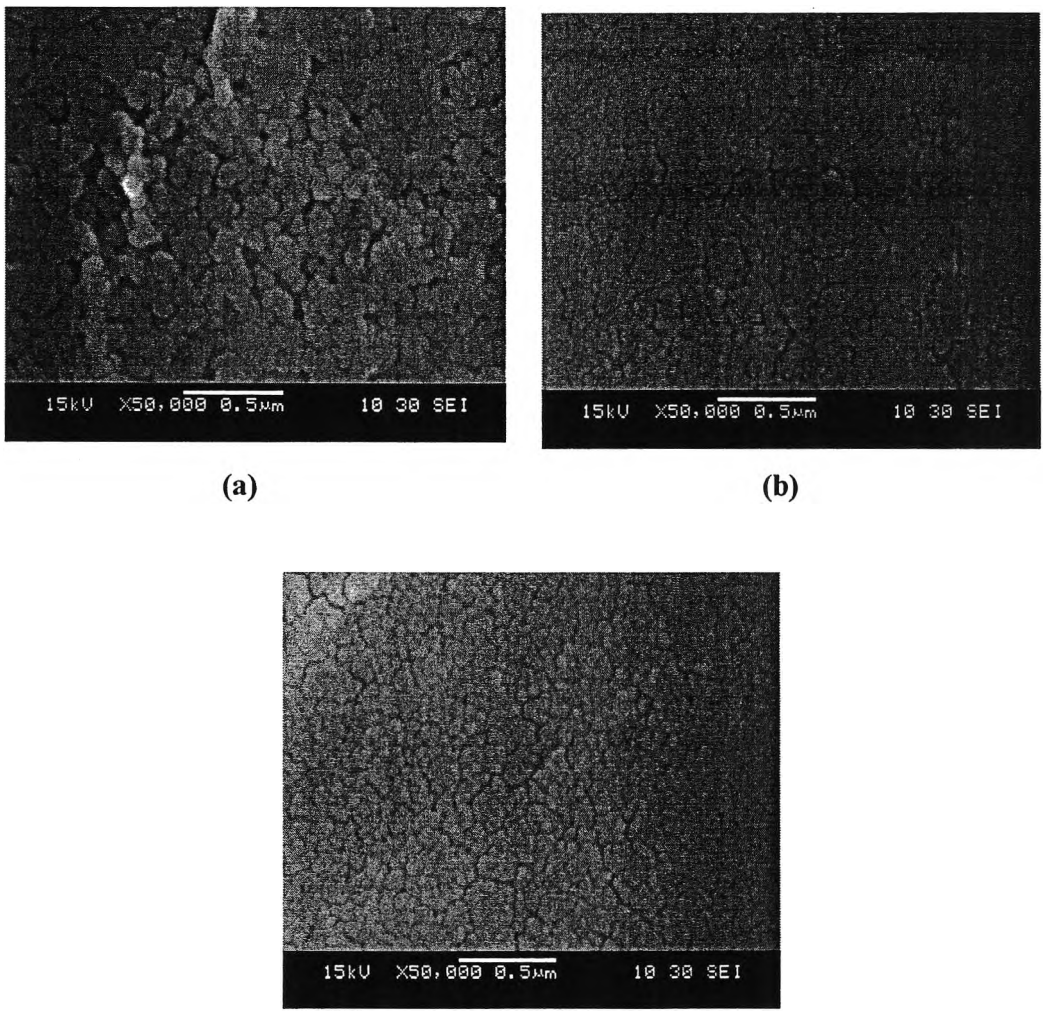
Table 5.1 Properties of ZnO thin films prepared at different withdrawal speeds and calcination temperatures

Zinc acetate concentration (M)	Withdrawal speed (cm/min)	Calcined at temperature (°C)	Average transmittance (%)(400-700 nm) (ref.=glass)	Atomic ratio of Zn:O
0.75	1.0	300	99.0	-
		400	98.7	-
		500	98.0	1.00:1.03
	3.0	300	99.0	-
		400	97.2	-
		500	98.2	1.00:0.95
	6.0	300	95.5	-
		400	96.1	-
		500	98.0	1.00:1.71

The visible light (400–700nm) transmittance of the prepared ZnO films coated on glass substrates which were calcined at temperature of 300, 400 and 500°C are higher than 90%. Though the optical transmittance are insignificantly different it is worth noted that with microscopic analyses, the grain size of ZnO particles deposited on the glass surface after calcination exhibited some difference as shown in Figure 5.1.

Typical SEM images of ZnO films prepared with the withdrawal speed of 1.0 cm/min and calcined at temperatures of 300, 400 and 500°C reveal that the film calcined at 300°C containing larger voids. Meanwhile the films calcined at 400 and 500°C also exhibits some cracks on their surface. Such voids and cracks lead to translucent appearance. This is due to the fact that at lower temperature the easily vaporized organic solvent (2-methoxyethanol; bp = 127°C) and stabilizer (MEA : bp = 170°C) were removed leaving larger voids. Though Ohyama, Kozuka and Yoko

(1997) reported that the decomposition of zinc acetate to form ZnO was found at 240°C, in this work even at 300°C, the decomposition would not be completed, resulting in the formation of voids on the film surface which would not totally consist of ZnO. However, at the calcined temperature up to 400°C the decomposition of organic compound would be completed. Accordingly, the oxidation of zinc could be expected but the increase in the calcination temperatures was found to lead to the formation of cracks, resulting in the translucency of the prepared film.



(a) (b)

(c)

Figure 5.1 SEM images of ZnO films prepared with zinc acetate concentration of 0.75 M coated at withdrawal speed of 1.0 cm/min and different calcined temperatures at (a) 300°C, (b) 400°C and (c) 500°C

Considering the effect of withdrawal speed, additional specimens of coated glass substrates were prepared by varying the speed from 1.0 to 6.0 cm/min and all specimens were also calcined with three different temperatures: 300, 400 and 500°C. It was found that all specimens still exhibited translucency regardless of their withdrawal speed. Their visible light transmittances are still insignificantly different. Therefore there should be other parameters which affect this transparency.

It should be noted that with the lower withdrawal speed the thinner film could be obtained (laudau and Levich, 1942). Such difference in the film thickness provided a hint in their constituent difference. Therefore, energy dispersive X-ray spectroscopic analysis has been performed for elemental analysis of the prepared film as shown Figures 5.2 and 5.3. A typical EDX spectrum reveals that the film coated on the glass substrate using zinc acetate concentration of 0.75 M coated at a withdrawal speed of 1.0 cm/min and calcined at 500°C was composed of C, O, Na, Mg, Al, Si, Ca and Zn. Meanwhile, the glass substrate consisted of C, O, Na, Mg, Al and Si. With these EDX analyses, the atomic ratio of zinc to oxygen in the thin films could be estimated. Based on the analytical results of atomic ration of zinc to oxygen in the prepared thin films shown in Table 5.1, it was found that with the highest withdrawal speed of 6.0 cm/min, the highest oxygen ratio was obtained. This is attributed to the fact that with the higher withdrawal speed the thicker films would be fabricated and the oxidation of such thick film would take place on the surface only, resulting in the remaining of organic constituents within the film. Therefore, the films still exhibits the translucent appearance.

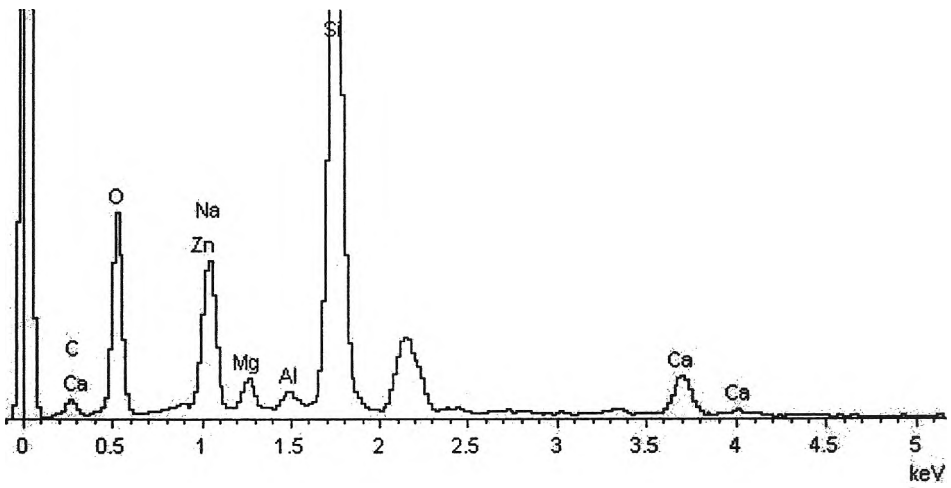


Figure 5.2 EDX analysis of ZnO film prepared with zinc acetate concentration of 0.75 M coated at withdrawal speed of 1.0 cm/min and calcined temperature at 500°C

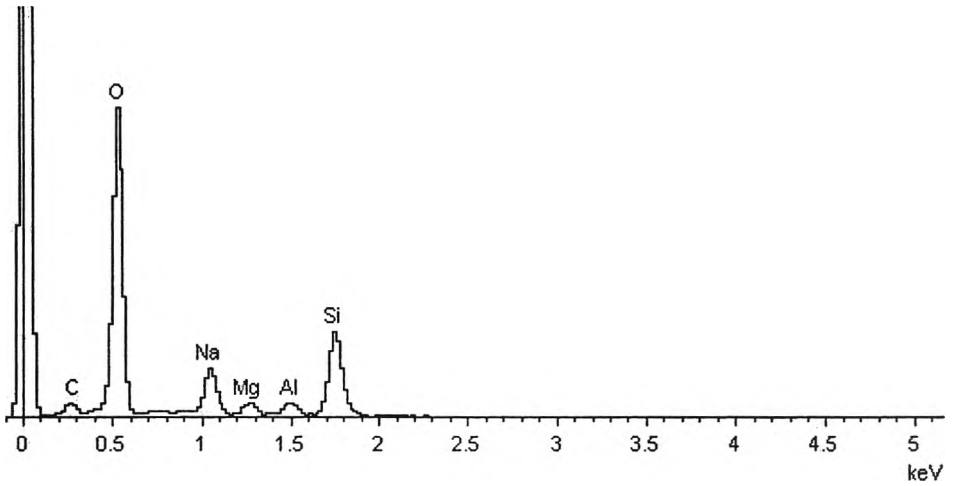


Figure 5.3 EDX analysis of glass substrate

5.2 Effect of concentration of precursor

From the previous experiment, it was found that the calcination temperature and withdrawal speed exerted insignificant effect on the film transparency. Therefore, concentration of zinc acetate precursor was further investigated to find out whether it was possible to improve the thin film transparency. The experimental parameters and results are summarized in Table 5.2.

ZnO thin films fabricated at withdrawal speed of 1.0 cm/min and calcined temperature at 500°C were prepared from zinc acetate precursor at four different concentrations: 0.10, 0.25, 0.50 and 0.75 M. The transmittance and morphology are compared in Figures 5.4 and 5.5, respectively.

Table 5.2 Properties of ZnO thin films prepared at different precursor concentrations

Withdrawal speed (cm/min)	Calcined at temperature (°C)	Zinc acetate concentration (M)	Transmit-tance spectra	Average transmittance (%) (400-700 nm) (ref.=glass)	Morpho-logy
1.0	500	0.10	Fig. 5.4	99.4	-
		0.25		95.0	Fig. 5.5
		0.50		96.9	
		0.75		98.0	

Based on the analytical results of optical transmission, it could be observed that the precursor concentration could affect the film transparency as shown in Figure 5.4. With the lowest precursor concentration of 0.10 M, the transmittance of the prepared film was highest, confirming the best transparency. Typical SEM images for the ZnO films prepared with the precursor concentrations of 0.25, 0.50 and 0.75 M are also presented in Figure 5.5. As the microscopic appearances were insignificantly different compared with Figure 5.1, it could also been observed there were some cracks and voids on those films prepared at either low or high concentration. This should be attributed to the fact that at high concentration the viscosity of the solution would become higher, leading to high deposited on the substrate. However, regarding to the optical transmission and its appearance, the lowest zinc acetate concentration of 0.10 M was selected as a preferential value for preparing ZnO thin films.

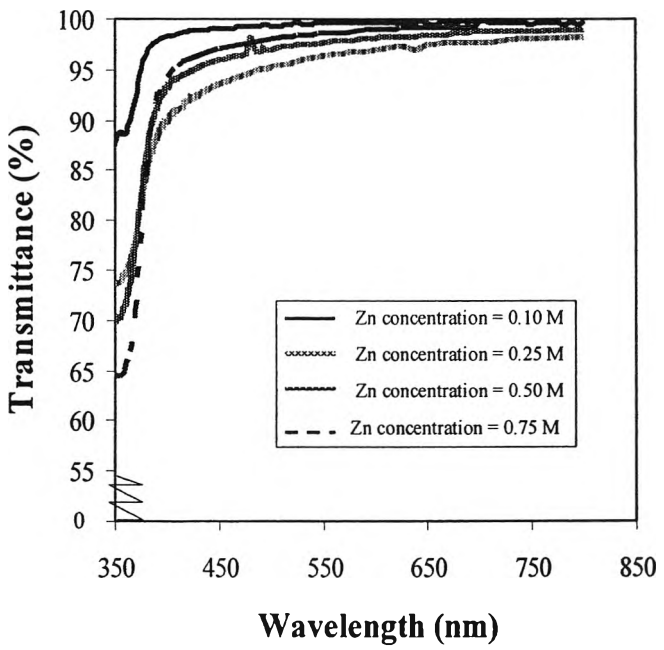
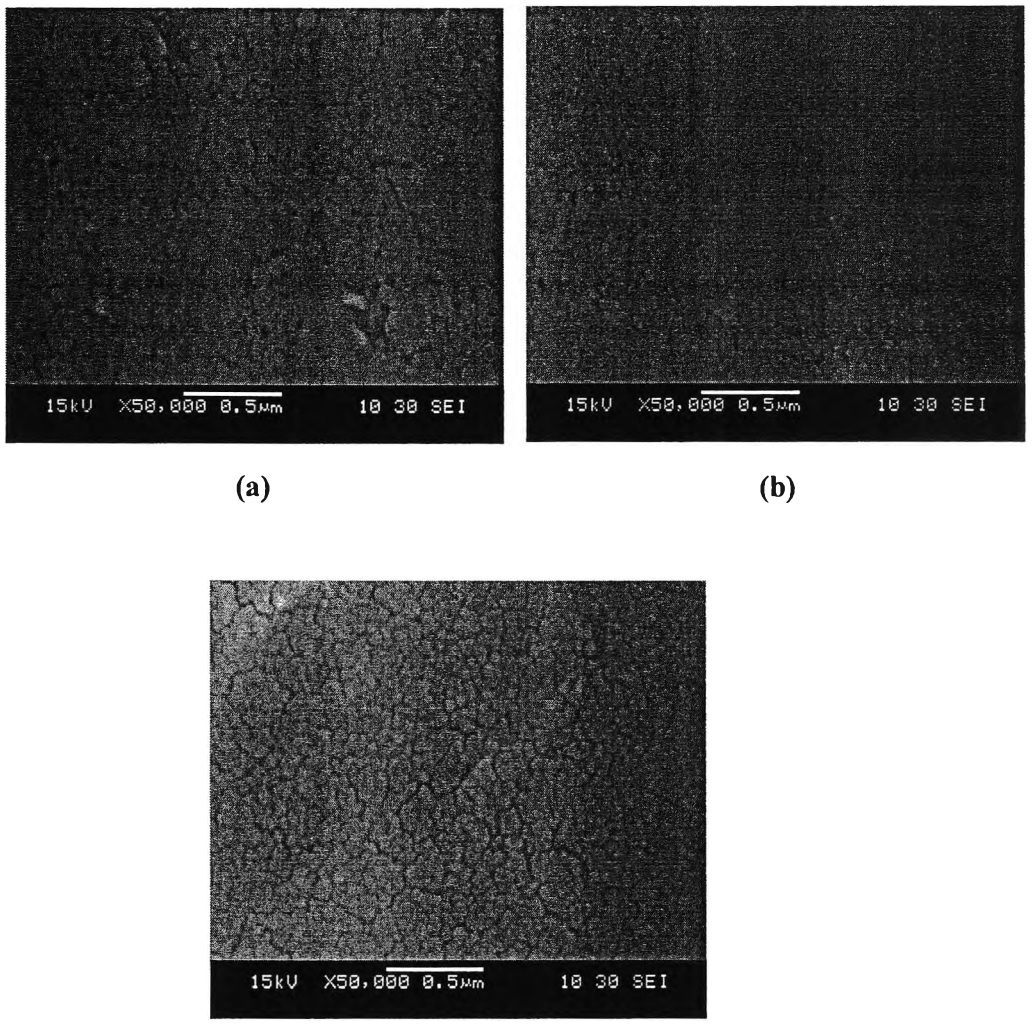


Figure 5.4 Optical transmittance spectra of ZnO films prepared with different precursor concentrations coated at withdrawal speed of 1.0 cm/min and calcined temperature at 500°C



(a) (b)

(c)

Figure 5.5 SEM images of ZnO films prepared with withdrawal speed of 1.0cm/min and calcined temperature at 500°C and different precursor concentrations (a) zinc acetate concentration=0.25 M, (b) zinc acetate concentration = 0.50 M and (c) zinc acetate concentration=0.75 M

5.3 Effect of types of solvents

So far, it has been found that 2-methoxyethanol could provide only translucent thin film of ZnO coated in glass substrates. Regarding to the fundamental knowledge on chemical composition of such solvent, ethanol was also selected as another alternative solvent for improving the thin film appearance.

It should be noted that with 2-methoxyethanol as the solvent, MEA was employed as stabilizer. However, with ethanol, acetic acid was selected as stabilizer, instead. Because ethanol has higher polarity, it could easily dissolve zinc acetate. Therefore, regarding to the ease of handling, ethanol would be a better candidate solvent. For the comparison of 2-methoxyethanol and ethanol, ZnO thin films prepared from zinc acetate solution with two solvents were prepares and examined their visible light transmittance referred to transmittance of glass substrate as summarized in Table 5.3. All of ZnO films coated on glass substrates were prepared with zinc acetate concentration of 0.10 and 0.50 M, withdrawal speed of 3.0 cm/min and calcination temperature of 500°C. All of the fabricated films exhibited transmittance of above 90% with respect to the range of visible light. However, it could be clearly seen that with the same zinc acetate concentration ethanol could provide better average transmission value. The best transmission of 95.5 % could be obtained when 0.50 M of zinc acetate was dissolved in ethanol.

From microscopic analyses shown in Figure 5.6, it could be seen that typical samples of substrates coated with ZnO thin films prepared with 0.10 M of zinc acetate, ethanol as solvent and three different withdrawal speeds could exhibit the excellent transparent appearance. It should be noted that SEM analysis could not provide their microscopic images because of the film transparency. These results would be attributed to the reason that ethanol could be easily vaporized due to its lower boiling point (67°C) compared with that of 2-methoxyethanol (127°C). This would lead to rapid disengagement of ethanol to enhance the continuous film formation with less cracks and voids.

Table 5.3 Properties of ZnO thin films prepared with different solvents and precursor concentrations and calcination temperature of 500°C

Solvent	Zinc acetate concentration (M)	Average transmittance (%) (400-700 nm) (ref.=glass)
2-methoxyethanol	0.10	99.3
	0.50	94.4
ethanol	0.10	99.5
	0.50	95.5

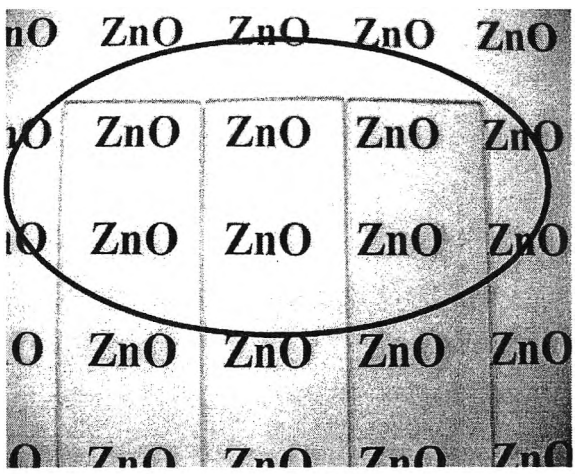


Figure 5.6 The appearance of transparency of ZnO films prepared with precursor concentrations of 0.10 M and calcined temperature at 500°C and withdrawal speeds of (a) 3.0 cm/min, (b) 6.0 cm/min and (c) 9.0 cm/min

As a result, these experiments suggest that zinc acetate precursor dissolved in ethanol as the solvent could provide ZnO thin films with excellent transparency. Calcination temperature, withdrawal speed and zinc acetate have exerted only slice effects on the thin film appearance. However, the photoinduced hydrophilic property of ZnO thin films should be further investigated and then discussed in the next part.

Part B: Effect of preparation conditions and number of layers on photoinduced hydrophilic properties of thin film

In Part B, transparent ZnO thin films prepared with the previously described method were investigated for dependence of their characteristics on experimental variables which were zinc acetate concentration and withdrawal speed. Morphology, roughness, grain size, film thickness and phase of ZnO thin films were analyzed to gain understanding for improvement of the film photoinduced hydrophilic property.

5.4 Effect of precursor concentration

In general, an increase in concentration of precursor would result in a change in its viscosity which would affect film characteristics including roughness, grain size, and thickness. Yimsiri and Mackley (2006) reported that the increasing viscosity would significantly affect the thickness of thin films prepared by spin and dip coating. Similarly, the viscosity of zinc acetate dissolved in ethanol was examined by varying in the precursor concentration in a range of 0.10 to 0.50 M. The effect of the precursor concentration of its viscosity is graphically shown in Figure 5.7.

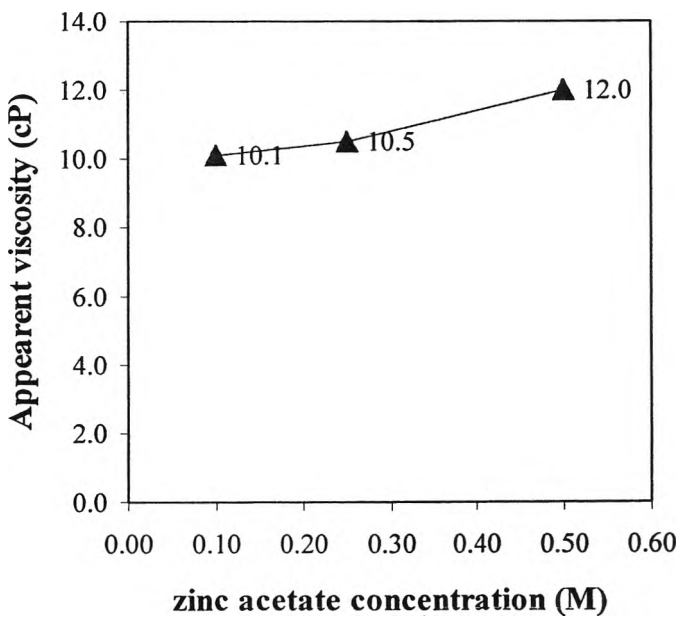
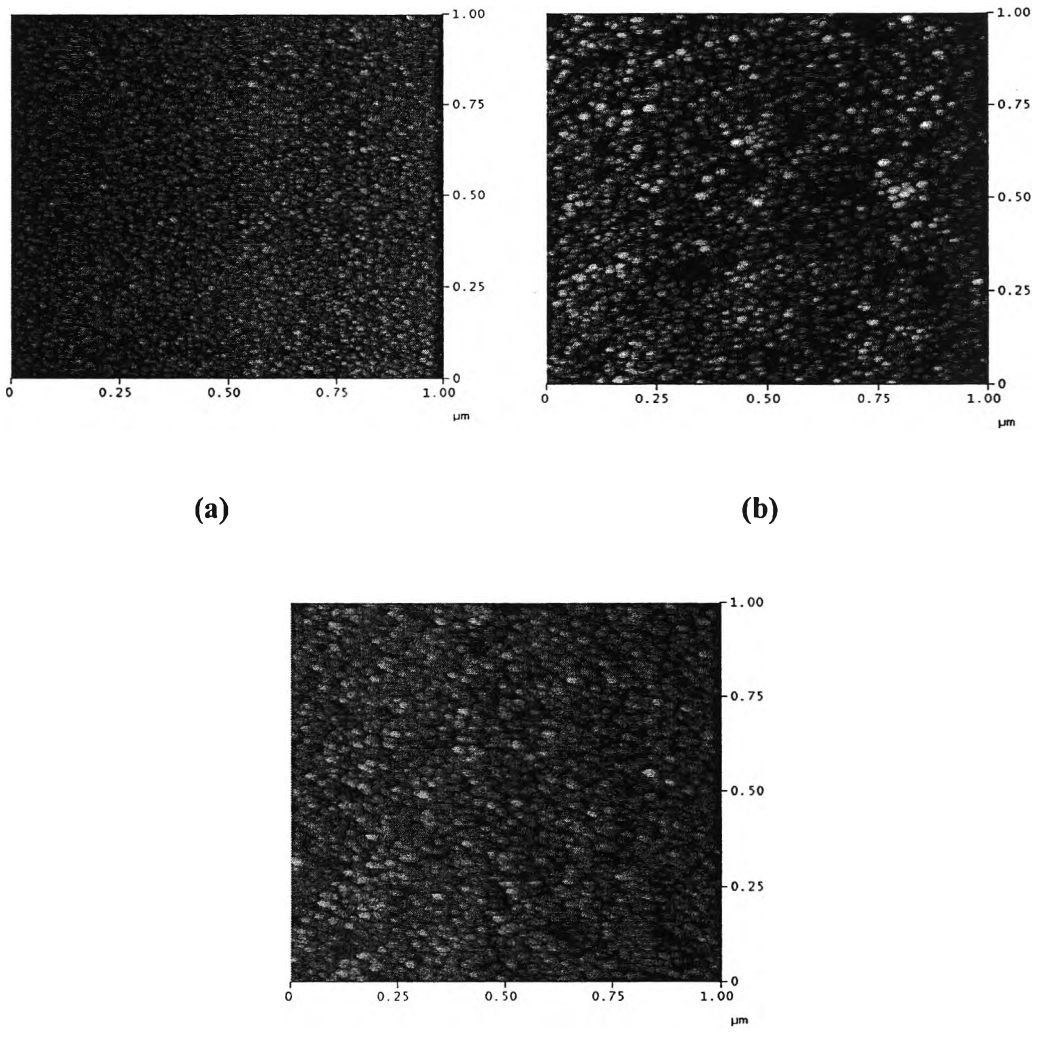


Figure 5.7 Relation between zinc acetate concentration and its viscosity

It could be clearly seen that the apparent viscosity of zinc acetate concentration was increased with the increasing precursor concentrations. The viscosity was 10.1, 10.5 and 12.0 cP when the precursor concentration was 0.10, 0.25 and 0.50 M, respectively. For the preliminary investigation, AFM technique was employed to observe the surface morphology of the ZnO films prepared from zinc acetate solution with those three concentrations. It should be noted that regarding to our experimental results in Part A, withdrawal speed was fixed at 3.0 cm/min and calcination temperature at 500°C. It could be clearly observed from Figure 5.8 that grain size of ZnO on the film prepared with lower concentration (zinc acetate concentration of 0.10 M) is significantly smaller than those of ZnO film prepared with higher concentration. From these AFM analyses, we could obtain the value of root mean square roughness (R_{rms}). This result suggests that the increasing concentration would lead to the increasing viscosity, which consequently affects the surface morphology. From our observation, the solution with higher concentration and higher viscosity could exert higher resistance while the substrates were dipped into the solution. Thickness of wetted film obtained from the solution with lower concentration would be thinner, resulting to faster vaporization rate. Accordingly, nucleation of ZnO within the calcined film would be faster, leading to smaller size of grains on the surface of the coated thin film.



(a) (b)

(c)

Figure 5.8 AFM images of ZnO films prepared with withdrawal speed of 3.0cm/min and calcined temperature at 500°C and different zinc acetate concentration (a) 0.10 M, (b) 0.25 M and (c) 0.50 M

Furthermore, other comprehensive investigation results with variation of precursor concentration and withdrawal speed were summarized in Table 5.4.

Table 5.4 Surface roughness and average grain size of ZnO thin films with different zinc acetate concentrations and withdrawal speeds

zinc acetate concentration (M)	withdrawal speed (cm/min)	R_{rms} (nm)	average grain size (nm)	Relative roughness
0.10	3.0	2.1	18.0	0.117
	6.0	2.4	19.5	0.123
	9.0	2.2	23.0	0.096
0.25	3.0	3.7	19.0	0.195
	6.0	3.2	20.5	0.156
	9.0	9.2	29.0	0.317
0.50	3.0	4.3	22.5	0.191
	6.0	4.6	20.5	0.224
	9.0	5.5	26.0	0.212

R_{rms} = Root mean square roughness

It was found that with the highest concentration of 0.50 M and the surface root mean square roughness of the coated films increased from 4.3 to 5.5 nm when the glass substrates were withdrawal from the solution with the speed of 3.0 to 9.0 cm/min, respectively. The increase in surface roughness which is subject to the higher withdrawal speed would be attributed to the thicker film formation. Based on the accuracy of these measurements, it would be able to imply that the R_{rms} and average grain size exhibit a consistent tendency. As already mentioned, a wetted film with a thicker thickness would be more slowly calcined and resulted in the formation of enhanced growth of grains on the coated surface. The large grain size would also agglomerate, leading to high surface roughness when the film was fabricated at high withdrawal speed.

In order to confirm these results, the surface profiler was also employed to examine the local roughness of the ZnO films fabricated with different precursor concentration and withdrawal speed as summarized in Table 5.5. Referring to measuring method described in Chapter 3, totally 15 positions on the fabricated film surfaces were scanned by the surface profiler to determine the film thickness. With the constant withdrawal speed, it could be clearly observed that the increasing concentration of zinc acetate precursor accompanying with the increasing viscosity would result in the thicker film. The effect of precursor concentration on the film thickness determined by the surface profiler is depicted in Figure 5.9. It could be

clearly seen that both concentration of precursor and withdrawal speed are the key variables affecting the average film thickness. However, the effect of concentration on the film thickness is more significant than the effect of withdrawal speed. These results are attributed to rheological behavior of the wetted film and the nucleation of ZnO grains within the calcined films. Verification of the film thickness was also conducted using FESEM. A typical micrograph of a ZnO film prepared with zinc acetate concentration of 0.50 M and withdrawal speed of 9.0 cm/min reveals that the film thickness is about 77 nm. It is slightly thicker than that of the surface profiler result.

It is also noted that when considering the relative ratio of R_{rms} to average grain size, with the lowest concentration of zinc acetate, the lowest relative ratio could be observed as shown in Table 5.4. Also based on AFM results, it could be supposed that 0.10 M zinc acetate would be the most promising concentration to prepare transparent film of ZnO to coat on glass substrates.

Table 5.5 The average of film thickness using surface profiler

Zinc acetate concentration (M)	Viscosity (cP)	Withdrawal speed (cm/min)	Position	$T_{AVG,P}$ (nm)	SD_P	$T_{AVG,T}$ (nm)	SD_T
0.10	10.1	3.0	T_1	15.4	7.0	13.4	7.5
			T_2	15.9	7.4		
			T_3	9.0	6.4		
		6.0	T_1	17.7	3.8	13.9	8.2
			T_2	18.9	5.2		
			T_3	5.0	1.3		
		9.0	T_1	11.0	4.1	16.2	9.7
			T_2	27.2	8.3		
			T_3	10.3	4.5		
0.25	10.5	3.0	T_1	25.4	11.6	32.7	21.9
			T_2	22.4	12.2		
			T_3	50.3	26.3		
		6.0	T_1	31.5	6.0	33.2	20.6
			T_2	50.0	21.4		
			T_3	18.0	8.1		
		9.0	T_1	38.6	11.4	33.7	14.1
			T_2	38.8	17.3		
			T_3	23.6	8.7		
0.50	12.0	3.0	T_1	60.2	15.9	64.5	44.8
			T_2	36.2	13.8		
			T_3	97.2	61.7		
		6.0	T_1	82.3	21.4	66.7	25.5
			T_2	74.9	9.6		
			T_3	43.0	23.6		
		9.0	T_1	83.9	23.2	71.4	29.2
			T_2	69.2	33.1		
			T_3	61.0	29.7		

$T_{AVG,P}$ = Average film thickness (position)

$T_{AVG,T}$ = Average film thickness (total positions)

T_1 = Average film thickness of top position

T_2 = Average film thickness of middle position

T_3 = Average film thickness of bottom position

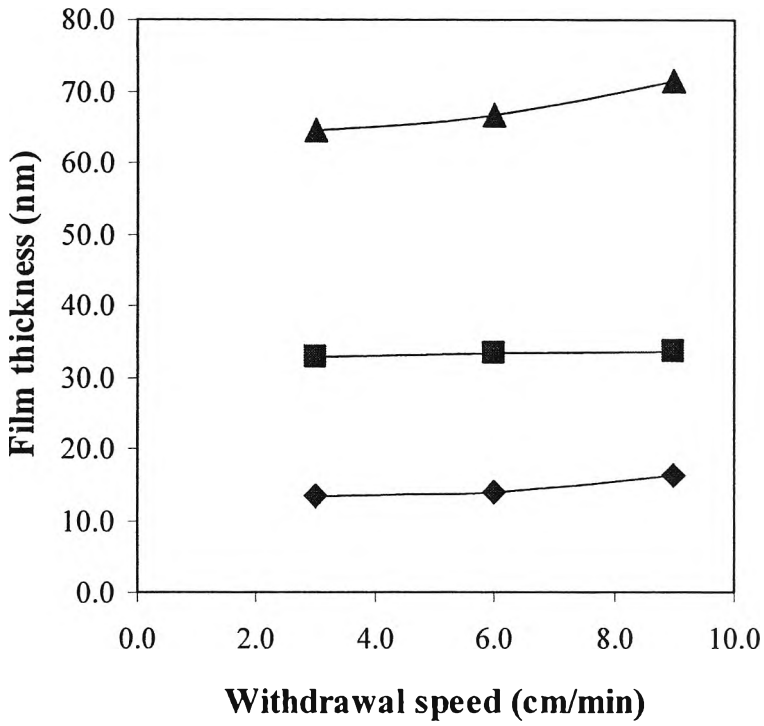


Figure 5.9 Film thickness as a function of withdrawal speed
(◆ ; precursor concentration of 0.10 M, ■ ; precursor concentration of 0.25 M and ▲ ; precursor concentration of 0.50 M)

Figure 5.10 Cross section of FESEM image of ZnO coating film prepared from 0.50 M zinc acetate concentration with the withdrawal speeds of 9.0 cm/min

The chemical composition of the fabricated film was also investigated using XRD. As could be seen from typical X-ray diffractograms shown in Figure 5.10, it could be confirmed that the thin films fabricated from either 0.10 M or 0.50 M of zinc acetate solution are mainly composed of ZnO. The diffraction peaks at 31.72°, 34.4° and 36.2° within X-ray diffratograms could be assigned to the (100), (002) and (101) planes of ZnO. These peaks were identified the presence of ZnO in hexagonal wurtzite structure. Similar observation of ZnO films has been reported in the literature (Berber et al. 2005). Based on the Scherrer's formula, crystal grain size in the films prepared from 0.10 and 0.50 M zinc acetate solutions are 30.2 and 32.4 nm, respectively. These values are slightly different from those of AFM analyses because of the difference in estimation basis. However, it also confirmed that with the lower zinc acetate concentration, ZnO with lower grain size could be prepared. Therefore, we have kept the zinc acetate concentration of 0.10 M as the basis for further investigation on the photoinduced hydrophilic property of fabricated ZnO thin films.

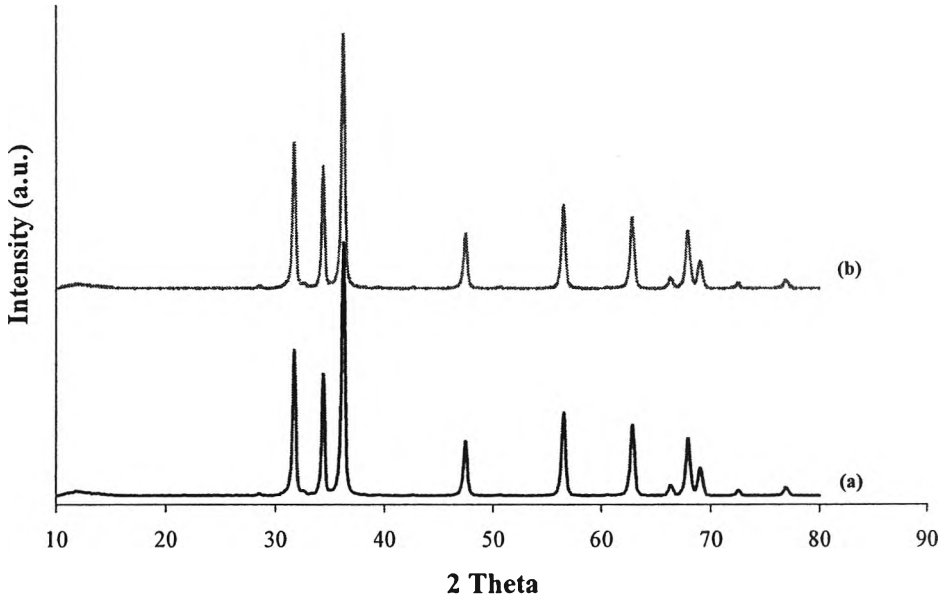


Figure 5.11 X-ray diffractograms of ZnO powder prepared by zinc acetate concentration of (a) 0.10 M and (b) 0.50 M with calcination temperature of 500°C

5.5 Photoinduced hydrophilic property of ZnO films

As mentioned in Part A, the prepared ZnO thin films could exhibit good transparency. Furthermore, it is also required to improve the photoinduced hydrophilic property of the fabricate films. Based on other reports, those photoinduced hydrophilic properties of metal oxide films coated on glass substrate could be examined by measuring water contact angle. The photoinduced hydrophilic property would be stimulated by UV irradiation for a certain time period (Sharma et al., 2006). Therefore, in this work, the effect of UV irradiation time on the film hydrophilicity and durability were further investigated.

5.5.1 Effect of UV irradiation time

To examine the hydrophilic property of the coated films, average water contact angle was measured and then plotted against the UV irradiation time as shown in Fig. 5.12. When zinc acetate concentration of 0.10 M was coated on the glass substrate with three different withdrawal speeds of 3.0, 6.0 and 9.0 cm/min, the decreasing trend of water contact angle could be observed, suggesting that the photoinduced hydrophilicity of the coated films were successfully simulated by UV irradiation. The water contact angle of any fabricated films was higher than 24 degree before UV irradiation. However, highly hydrophilic surface with the water contact angle of 5 degree could be obtained with UV irradiation for only 30 min. As observed from Figure 5.12, the longer the UV irradiation time was spent, the lower water contact angle was achieved.

When considering the effect of the withdrawal speed, it could be observed that with the withdrawal speed of 3.0 cm/min (▲), the lowest water contact angle of c.a. 5 degree could be achieved. As shown in previous section (Table 5.4), with the lower withdrawal speed, the film thickness would be reduced but the relative ratio of surface roughness (R_{rms}) to grain size would be amplified. Therefore, it is reasonable that this result would be attributable to the higher relative roughness of the fabricated film which could result in the capillary effect, leading to spreading out of water droplets (Shirtcliffe et al., 2007). However, there are some reports indicating a mechanism of electron-hole pairs generation on the thinner surface which would create oxygen

vacancies to dissociate water molecule and then enhance the hydropilicity. This issue would be also further investigated in the future.

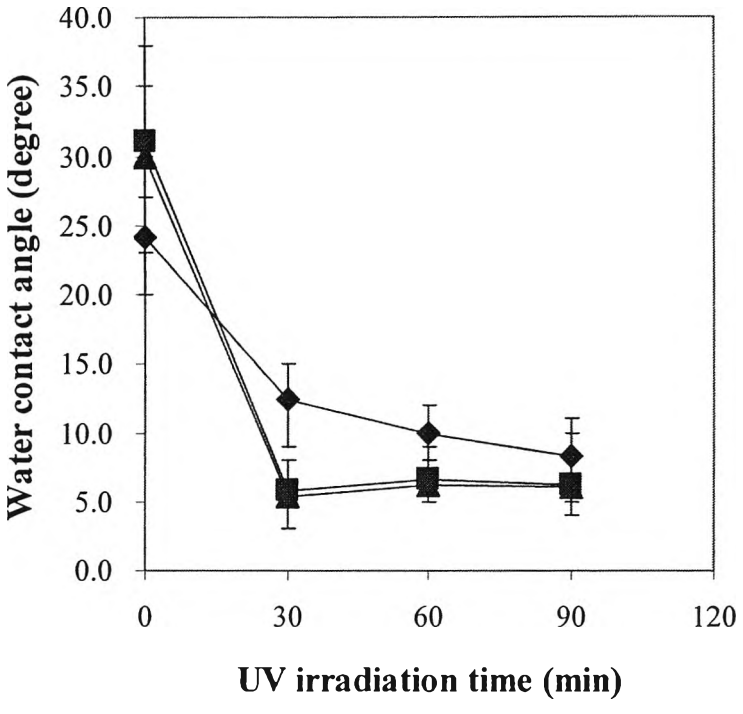
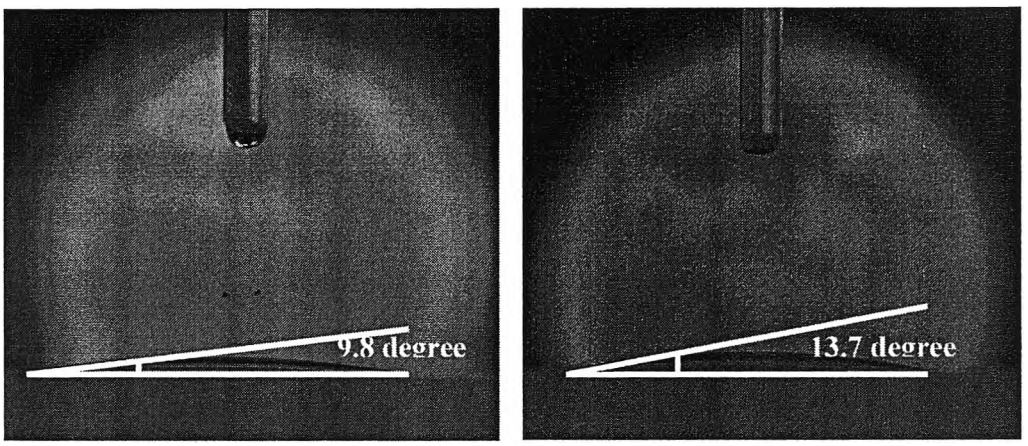


Figure 5.12 Dependence of water contact angle of ZnO films on UV irradiation time (▲; withdrawal speed = 3.0 cm/min, ■ ; withdrawal speed = 6.0 cm/min and ◆; withdrawal speed = 9.0 cm/min)

5.5.2 Durability of fabricated thin film

Regarding to hydrophilic property, durability, which is represented by the change of water contact angle before and after the stimulated film is kept in the dark, is also significant factor. Some typical evidences of water contact angle measurement are demonstrated in Fig. 5.13. It could be observed that after irradiation the ZnO film could provide the water contact angle of 9.8 but it became worse after kept in the dark for 7 days.



(a) (b)

Figure 5.13 Pictures captured during contact angle measurements, showing the water contact angles of ZnO thin film surfaces under the alternation of (a) UV irradiation and (b) dark storage are 9.8 and 13.7 degrees, respectively

Figure 5.14 reveals the durability of ZnO thin films fabricated with 0.10 M zinc acetate, withdrawal speed of 1.5 cm/min and calcinations temperature of 500 °C. UV irradiation time of 0, 10, 20, 30, 60 min were applied for investigating the effect of irradiation on the film durability. It could be clearly seen that after the stimulated films were kept in the dark for 7 days their water contact angle would become larger, suggesting that they lost their hydrophilicity. Anyway, the trend of the higher hydrophilicity due to a longer irradiation time could also be observed. It was found that at least an irradiation time of 30 min would be necessary for stimulating the fabricated ZnO films to exhibit the good hydrophilicity with water contact angle of c.a.

10 degree. These results would be attributed to the explanation of oxygen vacancy on the irradiated surface of photocatalytic film. Those oxygen vacancies are more favorable to hydroxyl adsorption, resulting in the spreading on water on the coated surface. However, existence of oxygen vacancies would not be stable unless the UV irradiation was not continuously applied onto the surface.

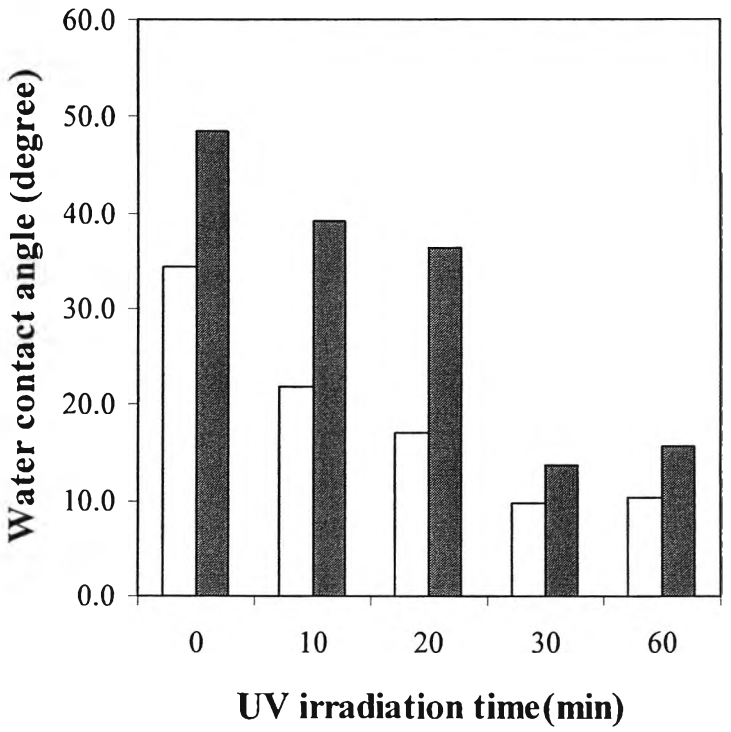


Figure 5.14 Durability of ZnO films under the alternation of UV irradiation and dark storage for seven days (□ ;UV irradiation, ▩ ; Dark storage)

5.6 Photoinduced hydrophilic property of multi-layer films

Finally, investigation on the effect of variation of number of coating layer on photoinduced hydrophilic property was also of interest in this thesis. Liu et al., (2002) suggested that TiO_2/SnO_2 composite thin films fabricated on glass substrate could reduce the contact angle with an increase in the number of coating layers. In this work, the number of coating layers was varied by varying the number of dipping cycles in a range of 1, 2 and 3 cycles. All films were prepared with zinc acetate concentration of 0.10 M, withdrawal speed of 3.0 cm/min and calcinations temperature of 500°C.

The average grain size and roughness of the ZnO films with different coating cycles are reported in Table 5.6. It could be seen that with an increase in the coating layers, the roughness and the average grain size of films significantly changed. Accordingly, considering the effect of coating layers on water contact angle shown in Fig. 5.15, it could be found that two or three coating layers could somehow provide lower water contact angle. Typical evidences of visual observations of water contact angles of two- and three-layer coating film are shown in Fig. 5.16. ZnO film coated with 2 and 3 cycles could exhibit highly hydrophilic property with the water contact angle of 2.2 and 3.7 degrees after UV irradiation for 10 min.

It has been demonstrated that transparent film of ZnO coated on glass substrates using sol-gel dip coating method could exhibit good photoinduced hydrophilic property. In summary based on all experimental results conducted in this work, the hydrophilicity of the fabricated ZnO films could be attributed to their relative roughness and grain size which are in turn affected by the precursor concentration, film dipping (withdrawal) speed, calcinations temperature and the number of coating layer.

Table 5.6 Properties of ZnO films prepared at different number of coating cycles

Number of coating cycle	R_{rms}(nm)	Average grain size(nm)	Relative roughness
1	2.1	18.0	0.117
2	2.1	16.0	0.131
3	2.7	16.0	0.169

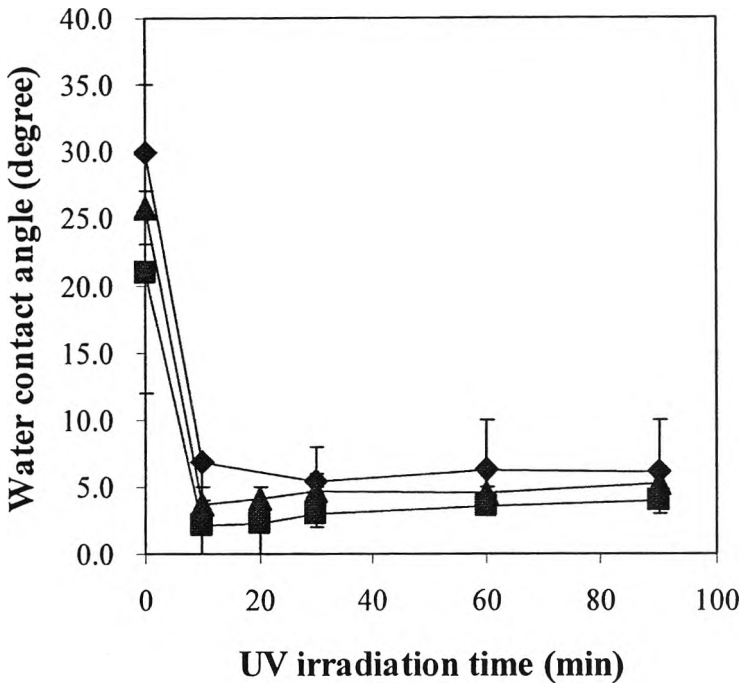
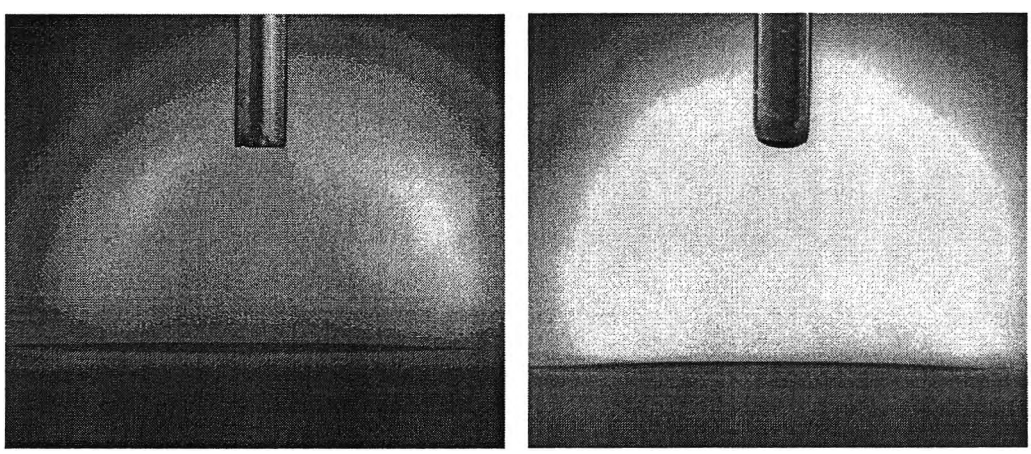


Figure 5.15 Number of coating cycles on water contact angle of ZnO films (◆ ;1 layer,■ ; 2 layers and ▲ ; 3 layers)



(a) **(b)**

Figure 5.16 Pictures captured during contact angle measurements, showing the water contact angles of ZnO thin film surfaces coated with (a) 2 layers and (b) 3 layers under UV irradiation for 10 min are 2.2 and 3.7 degrees, respectively