REFERENCES

Armelao, L., Fabrizio, M., Gialanella, S., and Zordan, F. Sol-gel synthesis and characterization of ZnO-based nanosystems. Thin solid films. 394 (2001): 90-96.

Berber, M., Bulto, V., Kliβ, R., and Hahn, H. Transparent nanocrystalline ZnO films prepared by spin coating. Scripta materialia. 53 (2005): 547-551.

Berg, J.C. Wettability. Washington: Washington University Press, 1993.

Bico, J., Uwe, T., and David, Q. Wetting of textured surfaces. Colloids and surface a: physicochemical and engineering aspects. 206 (2002): 41-46.

Binker, S. Sol-gel science: the physics and chemistry of sol-gel processing. Acadamic Press, 1990.

Carp, O., Huisman, C.L., and Reller, A. Photoinduced reactivity of titanium dioxide. Pregress in solid state chemistry. 32 (2004): 33-177.

Feng, X., Feng, L., Jin, M., Zhai, J., Jiang, L., and Zhu, D. Reversible super-hydrophobicity to super-hydrophilicity transition of aligned ZnO nanorod films. J/A/C/S COMMUNICATIONS. (2003).

Fujishima, A., Hashimoto, K., and Watanabe, T. TiO_2 photocatalyst fundamentals and applications. BKC. Tokyo 1999.

Fujishima, A., Rao, T.N., and Tryk, D.A. Titanium dioxide photocatalysis. Journal of photochemistry and photobiology c: photochemistry review. 1 (2000): 1-21.

Gao, X.D., Li, X.M., Yu, W.D., Li, L.L., Qiu, J.J., and Peng, F. Low-temperature deposition of transparent ZnO films by the ultrasonic-mediated stepwise method. Solar energy materials & solar cells. 91 (2007): 467-473.

Guan, K., Lu, B., and Yin, Y. Enhanced effect and mechanism of SiO_2 addition in super-hydrophilic property of TiO_2 films. Surface and coatings technology. 173 (2003): 219-223.

Gümüş, C., Ozkendir, O.M., Kavak, H., and Ufuktepe, Y. Structure and optical properties of zinc oxide thin films prepared by spray pyrolysis method. Journal of optoelectronics and advanced materials. 8 (2006): 299-303.

Guo, M., Diao, P., and Cai, S. Highly hydrophilic and superhydrophobic ZnO nanorod array films. Thin solid films. 515 (2007): 7162-7166.

Kita, H., Osumi, K., Iizuka, T., Fukushima, M., Yoshida, K., and Hyuga, H. Changes in microstructure and properties of ZnO-Added Al_2O_3 upon sliding. Journal of ceramic society of Japan. 114 (2006): 599-602.

Kontos, A.I., Kontos, A.G., Tsoukleris, D.S., Vlachos, G.D., and Falaras, P. Superhydrophilicity and photocatalytic property of nanocrystalline titania sol-gel films. Thin solid films. 515 (2007): 7370-7375.

Li, H., Wang, J., Liu, H., Yang, C., Xu, H., Li, X., and Cui, H. Sol-gel preparation zinc oxide films with highly preferential crystal orientation. Vacuum. 77 (2004): 57-62.

Lin, H., Feng, L., Zhai, J., Jiang, L., and Zhu, D. Reversible wettability of a chemical vapor deposition prepared Zno film between superhydrophobicity and superhydrophilicity. Langmuir. 20 (2004): 5659-5661.

Liu, Q., Wu, X., Wang, B., and Liu, Q. Preparation and super-hydrophilic properties of TiO_2/SnO_2 composite thin films. Materials research bulletin. 37 (2002): 2255-2262.

Maiti, U.N., Ghosh, P.K., Ahmed, Sk.F., and Mitra, M.K. Structure, optical and photoelectron spectroscopic studies of nano/micro ZnO:Cd rods synthesized via sol-gel route. Journal of sol-gel technology. 41 (2007): 87-92.

Ohyama, M., Kozuka, H., and Yoko, T. Sol-gel preparation of ZnO films with extremely preferred orientation along (002) plane from zinc acetate solution. Thin solid films. 306 (1997): 78-85.

Sharma, S.D., Singh, D., Saini, K.K., Kant, C., Sharma, V., Jain, S.C., and Sharma, C.P. Sol-gel-derived super-hydrophilic nickel doped TiO_2 film as active photo-catalyst. Applied catalysis a. 314 (2006): 40-46.

Shirtcliffe, N.J., McHale, G., Newton, M.I., Perry, C.C., Roach, P. Superhydrophobic transitions of sol-gel films for temperature, alcohol or surface measurement. Materials chemical and physics. 103 (2007): 112-117.

Sun, R.D., Nakajima, A., Fujishima, A., Watanabe, T., and Hashimoto, K. Photoinduced surface wettability conversion of ZnO and TiO_2 thin films. Journal of physical and chemical b. 105 (2001): 1984-1990.

Watanabe, T., Nakajima, A., Wang, R., Minabe, M., Koizumi, S., Fujishima, A., and Hashimoto, K. Photocatalytic activity and photoinduced hydrophilicity of titanium dioxide coated glass. Thin solid films. 351 (1999): 260-263.

Yimsiri, P., and Mackley, M.R., Spin and dip coating of light-emitting polymer solutions: matching experiment with modeling. Chemical engineering science. 61 (2006): 3496-3505.

APPENDICES

APPENDIX A

Publication of the research

Publication

International Research Paper

1. P. Numpud, T. Charinpanitkul and W. Tanthapanichakoon, "Photoinduced hydrophilic property of zinc oxide thin films prepared by sol-gel dip coating method," Journal of ceramic society of Japan, vol. 116, 2008, pp. 414-417.

International Proceeding

1. P. Numpud, T. Charinpanitkul and W. Tanthapanichakoon, "Photoinduced hydrophilic property of zinc oxide thin films prepared by sol-gel dip coating method," *Proceedings of International Conference on 7th Pacific Rim Conference on Ceramic and Glass Technology (PAC RIM 7)*, November 11-14, 2007, Shanghai, China, p.64.

7TH PACIFIC RIM CONFERENCE ON CERAMIC AND GLASS TECHNOLOGY

Organized & Sponsored by:

SICCAS Since 1928

Endorsed by:

The American Ceramic Society
The Australasian Ceramic Society
The Ceramic Society of Japan
The Korean Ceramic Society

PacRim 7 Abstract Book

11-14 Nov. 2007

Shanghai, China
Shanghai International Convention Center

Session Chair: Shu Yin, Tohoku University, Japan

S1-35-O, Nov. 14, 15:20-15:40

Improvement Photoinduced Hydrophilic Property of Glass by Zinc Oxide Thin Film Prepared by Sol-Gel Method

P. Numpud,*[1] W. Tanthapanichakoon[2] and T. Charinpanitkul[1]
[1]Chulalongkorn University, Thailand; [2]National Nanotechnology Center (NANOTEC), Thailand

ZnO thin film could be fabricated on soda lime glass substrates by sol-gel dip coating method. The ZnO thin films which are synthesized by using the concentration of zinc acetate ranged 0.02 to 0.75 mol/L, withdrawal speed ranged 0.16 to 2.00 mm/s and heated at 773 K have been experimentally investigated. The transparent and hydrophilic properties of ZnO thin film have been characterized by UV-VIS spectrophotometer and contact angle measurement, respectively. As a preliminary result, the decreasing withdrawal speed could result in a decrease in film thickness and photoinduced hydrophilicity.

S1-36-O, Nov. 14, 15:40-16:00

Synthesis and Photochemical Properties of La-doped $HCa_2Nb_3O_{10}$

Y. F. Huang,* J. H. Wu, Y. M. Xie, J. M. Lin, M. L. Huang and Y. L. Wei
Huaqiao University, China

The photocatalysts series $HCa_2Nb_3O_{10}$ doped with La^{3+} were synthesized by conventional solid state method followed by an ion-exchange reaction. The samples were characterized by power X-ray diffraction, UV-vis diffusive reflectance and scan electron microscope. The influence of substitution of La^{3+} for Ca^{2+} in $HCa_2Nb_3O_{10}$ had been studied on the photocatalytic decomposition of water under UV light irradiation (more than 290 nm) with methanol as electron donor and Pt as promoter catalyst. Both the optical property and photocatalytic activity of $H_{1-x}Ca_{2-x}Nb_3La_xO_{10}$ are varied by the substitution of La for Ca. As La content increased the band gap and light response range are changed, which have a positive effect on the photocatalytic activity in the water splitting reaction. The results show that the doping of La improves the photocatalytic activity of $HCa_2Nb_3O_{10}$, the difference of photocatalytic activity among them is also discussed.

S1-37-O, Nov. 14, 16:00-16:20

Crystal Structure and Raman Spectroscopy Analysis of Sm and Ce Double-Atom Filled Skutterudites

T. X. Liu* and X. F. Tang
Wuhan University of Technology, China

Polycrystalline double-atom filled skutterudites $Sm_mCe_nFe_xCo_{4-x}Sb_{12}$ have been characterized by the Rietveld refinement and Raman spectra. The results of Rietveld refinement demonstrated that the obtained $Sm_mCe_nFe_xCo_{4-x}Sb_{12}$ compounds possess a filled skutterudite structure. The thermal parameter (B) of Sm/Ce is larger than that of Sb, Fe and Co, indicating that Sm and Ce "rattles" in Sb-icosahedron voids. In comparison with the Sm or Ce filling, the Sm and Ce double filling can enlarge the thermal parameter (B). Raman spectroscopy investigation shows that the filling atoms Sm and Ce in voids interrelate with some of the lattice vibrations in the skutterudite structure and lead to a shift and broadening of the Sb_4 ring breathing modes. In comparison with the Sm or Ce filling, the Sm and Ce double filling can increase the extent of move and widening of the observed lines.

S1-38-O, Nov. 14, 16:20-16:40

Fabrication of Mg_2Si Thermoelectric Generator by Spark Plasma Sintering

L. M. Zhang,* M. J. Yang, L. Q. Han, Q. Shen and C. B. Wang
Wuhan University of Technology, China

Elemental Mg and Si powders were used to fabricate Mg_2Si bulk thermoelectric generator by Spark Plasma Sintering (SPS). Mg_2Si bulk was synthesized and sintered simultaneously at a low temperature (550°C) and a high pressure (>100MPa). However, the product could not densified with some micro-cracks on the surface, and the reaction between Mg and Si was not complete. Then Mg and Si reacted at 550°C to synthesis Mg_2Si powders, and the produced powers were further densified by SPS under 750°C -20MPa. The sample had a high relative density (nearly 100%) containing pure Mg_2Si phase, and the Mg_2Si grains were fine and homogeneous. The power factor of the Mg_2Si bulk thermoelectric generator was 9.57×10^{-4} W/mK^2 at 700°C.

Poster Session

Nov. 13, 13:30-17:30

S1-39-P

Fabrication of ZnO Nanotubes by Template-Wetting Process

U. A. Shaislamov,*[1] G. Komilkhon,[1] S. I. Kim,[1] S. W. Kim,[1] J. M. Yang,[2] S. K. Hong[3] and B. Yang[1]
[1]Kumoh National Institute of Technology, Korea; [2]National Nanofab Center, Korea; [3]Hynix Semiconductor Inc., Korea

Recently, considerable research efforts have been focused on fabrication and characterization of one-dimensional (1D) nanomaterials because of their fundamental importance in physics and potential applications for realizing nano-devices. ZnO is recognized as a promising material for short-wavelength optoelectronic applications because

Journal of the Ceramic Society of Japan 116 [3] 414-417 2008 **Paper**

Photoinduced hydrophilic property of zinc oxide thin films prepared by sol-gel dip coating method

P. NUMPUD, T. CHARINPANITKUL[†] and W. TANTHAPANICHAKOON[*]

Center of Excellence in Particle Technology, Department of Chemical Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok 10330, Thailand
[*]National Nanotechnology Center, National Science and Technology Development Agency Thailand Science Park, Thailand

ZnO thin films could be fabricated on soda lime glass substrates by sol-gel dip coating method. The thin films fabrication conditions were zinc acetate concentration of 0.10–0.50 × 10^3 mol/m^3, withdrawal speed of 0.5–1.5 × 10^{-3} m/s and calcination temperature of 500°C. The film characteristics (roughness, transparency and photoinduced hydrophilicity) were characterized by atomic force microscopy, UV-vis spectrophotoscopy and contact angle analyzer, respectively. It was found that the decreasing withdrawal speed of the coated film using 0.10 × 10^3 mol/m^3 zinc precursor could result in a decrease in the film thickness and the film roughness, consequently leading to highly photoinduced hydrophilicity.

Key-words : Hydrophilic, Zinc oxide, Sol-gel, Dip coating

[Received November 18, 2007; Accepted February 21, 2008]

1. Introduction

The hydrophilicity of substrate surface refers to a physical property that can transiently bond with water through hydrogen bonding, leading to spreading of water across the surface rather than remaining as droplets. Normally hydrophilicity could be achieved after UV irradiation to substrate surface coated with some specific semiconductor. This property could physically be indicated by water contact angle. A surface with water contact angle lower than 10° is classified as highly hydrophilic surface while a highly hydrophobic surface will show water contact angle higher than 150°.

Zinc Oxide (ZnO) is of great interest due to its unique optical, electrical and photo-catalyst properties.[1)-5)] ZnO thin film can be coated on glass or plastic substrate with excellent transparency, which will not obstruct the substrate optical visibility, and can provide photoinduced hydrophilic function. Sol-gel method is widely employed for preparing ZnO because of its simplicity, safety and low cost. Moreover, incorporation of dip coating method could simply provide a smooth thin film of ZnO on substrate with large area. Sun et al.[2)] reported that UV irradiation can generate electron-hole pairs on substrate surface coated with ZnO and leads to hydrophilic property due to some of the holes reacting with lattice oxygen to produce surface oxygen vacancies. However, there is a remaining issue that preferential adsorption of water on the coated surface cannot last long and reversibly turns to its initial condition after storage in the dark.[6)-9)]

The main purpose of the present work was to investigate the photoinduced hydrophilic property of glass substrate coated with ZnO thin film which was prepared by sol-gel process incorporated with dip coating technique. The hydrophilic surface was characterized by AFM, contact angle measurement and UV-vis spectroscopy. The effect of withdrawal speed and precursor concentration on the transmittance of the ZnO thin film was consequently investigated for finding systematic means to improve preparation of highly hydrophilic coated glass substrate.

2. Experimental

Starting precursor was prepared using zinc acetate (95% purity, M = 219.49, $Zn(CH_3COO)_2.2H_2O$, Ajax Chemfine Australia), absolute ethanol (99.99% purity, M = 46.07, CH_3CH_2OH, Merck), acetic acid (99.9% purity, M = 46.07, CH_3COOH, Merck) and deionized water. The zinc acetate was dissolved in 0.05 × 10^{-3} m^3 of absolute ethanol at room temperature. Deionized water and acetic acid were respectively added to the mixture solution with molar ratio of 2:1 and 0.01:1 with respect to the zinc acetate molar concentration. Then the solution was subject to heating at 60°C with magnetic stirring for 3600 s until a transparent and homogeneous solution was obtained. The concentration of zinc acetate was varied from 0.10 to 0.50 × 10^3 mol/m^3. Then thin film was deposited on cleaned glass substrate (0.25 mm × 0.30 mm × 0.01 mm) by the dip coating technique, in which the glass was immersed into the precursor solution for a certain period of 30 s and then withdrawn from the solution with a different withdrawal speed (0.5, 1.0 or 1.5 × 10^{-3} m/s) under ambient condition by a step motor. The coated film was calcined in air at a heating rate of 0.05°C/s and held for 3600 s at 500°C. A UV-A lamp (SAPHIT A.J.L. Supplies, Thailand) with emission wavelength in a range of 300–460 nm and output of 20 W is employed to irradiate each coated glass specimen in priori to water contact angle investigation. Optical transmission of the ZnO thin films were characterized by comparison with uncoated substrate using a Perkin-Elmer Lambda 650 UV-Vis spectrophotometer. The particle size, roughness and uniformity of ZnO constituting in the films were characterized by an atomic force microscopy (AFM). The hydrophilicity of the thin films was then examined by measuring the contact angle of water droplets by a contact angle meter. Water droplets with consistent volume of 0.012 × 10^{-6} m^3 were placed at five difference positions on

[†] Corresponding author: E-mail: ctawat@chula.ac.th

(a)

(b)

(c)

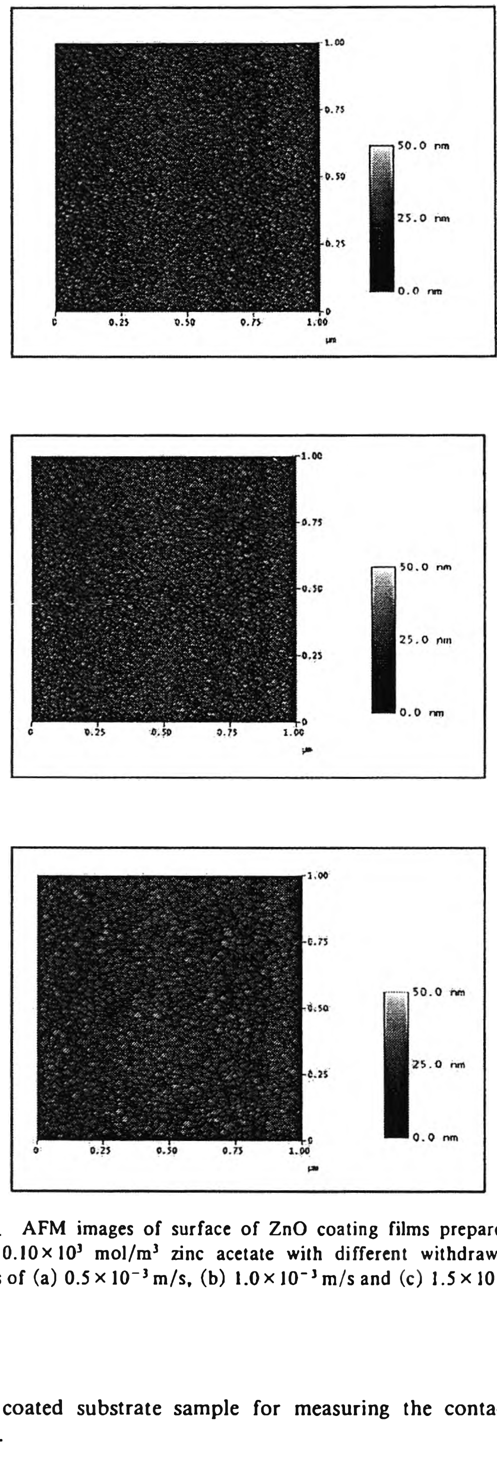


Fig. 1. AFM images of surface of ZnO coating films prepared from 0.10×10^3 mol/m^3 zinc acetate with different withdrawal speeds of (a) 0.5×10^{-3} m/s, (b) 1.0×10^{-3} m/s and (c) 1.5×10^{-3} m/s.

each coated substrate sample for measuring the contact angle.

3. Results and discussion

Figures 1a, b and c represent typical AFM images of the morphology of ZnO thin films prepared from 0.10×10^3 mol/m^3 zinc acetate with three different withdrawal speeds of 0.5, 1.0 and 1.5×10^{-3} m/s, respectively. It could be clearly observed that the grain size depends on the withdrawal speed. The grain sizes of ZnO in the coated films prepared from the same zinc acetate concentration are 18.0, 19.5, 23.0

Table 1. Surface Roughness and Average Grain Size of ZnO thin Films with Different zinc Acetate Concentrations and Withdrawal Speeds

Zinc acetate concentration ($\times10^3$ mol/m^3)	withdrawal speed ($\times10^{-3}$ m/s)	R_{rms} (nm)	average grain size (nm)
0.10	0.5	2.1	18.0
	1.0	2.4	19.5
	1.5	2.2	23.0
0.25	0.5	3.7	19.0
	1.0	3.2	25.5
	1.5	9.2	29.0
0.50	0.5	4.3	22.5
	1.0	4.6	20.5
	1.5	5.5	26.0

nm as shown in Fig. 1a, b, and c, respectively. The surface roughness and average grain size of the ZnO thin films with different zinc acetate concentration of 0.10, 0.25, 0.50×10^3 mol/m^3 and different withdrawal speed were also summarized in **Table 1**. It was found that with the highest concentration of 0.50×10^3 mol/m^3 the surface roughness mean square (rms) 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 0.5 to 1.5×10^{-3} m/s, respectively. The increase in film thickness which is subject to the withdrawal speed is attributed to competitive effects of gravitational and frictional viscous forces acting on the liquid coating film and evaporation of solvent.[10)-12)]

Figure 2 reveals the optical transmittance spectra of the ZnO films coated on glass substrates using zinc acetate concentration of 0.10 and 0.50×10^3 mol/m^3 with different withdrawal speed of 0.5, 1.0 and 1.5×10^{-3} m/s. All of the fabricated films exhibited transmittance of above 90% with respect to the range of visible light (400–700 nm), pointing out the evidence of their superior transparency. Meanwhile, it could also be seen that all coated substrates exhibited remarkable ultraviolet absorption at around 380 nm, which is attributed to the intrinsic band gap of ZnO. Lee et al confirmed that ZnO fine particles synthesized by sol-gel method contain ionized oxygen vacancy which could emit photons with specific wavelength of ~500 nm depending on their crystal structure.[13)] In our investigation change of withdrawal speed provides an appreciable effect on the transmittance of the coating film because there was difference in the grain size of ZnO film on each substrate. With 0.10×10^3 mol/m^3 zinc acetate, substrates with thicker coating layer could somehow absorb ultraviolet spectra with higher intensity. This result is in good agreement with that of Berber et al even though they used spin coating technique to prepare the ZnO thin film.[5)] However, it is interesting that with 0.50×10^3 mol/m^3 zinc acetate, the different trend could be observed. Significantly low transmittance and transparency compared with those of 0.10×10^3 mol/m^3 zinc acetate would be attributed to the increasing crystallinity due to the higher concentration.

To examine the hydrophilicity of the coated glass substrates, average water contact angle is plotted against the UV irradiation time as shown in **Fig. 3**. When 0.10×10^3 mol/m^3

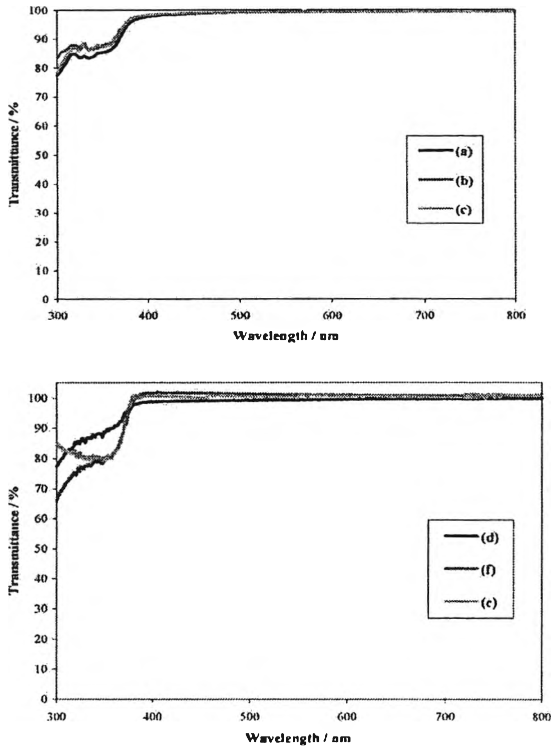


Fig. 2. Optical transmittance spectra of ZnO films prepared by dip coating. Above: in 0.10×10^3 mol/m^3 of zinc acetate with withdrawal speed of (a) 0.5×10^{-3} m/s, (b) 1.0×10^{-3} m/s and (c) 1.5×10^{-3} m/s, Below: in 0.50×10^3 mol/m^3 of zinc acetate with withdrawal speed of (d) 0.5×10^{-3} m/s, (e) 1.0×10^{-3} m/s and (f) 1.5×10^{-3} m/s.

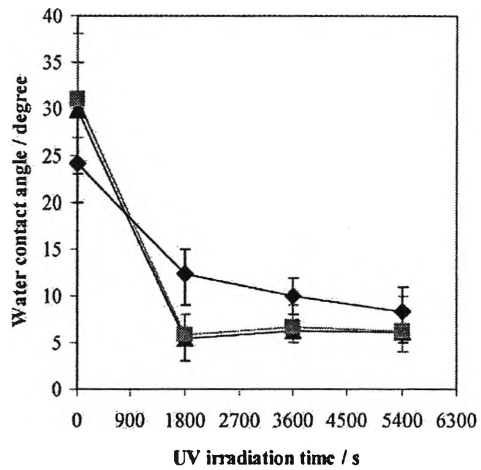


Fig. 3. Dependence of water contact angle of ZnO films on UV irradiation time (▲; withdrawal speed $= 0.5 \times 10^{-3}$ m/s, ■; withdrawal speed $= 1.0 \times 10^{-3}$ m/s and ◆; withdrawal speed $= 1.5 \times 10^{-3}$ m/s).

zinc acetate was prepared to coat on the glass substrate with different withdrawal speed of 0.5, 1.0, 1.5×10^{-3} m/s, it

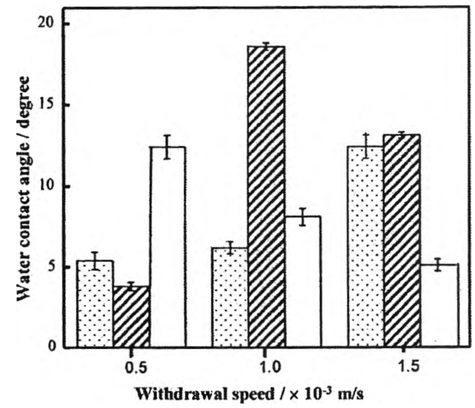


Fig. 4. Effect of precursor concentration on water contact angle of the coated film after UV irradiation for 1,800 s (⬚; zinc acetate concentration $= 0.10 \times 10^3$ mol/m^3, ▨; zinc acetate concentration $= 0.25 \times 10^3$ mol/m^3 and □; zinc acetate concentration $= 0.50 \times 10^3$ mol/m^3).

could be observed that highly hydrophilic substrates with the water contact angle lower than 5° could be obtained with UV irradiation for only 1800 s. As the whole tendency, the longer the UV irradiation time was spent, the lower the water contact angle was achieved. Therefore, with the lowest withdrawal speed of 0.1×10^{-3} m/s the average water contact angle became significantly smaller. This would be attributable to the formation of thinner coating film containing smaller crystal which could adsorb more UV, resulting in higher hydrophilicity.

The effect of concentration of zinc acetate precursor on the water contact angle of the coating films is depicted in **Fig. 4**. As suggested by the experimental results shown in Fig. 3, all the substrates were prepared using different concentration of zinc acetate and different withdrawal speed with a constant UV irradiation time of 1,800 s. However, the whole experimental results suggested the complicated dependence of the water contact angle on the film preparing parameters. When the 0.10×10^3 mol/m^3 zinc acetate precursor was employed the increasing withdrawal speed gave rise to worse hydrophilicity which was indicated by the higher water contact angle. This might be attributable to the increasing grain size and surface roughness, which could also be confirmed in Fig. 1. However, with the highest precursor concentration of 0.50×10^3 mol/m^3, opposite trend of the contact angle decreasing with the increasing withdrawal speed was observed. As already mentioned, the coated surface roughness increased with the increasing withdrawal speed. The hydrophilicity of the coated film would be controlled by both physical and chemical factors, which include change of surface roughness due to physical grain growth and change in surface polarity due to chemical adsorption.[14] The remaining issues would be how the hydrophilicity could be improved and kept longer after UV irradiation. Functional groups containing stronger hydrogen bonding would have to be taken into account to explain how dissociative adsorption of water molecules on the defective sites of UV-induced surface contributes to the formation of superior hydrophilic ZnO coated surface.

4. Conclusion

With sol-gel dip coating method, zinc acetate could be used for preparing transparent ZnO film coated on glass substrates. All ZnO films coating on glass substrates could exhibit the excellent transparency with 90% visible light transmittances. It was also found that the ZnO grain size, surface roughness and hydrophilicity of the coating films were crucially affected by the precursor concentration and withdrawal speed. With UV irradiation for 1,800 s, the highly hydrophilic ZnO thin films could be prepared. With the zinc acetate concentration of 0.10×10^3 mol/m^3, the lower withdrawal speed would lead to the thicker and rougher coating film with the water contact angle of 5°, which exhibited better hydroplicity.

Acknowledgement This work is a part of self-cleaning glass project which is supported by National Nanotechnology Center, National Science and Technology Development Agency. Also, partial support of Silver Jubilee Fund of Chulalongkorn University to Center of Excellence in Particle Technology is gratefully acknowledged.

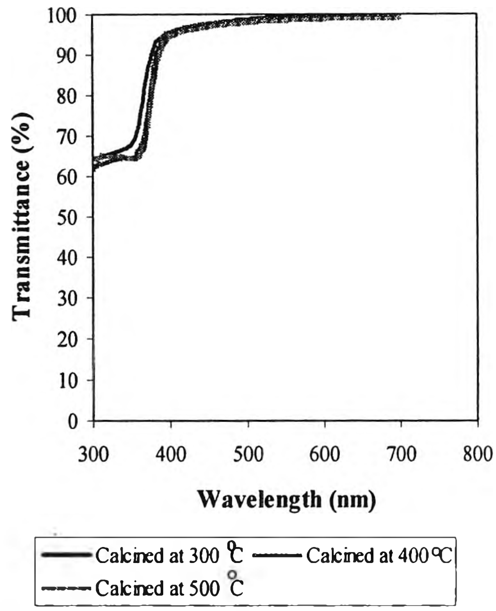
References

1) G. Kaishu, *Surface & Coating Technology*, 191, 155‐160 (2005).
2) R. D. Sun, A. Nakajima, A. Fujishima, T. Watanabe and K. Hashimoto, *J. Phys. Chem. B*, 105, 1984‐1990 (2001).
3) C. Y. Kim, B. S. Kim, J. W. Choi, D. K. Choi and T. Y. Lim, *J. Ceram. Soc. Japan*, 112, 244‐247 (2004).
4) X. Feng, L. Feng, M. Jin, J. Zhai, L. Jiang and D. Zhu, *J/A/C/S communications* (2003).
5) M. Berber, V. Bulto, R. KloB and H. Hahn, *Scripta Material*, 53, 547‐551 (2005).
6) Q. Yu, H. Yang, W. Fu, L. Chang, C. Yu, R. Wei, K. Du, M. Li and G. Zou, *Thin Solis Films*, 515, 3840‐3843 (2007).
7) T. Watanabe, A. Nakajima, R. Wang, M. Minabe., S. Koizumi, A. Fujishima and K. Hashimoto, *Thin Solid Films*, 351, 260‐263 (1999).
8) Y. K. Du, Y. Q. Gan, P. Yang, F. Zhao, N. P. Hua and L. Jiang, *Thin Solid Films*, 491, 133‐136 (2005).
9) S. Sharma, D. Singh, K. K. Saini, C. Kant, V. S harma, S. C. Jain and C. P. Sharma, *Appl. Catal. A*, 314, 40‐46 (2006).
10) P. Yimsiri and M. R. Mackley, *Chem. Eng. Sci.*, 61, 3496‐3505 (2006).
11) C. J. Brinker and G. W. Scherer, Sol-gel Science, Academic Press New York (1990). pp. 790‐799.
12) M. Ohyama, H. Kozuka and T. Yoko, *Thin Solid Films*, 306, 78‐85 (1997).
13) G. H. Lee, N. Iwata, S. J. Kim and M. S. Kim, *J. Ceram. Soc. Japan*, 113, 64‐66 (2005).
14) H. Kita, K. Osumi., T. Iizuka., M. Fukushima., K. Yoshida. and H. Hyuga, *J. Ceram. Soc. Japan*, 114, 599‐602 (2006).

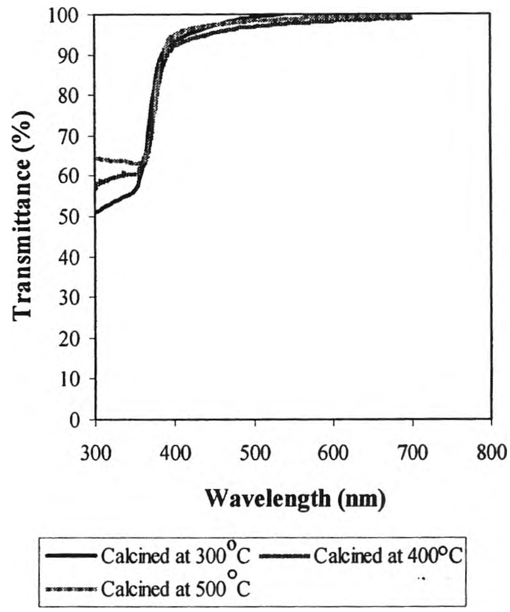
APPENDIX B

Experimental results

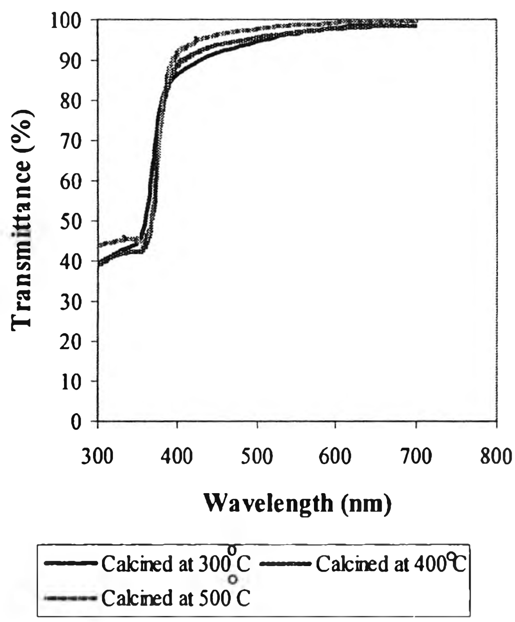
Part A: Effect of solvents and preparation condition on thin film properties



(a)



(b)



(c)

Figure B1 Optical transmittance spectra of ZnO films prepared with zinc acetate concentration of 0.75 M and calcined temperatures at 300°, 400°, 500°C and coated at withdrawal speeds of (a) 1.0 cm/min, (b) 3.0 cm/min and (c) 6.0 cm/min

Appendix B1 The elemental of ZnO film coated on glass substrates (zinc acetate concentration of 0.75 M, coated at different withdrawal speeds, calcined at 500°C) and glass substrate using as standard

Element	WS=1.0cm/min		WS=3.0 cm/min		WS=6.0cm/min		standard	
	wt%	atomic%	wt%	atomic%	wt%	atomic%	wt%	atomic%
C	8.06	14.17	6.52	11.79	6.75	11.87	6.97	6.97
O	35.00	46.19	32.98	44.78	34.18	45.12	69.54	69.54
Na	7.57	6.96	8.62	8.15	8.59	7.89	7.97	7.97
Mg	2.01	1.75	2.12	1.90	2.49	2.17	1.91	1.91
Al	0.85	0.66	1.08	0.87	0.92	0.72	1.52	1.52
Si	33.11	24.89	34.26	26.50	37.22	27.98	12.09	12.09
Ca	5.12	2.70	5.90	3.20	5.26	2.77	-	-
Zn	8.28	2.68	8.51	2.83	4.59	1.48	-	-

WS = withdrawal speed

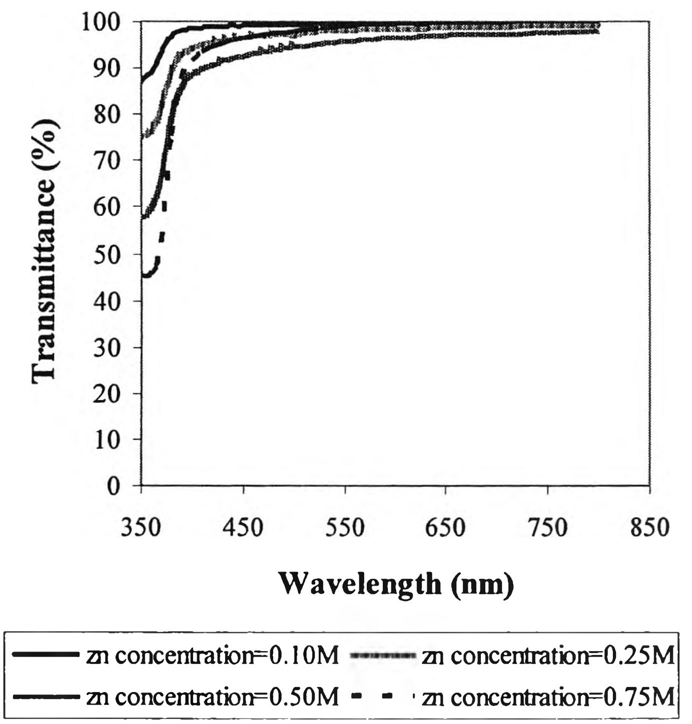


Figure B2 Optical transmittance spectra of ZnO films prepared withdrawal speed of 6.0cm/min, calcined temperature at 500°C and difference precursor concentration

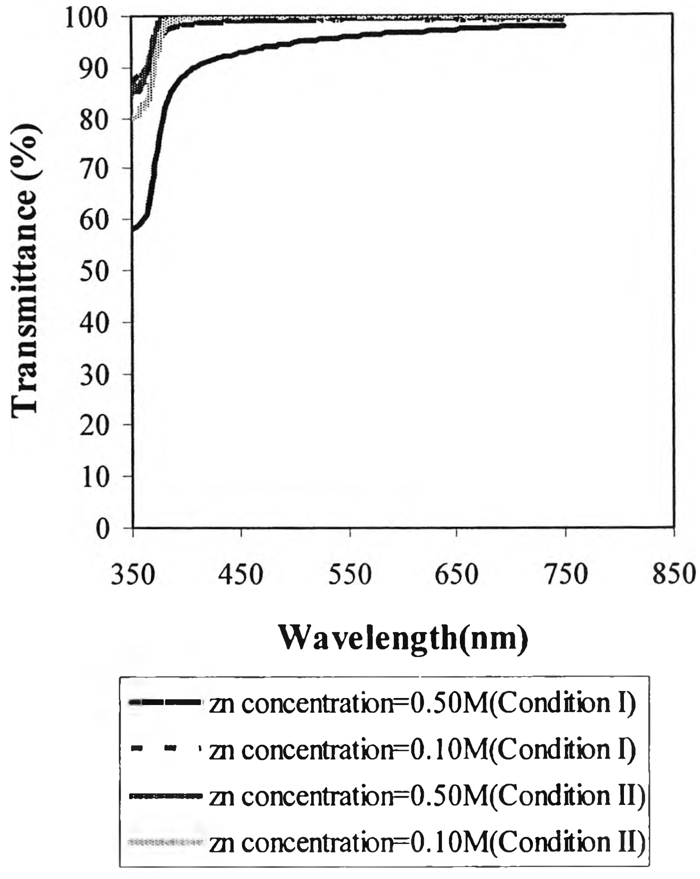


Figure B3 Optical transmittance spectra of ZnO films prepared with different solvents and precursor concentrations and withdrawal speed of 3.0 cm/min and calcined temperature at 500°C

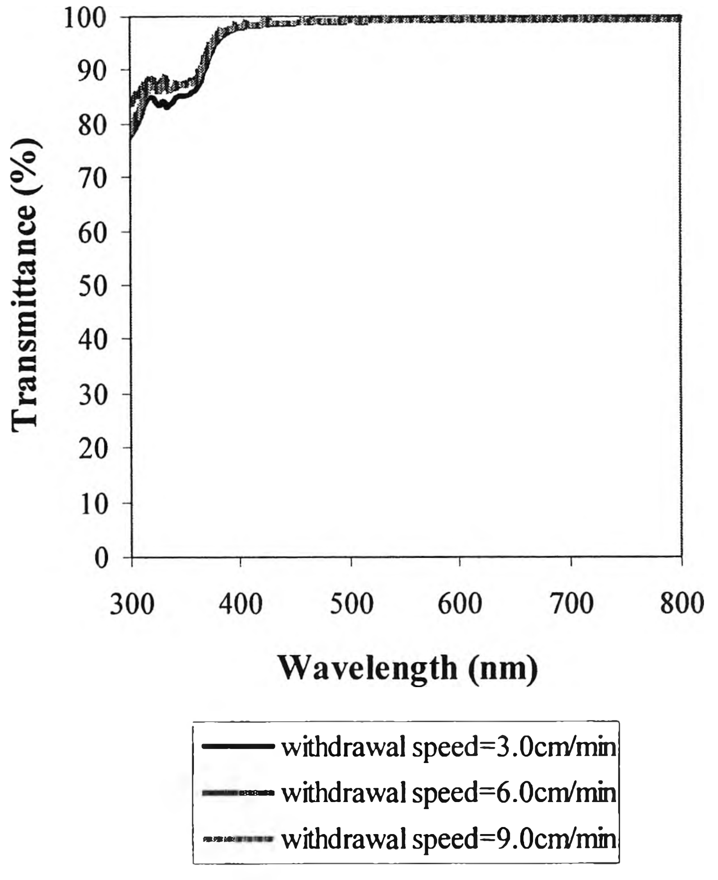


Figure B4 Optical transmittance spectra of ZnO films prepared zinc acetate concentration of 0.10 M coated at different withdrawal speeds and calcined temperature at 500°C

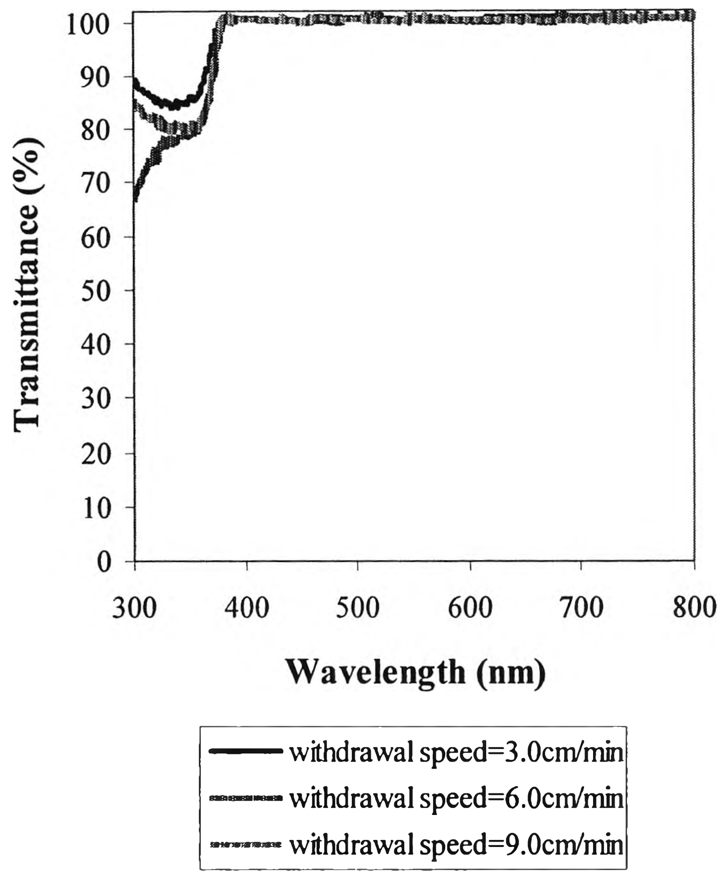


Figure B5 Optical transmittance spectra of ZnO films prepared zinc acetate concentration of 0.50 M coated at different withdrawal speeds and calcined temperature at 500°C

Appendix B2 Comparison the transmittance of ZnO films using air and glass substrate as reference

Solvent	Calcined at temperature (°C)	Average transmittance (%) (400-700nm) (ref.=air)	Average transmittance (%) (400-700nm) %T=%(T_s/T_g) (ref.=air)	Average transmittance (%) (400-700nm) (ref.=glass)
2-methoxyethanol	300	85.5	93.4	95.5
	400	86.3	94.3	96.1
	500	87.2	95.3	98.0
ethanol	500	90.8	99.2	99.5

%T of glass substrate = 91.5% (ref.=air)

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

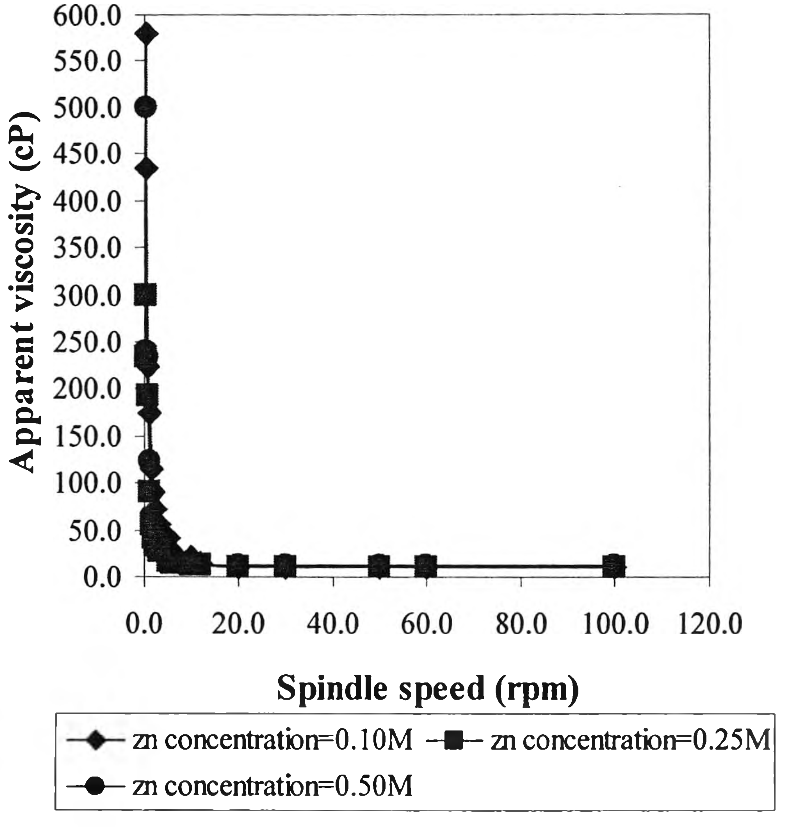
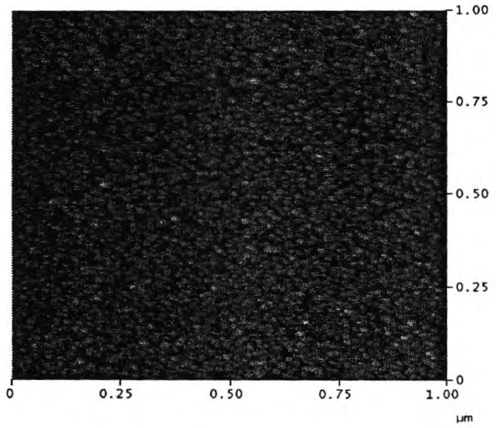
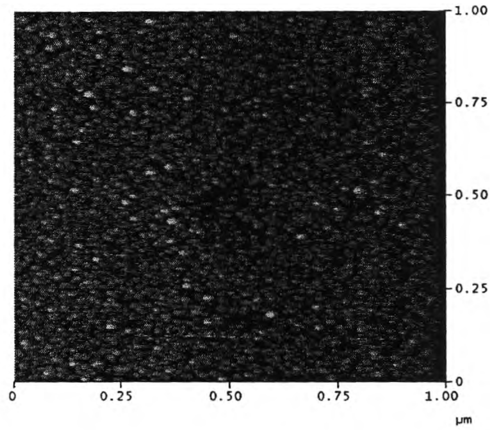


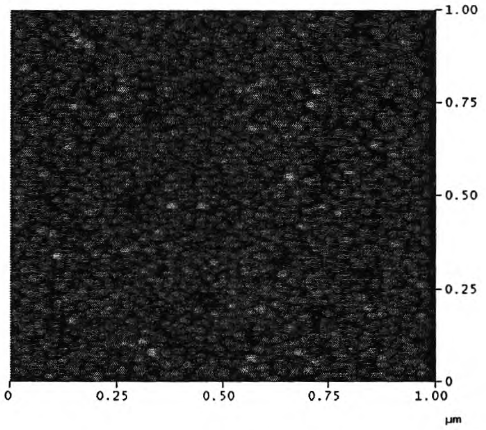
Figure B6 The effect of spindle speed on the viscosity of the precursor with different concentrations



(a)

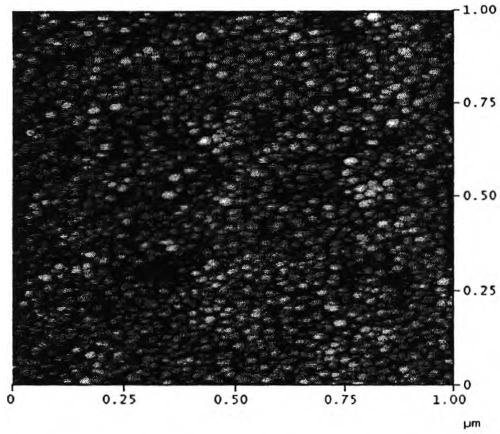


(b)

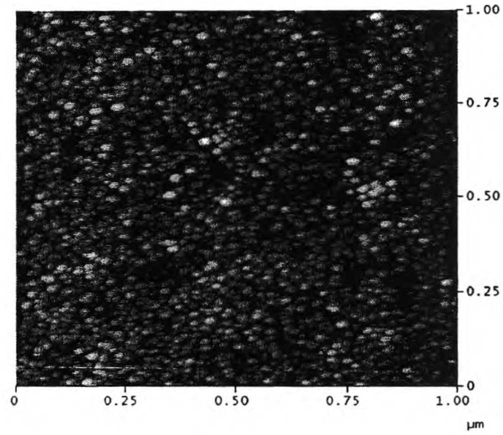


(c)

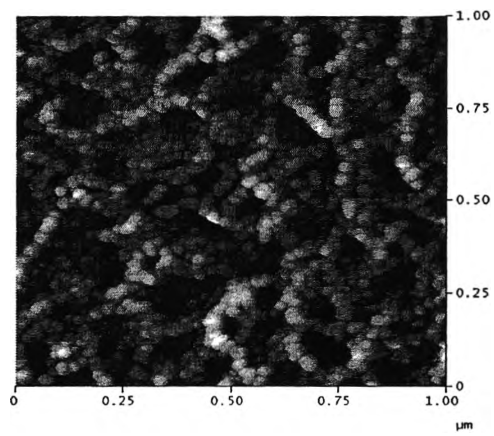
Figure B7 AFM images of surface of ZnO coating films prepared from zinc acetate concentration of 0.10 M with different withdrawal speeds of (a) 3.0 cm/min, (b) 6.0 cm/min and (c) 9.0 cm/min



(a)

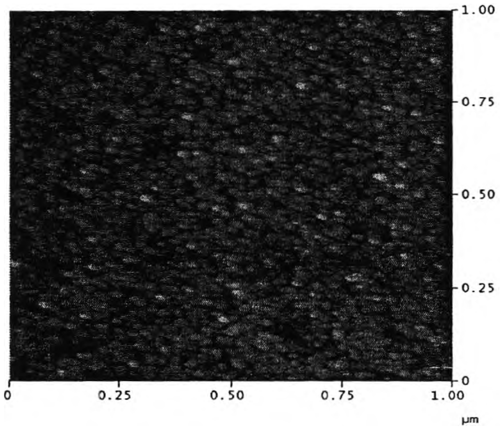


(b)

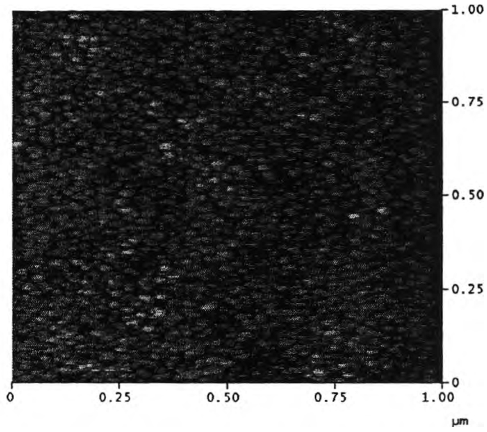


(c)

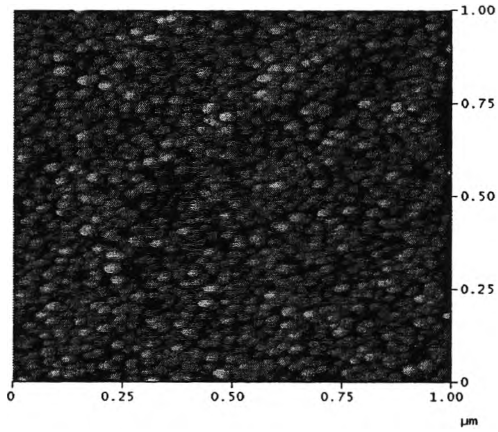
Figure B8 AFM images of surface of ZnO coating films prepared from zinc acetate concentration of 0.25 M with different withdrawal speeds of (a) 3.0 cm/min, (b) 6.0 cm/min and (c) 9.0 cm/min



(a)

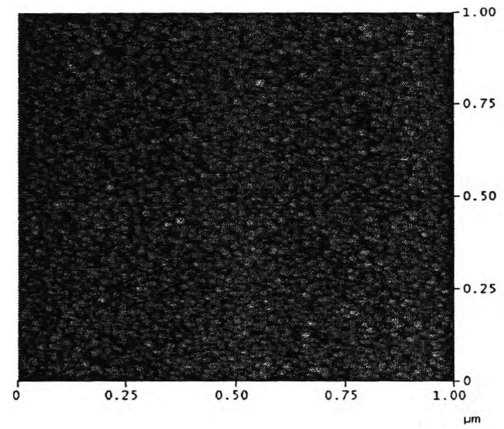


(b)

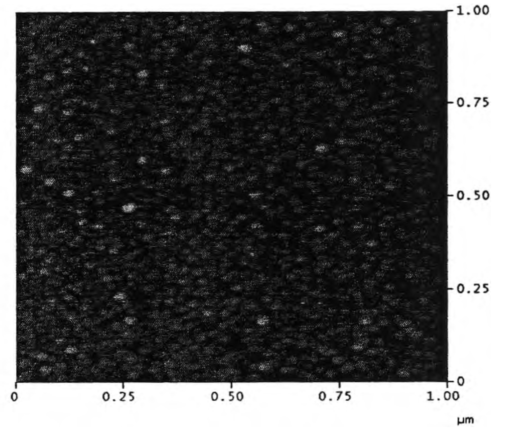


(c)

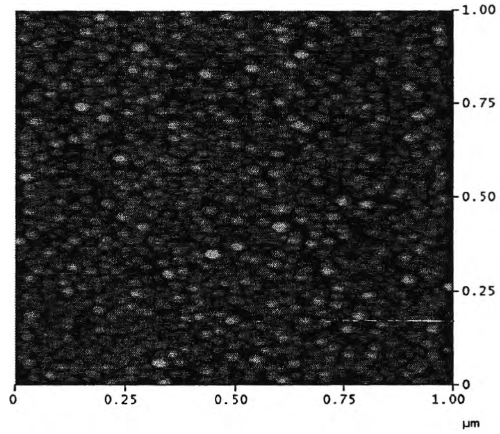
Figure B9 AFM images of surface of ZnO coating films prepared from zinc acetate concentration of 0.50 M with different withdrawal speeds of (a) 3.0 cm/min, (b) 6.0 cm/min and (c) 9.0 cm/min



(a)



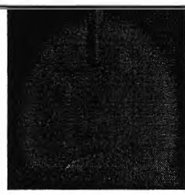
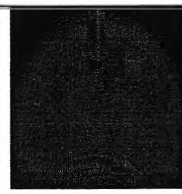
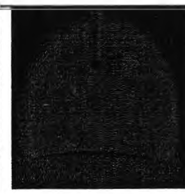
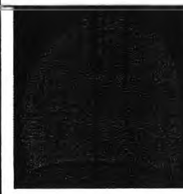
(b)



(c)

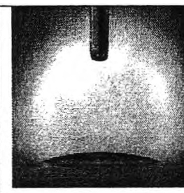
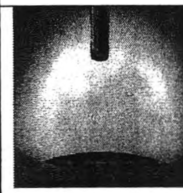
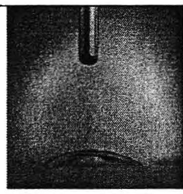
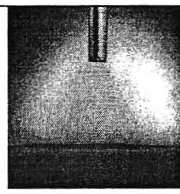
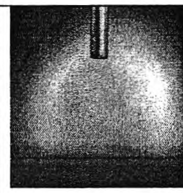
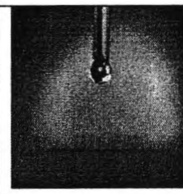
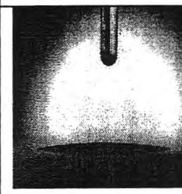
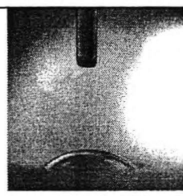
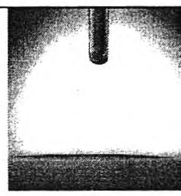
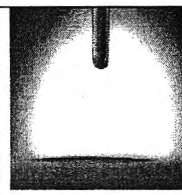
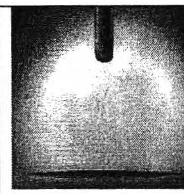
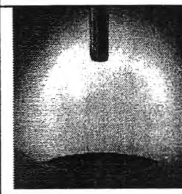
Figure B10 AFM images of surface of ZnO coating films prepared from zinc acetate concentration of 0.10 M with withdrawal speeds of 3.0 cm/min and different number of coating cycles (a) 1 layer, (b) 2 layers and (c) 3layers

Appendix B2 Durability of ZnO films under the alternation of UV irradiation and dark storage for 7 days

	UV irradiation time (min)				
	0 min	10 min	20 min	30 min	60 min
UV irra-dia-tion	-	-	-		
θ(°)	34.4±2.4°	21.9±5.8°	17.1±6.1°	9.8±2.9°	10.4±3.7°
In dark					
θ(°)	48.5±2.2°	42.3±7.2°	36.3±8.5°	13.7±3.2°	15.7±2.3°

θ = water contact angle

Appendix B3 Number of coating cycles on water contact angle of ZnO films

Number of coating cycles	UV irradiation time (min)				
	0 min	10 min	20 min	30 min	60 min
1	-	-	-		
θ(°)	29.9±3.7°	6.8±1.5°	5.4±1.2°	6.2±1.3°	6.1±1.4°
2					
θ(°)	20.9±4.8°	2.2±1.1°	2.3±0.9°	3.0±0.9°	3.6±0.8°
3					
θ(°)	25.8±3.0°	3.7±1.0°	4.1±1.1°	4.7±1.0°	5.0±2.4°

θ = water contact angle

VITA

Miss Paweena Numpud was born in Trang, Thailand, on March 28, 1983. She studied in primary and secondary educatuions at Hui Yot School. In 2005, she received the degree of Bachelor of Science in Chemical Science from Prince of Songkla University. After that, she continued to study the degree of Master of Chemical Engineering Department, Faculty of Engineering, Chulalongkorn University with the master thesis entitled “Zinc oxide thin film prepared by sol-gel process for improving photoinduced hydrophilic property of glass”. She received financial support from National Nanotechnology Center which covered research materials and monthly expenses.