J. Phys. D: Appl. Phys. **31** (1998) L71–L72. Printed in the UK PII: S0022-3727(98)95385-2

RAPID COMMUNICATION

On the transmittance properties of electrolytically deposited thin zinc oxide films

F Ng-Cheng-Chin, M Roslin, Z H Gu and T Z Fahidy†

Department of Chemical Engineering, University of Waterloo, Waterloo, ON, N2L 3G1, Canada

Received 29 June 1998, in final form 11 August 1998

Abstract. The effect of incident radiation in the ultraviolet-to-visible light transition region on the transmittance properties of thin zinc oxide layers deposited electrolytically on ITO-coated glass substrates has been studied and the optical band gap–layer thickness relationship has been established. The results indicate the viability of a low-temperature deposition process yielding transmittance properties comparable to those exhibited by conventionally obtained ZnO layers.

In recent years, a relatively new, low-temperature technique based on the cathodic deposition of various oxides allowing *in situ* doping [1] has been adapted [2–4] to ZnO deposition from an aqueous nitrate solution. This rapid communication summarizes the results of a subsequent study [5] in which transmission measurements on zinc oxide deposited electrolytically on ITO-coated glass in the transitional region between UV and the visible spectrum [6, 7] were carried out. ZnO was deposited onto a single face of 25 mm $\times$ 52 mm flat ITO-coated 3 mm thick glass slides from a 0.075 mol dm^{-3} aqueous zinc nitrate solution maintained at pH 6 and 65 °C. The cathode potential was controlled in the range 700–950 mV by a PINE potentiostat linked to a microcomputer through an OPTO-22 interface. The transmittance was measured with an HP 8452A diode array spectrophotometer and wavelength scanning from 190 to 500 nm was carried out by a dual-beam spectrophotometer.

Table 1 illustrates the beneficial effect of the deposition potential and the duration of deposition on the radiation absorption. Slight variations in the case of bare ITO-coated glass are due to slight structural differences among the specimens. Experimental observations also indicate that wavelengths associated with the appearance of the absorption edge are consistently higher when a ZnO layer is present and that the onset of absorption edges occurs at somewhat lower wavelengths than 375 nm when ZnO is deposited via spray pyrolysis [8] and at 350 nm when it is deposited by chemical means [9]. The electrolysis-based results compare with the 20–45% transmittance range reported for visible light in the cited publications. The variation of the optical band gap with the ZnO layer thickness is depicted in figure 1. The (direct allowed) transition energy gap E_g determined [6, 10, 11] by extrapolating the experimental α^2 (the square of the absorption coefficient in Beer's law) versus photon energy curve to $\alpha^2 = 0$ expectably decreases [10] with increasing film thickness. The latter was estimated via Faraday's law of electrolysis based on the mean value of the electrical charge passed during deposition. The mean cathodic current efficiency was taken to be 85% due to simultaneous hydrogen evolution [4]. It is instructive to compare these results with $E_g = 3.3$ eV found in the case of chemical ZnO preparation methods [9]. In conclusion, there is now sufficient evidence for the viability of the electrolytic deposition of zinc oxide with transmittance properties similar to those of ZnO films deposited by non electrochemical means. The optimal conditions for the electrochemical path still need to be determined, but its

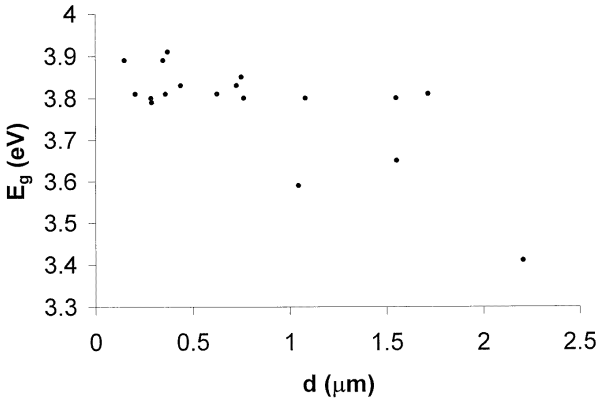

Figure 1. The effect of the ZnO layer thickness on the band gap energy: the relationship is weakly linear with a 95% confidence interval of [3.88; 3.91 eV] for the intercept and [−0.21; −0.07 eV μm^{-1}] for the slope of the regression line with parameters of 3.90 eV and −0.12 eV μm^{-1}.

† Author to whom correspondance should be addressed.

 © 1998 IOP Publishing Ltd

Table 1. Typical variations of transmittance with wavelength in the absence and the presence of a ZnO layer on ITO-coated glass. The potential was measured against the potential of the saturated calomel electrode (242 mV at 25 °C).

Cathodic potential (mV)	Electrolysis time (min)	Transmittance % at different wavelengths					
		ZnO-covered ITO-glass			Bare ITO-glass		
		350 nm	375 nm	400 nm	350 nm	375 nm	400 nm
700	5.0	23.5	30.6	35.4	35.5	45.0	51.4
700	20.0	10.0	12.6	15.0	30.0	40.0	46.4
800	20.0	4.2	4.4	4.5	40.0	50.0	57.1
850	20.0	1.6	4.0	5.0	40.0	50.0	57.4
950	5.0	13.3	23.3	28.7	40.9	49.6	56.5
950	10.0	1.7	8.7	12.5	37.0	47.5	54.2
950	20.0	0	3.5	5.7	37.8	47.8	54.3

relative simplicity, easy controllability and reproducibility hold considerable promise for electrochemical technology.

This research was supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) and the Department of Chemical Engineering of the University of Waterloo.

References

[1] Switzer J A, Hung C J, Breyfogle B E, Shumsky M G, Leeuwen R V and Golden T D 1994 *Science* **264** 1505
[2] Izaki M and Omi T 1996 *J. Electrochem. Soc.* **143** L53
[3] Izaki M and Omi T 1996 *Appl.Phys.Lett.* **68** 2439
[4] Gu Z H, Fahidy T Z, Hornsey R and Nathan A 1997 *Can. J. Chem.* **75** 1439
[5] Ng-Cheng-Hin F and Roslin M 1998 Electrolytic preparation of thin metal doped zinc oxide films, final year research report (ChE 047), Department of Chemical Engineering, University of Waterloo
[6] Wen Fa Wu, Chion Bi-Shiou and Shu-Ta-Hsieh 1994 *Semicond. Sci. Technol.* **9** 1242
[7] Besseis B, Ezzaouia H and Bennaceur R 1993 *Semicond. Sci. Technol.* **8** 1671
[8] Krunks M and Mellikov E 1995 *Thin Solid Films* **270** 33
[9] Izaki M and Omi T 1997 *J. Electrochem. Soc.* **114** L3
[10] Chion B S and Hsieh S T 1993 *Thin Solid Films* **229** 146
[11] Ohhata Y, Shinaki F and Yoshida S 1979 *Thin Solid Films* **59** 255