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ELECTROTHERMAL SWITCHING EFFECT IN ZnO DEPOSITED FILMS

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Switching effect in ZnO deposited films have been investigated. The films exhibit memory type switching. The rapid transition between the high resistive and conductive states was attributed to an electrothermal origin from Joule's heating of a current channel.

1. *Introduction*

Much research and interest have been devoted to the understanding of electric switching phenomena in amorphous and liquid semiconductors. The switching process can be regenerative[1], and the mechanism of breakdown is still unclear. Various models have been proposed[1-4] based on thermal and mixed electrothermal mechanisms. The switching phenomenon has been explained on the basis of two types of theories: (a) thermally initiated due to thermal instability[2,3,5] and, (b) electronically initiated[6,7,8] due to breakdown of the electronic equilibrium as a result of an applied field or current. Boer and Ovshinsky[3] have shown that the phenomena is initiated by Joule heating of a current channel causing thermally stabilized high electric field effects close to the electrodes which is sufficient for starting the switching transition.

The aim of the present contribution is to investigate the electric switching effects in ZnO semiconductor film prepared by electrolytic deposition. The method of preparation, the structural and photoelectric properties of these films have been investigated[9,10].

2. *Experimental*

The film used was prepared by anodic oxidation of zinc metal in anodizing electrolyte KOH in aquous solutions with concentration 2 molar[9]. Measurements of the electrical conductivity and the current-voltage characteristics were carried out in a measuring cell made of copper, and the lower electrode is made of a copper plate in contact with the lower surface of the sample. The upper electrode is a copper wire with thin circular end of diameter 1.0 mm, which provides gentle and good contact with the upper surface of the film. Measurements were carried out using a highly stabilized power supply, a sensitive voltmeter and a sensitive micrometer.

3. *Results and discussion*

Figs. 1 and 2 show the current-voltage characteristics for ZnO film. The curves show typical memory type switching, where transformation from high resistive (off) state into low resistive (on) state takes place as the voltage exceeds a threshold value V_{th}. On decreasing the voltage, the current decreases linearly and differs from that before switching which indicates a memory type switching.

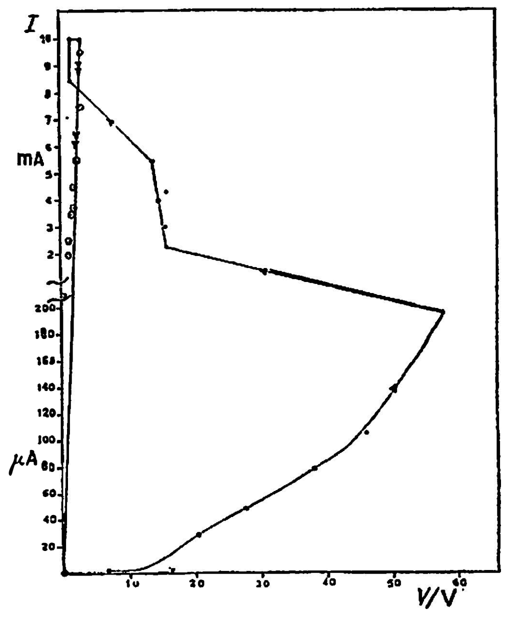

Fig. 1. Current-voltage characteristics for ZnO film.

Crevecoeur[11] have found that the switching phenomenon in As_2Se_3 films could be attributed to thermal processes due to self-heating, while in bulk As_2Se_3, the breakdown process is mainly dielectric, moreover electrothermal switching was observed in $AgTlSe_2$ and $CuTlSe_2$ films[12]. The switching process can be understood in terms of the following electrothermal model[11,13] for the pre-switching region. The temperature of the semiconductor is raised due to Joule-heating. Since the conduction process in the material is of an activated type as shown from the temperature dependence of the conductivity, then the conductivity of the sample will increase when heated. This will allow more current to flow through the heated regions and allow more Joule-heating, resulting in a further increase in the current density. A stationary state is reached when the heat lost by the conduction from the current filament become equal to the Joule-heat generated in that region.

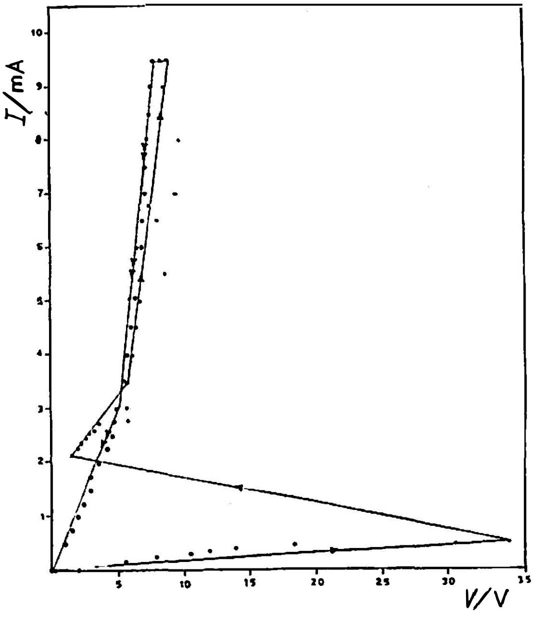

Fig. 2. Current-voltage characteristics for ZnO film at different point of contact.

The thermal model can be solved by finding a stationary state solution of the heat transport equation

$$C\frac{\mathrm{d}T}{\mathrm{d}t} = \sigma E^2 + \nabla(K\nabla T) \tag{1}$$

where C is the heat capacity, K is the thermal conductivity coefficient, E is the electric field and σ is the electrical conductivity which is given by

$$\sigma = \sigma_0 \exp\left(-\frac{E_\sigma}{kT}\right) \tag{2}$$

where σ_0 is the pre-exponential factor, E_σ is the conductivity activation energy and k is Boltzmann's constant, and charge conservation equation,

$$-\frac{d^2\varrho}{dt} = \nabla E \tag{3}$$

where ϱ is the resistivity.

In the case of steady state breakdown $\frac{dT}{dt} = 0$, then, the heat conduction equation (1) for a small difference $\Delta T = T_m - T_s$ between the temperature of the middle of the specimen (current filament) T_m and that of the surface T_s gives[11]

$$\frac{8K\Delta T}{L^2} + \sigma E^2 = 0 \tag{4}$$

where L is thickness of the sample. For small ΔT the field remains uniform and one obtains for the magnitude of ΔT

$$\Delta T = \frac{\sigma E^2 L^2}{8K}. \tag{5}$$

Breakdown occurs when the increase of the heat dissipated by Joule-heating in the specimen of a temperature rise $(\Delta T)_{\mathrm{breakdown}}$ becomes larger than the extra heat flowing away or removed by thermal conduction as a result of this temperature rise. The condition of breakdown can be obtained by differentiating the heat balance equation with respect to temperature and using (2), one obtains

$$(\Delta T)_{\mathrm{breakdown}} = \frac{T^2}{B} = \frac{T^2 k}{E_\sigma} \tag{6}$$

Table 1 shows the calculated values of ΔT and $(\Delta T)_{\mathrm{breakdown}}$ using Eqs. (5) and (6) with the thermal conductivity value $K = 83.7 \times 10^{-4} \left(\frac{\mathrm{J \cdot cm}}{\mathrm{cm^2\,s\,K}}\right)$ of ZnO[14].

TABLE 1.

Thickness (micron)	V_{th} (V)	E_{th} (V/cm)	σ $(\Omega^{-1} \cdot \mathrm{cm}^{-1})$	ΔT (K)	$\Delta T_{\mathrm{breakdown}}$ (K)
6.8	58	8.44×10^4	7.16×10^{-7}	0.15	4.69

The threshold electric field for switching, the temperature difference ΔT and $(\Delta T)_{\mathrm{breakdown}}$.

It appears that a significant rise in the temperature of the filament occurs, and the value of $(\Delta T)_{\mathrm{breakdown}}$ is in good agreement with the values observed for other semiconductors[11,12]. The observed memory type switching could be explained when the structure of the films is considered.

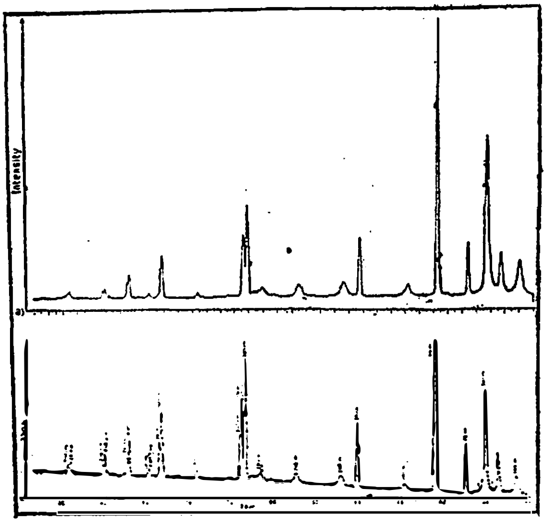

Fig. 3. X-ray diffraction pattern, a) before switching b) after switching.

TABLE 2.

hkl	Before switching		After switching	
	Zn *I*	ZnO *I*	Zn *I*	ZnO *I*
100	1.48	0.96	7.0	2.7
101	7.84	4.4	36.8	14.7
102	1.68	0.32	9.2	0.9
110	1.8	0.4	11.7	1.6
103	2.6	0.36	10	1.6
112	1.2	0.28	5.1	1.5
004	0.12	—	1.3	6.7
200	0.12	—	1.0	—
201	0.68	—	5.2	17.3
104	0.48	—	3.0	9.4
202	0.2	—	1.9	—
203	—	0.28	—	3.2
211	—	0.16	—	1.5
002	—	1.2	—	3.2
210	—	0.16	—	2.0

X-ray diffraction data for the investigated film before and after switching.

The structure of the investigated films, had been examined using Philips X-ray generator, PW 1729, with copper target and nickel filter ($K_a = 0.15417$ nm). Figs. 3.a and b, show X-ray diffraction patterns for the film before and after switching and Table 2 shows the characteristics of the pattern. From the pattern it is clear that there are three new crystal structures for zinc oxide with *hkl* (004), (201) and (104). Moreover, the ZnO and Zn crystal have a hexagonal crystal class, the intensity of X-ray lines of both of them was increased, which confirms a structural changes after switching. This explains the memory behaviour of the switching characteristics which connected with the structural changes.

4. Conclusions

Measurements of the current voltage characteristics of deposited ZnO films show a typical memory switching phenomenon. The observed phenomenon can be satisfactorily analyzed using electrothermal model of breakdown.

References

1) S. R. Ovshinsky, Phy. Rev. Lett. **21** (1968) 1450;
2) H. Fritzsche and S. R. Ovshinsky J. Non. Crystalline Solids **4** (1970) 464;
3) K. W. Boer and S. R. Ovshinsky, J. Appl. Phys. **41** (1970) 6;
4) D. M. Kroll and M. H. Cohen, J. Non-Crystalline Solids **8—10** (1972) 544;
5) H. J. Stocker, J. Non-Crystalline Solids **2** (1970) 371;
6) D. C. Mattice, Phys. Rev. Letters **22** (1969) 936;
7) M. Lida and A. Hamada, Japan J. Appl. Phys. **10** (1971) 224;
8) D. Haberland and H. Steigler, J. Non-Crystalline Solids, **8—10** (1972) 408;
9) A. H. Abou El Ela, S. M. El Raghy and M. El Bahay, J. Mat. Sci. **16** (1981) 2726;
10) A. H. Abou El Ela, S. M. El Raghy and M. El Bahay, Fizika **14**(4) (1982) 225;
11) H. J. De Wit and C. Crevecoeur, Solid State Elect. **15** (1972) 729;
12) M. A. Afifi, H. H. A. Labib A. H. Abou El Ela and K. A. Sharaf, Appl. Phys. **A46** (1988) 113;
13) R. M. Mehra, R. Shyam and P. C. Mathur, J. Non-Crystalline Solids **31** (1979) 435;
14) Handbook of Chemistry and Physics 69th Edition, 1988—1989.

EFEKT ELEKTROTERMALNOG PREKIDANJA U DEPONIRANIM FILMOVIMA ZnO

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Originalni znanstveni rad

Istraživan je efekt elektrotermalnog prekidanja u deponiranim filmovima ZnO. Film pokazuje prekidački efekt memorijskog tipa. Brzi prijelaz između stanja visoke otpornosti (zaporno stanje) i vodljivog stanja, pripisan je elektrotermalnom porijeklu od Joulovog zagrijavanja strujnog kanala.