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Some Properties of Doped SnO_2 Thin Films Used in EL and LC Display Structures*

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Abstract. The influence of doped antimony and fluorine ions on the properties of SnO_2 thin films were examined. The physical, electrical and optical characteristics of the films as a function of preparation conditions were investigated. The absorption curves of SnO_2: F, Sb films were taken down and the obtained values of the separate parameters discussed. Possibilities for application of these doped SnO_2 films as transparent electrodes in electroluminescent and liquid crystal display structures were shown.

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1 Introduction

The preparation, the properties and the different characteristics of doped SnO_2 thin films have been the object of intensive investigations. That is because of their wide application in various fields and it is connected with the mechanical and chemical stability of the films, their good adhesion to different substrates, steadiness under the action of aggressive media, high conductivity and transparency in the visible spectral region [1-3]. The combination of their electrical and optical properties permits these films to be successfully applied in various electronic and optoelectronic devices as transparent electrodes in liquid crystal and electroluminescent displays, photocells, detectors, sensors, antireflection coatings, *etc.* [4-11].

The aim of this paper is to study SnO_2 thin films doped with fluorine and antimony ions. The absorption curves of the SnO_2: F, Sb are taken down and their basic physical, electrical and optical parameters are determined. Possibilities for the practical use of the doped SnO_2 thin films as transparent electrodes in various electroluminescent and liquid crystal display structures are pointed out.

*This work is dedicated to Professor Alexander Derzhanski DSci, Corresponding Member of the Bulgarian Academy of Sciences, on occasion of his 70th anniversary.

2 Experimental Details

The doped SnO_2 thin film samples were deposited onto reclined and heated quartz substrates using a spray pyrolytic technique [12]. The antimony ions were introduced in the spray mixture from $SbCl_3$ and the fluorine ions — from NH_4F. The chemicals used were of proanalysis purity. The antimony concentration c_{Sb} was 0.5 wt % and fluorine concentration c_F 0.4 wt %.

The transmission spectra in the UV and the visible region were measured by a Hewlett-Packard 8452 Å and a Shimadzu UV-190 Spectrophotometer, the electrical sheet resistance by a four-probe FPP-5000, Vecco Instruments Inc. and the thickness by a Talystep surface profilometer. The average visible transparency, absorption edge, direct and indirect band gap width, optical quality factor and resistance were determined from the transmission spectra.

3 Results and Discussion

From the transmission spectra in the UV region, and if the reflectance is neglected, the absorption coefficient α can be calculated from the dependence [13]

$$\alpha = \frac{1}{d} \ln \left(\frac{1}{T} \right), \tag{1}$$

where d is the film thickness and T is the transmission in %.

The curves of the absorption coefficient α, α^2 and $\alpha^{1/2}$ vs wavelength λ for SnO_2: F, Sb film samples are given in Figure 1.

It is known that for direct transmission α varies as $(h\nu - E_g)^{1/2}$, while for indirect phonon-assisted transmission α varies as $(h\nu - E'_g + E_{ph})^2$, where E_g is the direct band gap, E'_g is the indirect band gap and E_{ph} the photon energy. From these plots the absorption edge α, the direct band gap E_g and the indirect transition energy $(E'_g + E_{ph})$ were calculated. The obtained results (from the calculation carried out) are given in Table 1.

It can be seen from Table 1 that the values of absorption edge, E_g and $(E'_g + E_{ph})$ of the investigated SnO_2: F, Sb film samples vary in the ranges 3.865–3.955 eV, 4.046–4.168 eV and 3.579–3.735 eV. The higher values of E_g are due to F-Sb doping. The average transparency in the visible region varies from 81.2 to 84.4%. The optical quality factor $Q = T/R_S$ was higher than unity as it reaches 3.238. This is mainly due to the presence of simultaneous fluorine-antimony doping, resulting in low electrical sheet resistance R_S which is in the borders of 26 to 34 $\Omega/\Box$.

Comparing the obtained results for SnO_2: F, Sb films to those for SnO_2: F, P films [14,15] a considerable change in the values of their physical, electrical and optical parameters can be marked. The average transparency T of SnO_2: F, P

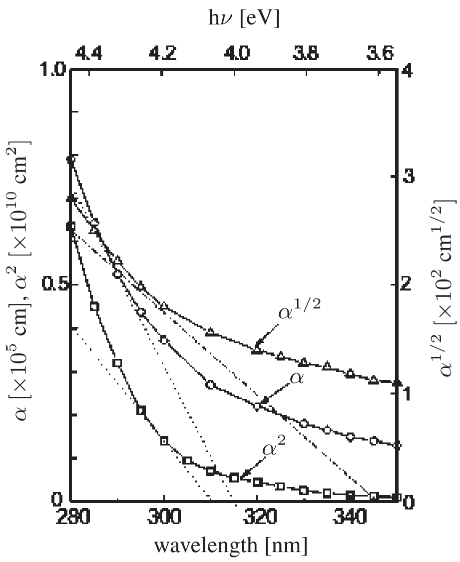

Figure 1. Typical absorption curves for film sample 40 a.: ○ – α; □ – α^2; Δ – $\alpha^{1/2}$.

films in the visible spectral region varies from 76 to 81%, their electrical sheet resistance R_S is higher from 38 to 71 $\Omega/\square$ and their optical quality factor Q is hardly 2.132. This can be used a fact that the ionic radius of F (1.33 Å) is the nearest to that of O_2 (1.32 Å). This does matter at the substitution of O_2 in the thin oxide crystal lattice. On the other hand, it is importance metallic characters

Table 1. Physical, electrical, optical parameters of SnO_2: F, Sb films

N	Sample	c_F wt %	c_{Sb} wt %	d μm	T %	Abs. edge eV
1	40 a	0.4	0.5	0.30	82.1	3.930
2	40 b	0.4	0.5	0.32	84.4	3.955
3	41 a	0.4	0.5	0.28	81.2	3.865
4	41 b	0.4	0.5	0.33	84.2	3.906

Table 1 (continued)

N	Sample	E_g eV	$E'_g + E_{ph}$ eV	R_S Ω/cm^2	$Q = T/R_S$	ρ Ω.cm
1	40 a	4.046	3.632	28	2.932	$0.84.10^{-3}$
2	40 b	4.168	3.579	34	2.482	$1.09.10^{-3}$
3	41 a	4.167	3.590	32	2.537	$0.90.10^{-3}$
4	41 b	4.106	3.735	26	3.238	$0.86.10^{-3}$

of Sb impurity which has an atomic radius $r_a = 1.61$ Å.

It is known that SnO_2 thin film conductivity depends on the concentration of oxygen vacancies in its crystal lattice. The introduction of suitable doping ions as F plus Sb^{3+} leads to its increase [16]. When these ions are introduced in SnO_2 films, they substitute O^{2-} anions or Sn^{4+} cations in the lattice, respectively. In this way some new donor levels are created in the energy band gap and their presence leads to an increased conductivity of the SnO_2 films without causing much reduction in their transmission [17,18].

The higher transparency and the low electrical sheet resistance of the investigated SnO_2: F, Sb films as compared to these of SnO_2: F, P films are of importance for their practical application.

4 Conclusion

The SnO_2: F, Sb thin films, prepared by spray pyrolytic technique were obtained. The change of the absorption coefficient α of these films vs wavelength λ at an optimal concentration of doping F and Sb ions was investigated. The average transparency T, the electrical sheet resistance R_S and the optical quality factor $Q = T/R_S$ at the same optical concentration were determined. The obtained values of the above parameters, compared to the same for SnO_2: F, P thin films, are higher. Because of that the SnO_2: F, Sb thin films are more suitable for application as transparent electrodes in various electroluminescent and liquid crystal display structures.

References

[1] A.L. Unogi, C.E. Okeke (1990) *Sol. Energy Mater.* **20** 29.

[2] C. Crujak, B. Orel, B.R. Marathe (1993) *J. Phys.: Appl. Phys.* **26** 204.

[3] K. Kolentsov, A. Rachkova, L. Yourukova, V. Pamukchieva (1994) *Proceeding SRIE* **2262** 302.

[4] T.Kallard (1973) *Liquid Crystal Devices*, Optosonic Press, London.

[5] *Display Devices* (1980), ed. J.J. Pankove; Springer Verlag, Berlin–Heidelberg–New York.

[6] *Liquid Crystal Display Devices* (1980), ed. Z.Yu. Gotra; Soviet Radio, Moskow.

[7] *Electroluminescent Light Sources* (1990), ed. I.K. Vereschagin; Energoatomizdat, Moskow.

[8] K. Fang, J.J. Lee (1989) *Thin Solid Films* **169** 51.

[9] S.R. Vishwakarma, Rahmatullah, H.C. Prasad (1992) *Indian J. Pure & Appl. Phys.* **30** 470.

[10] T. Racheva, G.W. Crichlov (1997) *Thin Solid Films* **292** 299.

[11] Kolentsov, L. Yourukova, A. Rachkova, N. Tsvetanov (2000)*Proceeding ISCMP*, 276.

[12] T. Racheva, K. Kolentsov, L. Yourukova (2000) *Proceeding of Electronics*, 130.

[13] R.D. Tarey, T.A. Raju (1985) *Thin Solid Films* **128** 181.

[14] K. Kolentsov, A. Rachkova, L. Yourukova, K.P. Kirilov, V.D. Pamu-kchieva (1994) *Proc. Suppl. Balkan Phys. Lett.*, **2**, 533.

[15] K. Kolentsov, L. Yourukova, A. Rachkova, A. Oprea (1997) *Proc. ISCMP*, 473.

[16] R. Rommiar, G. Griland, J. Macucchi (1981) *Thin Solid Films* **77**.

[17] K.L. Chopra, N.S. Major, D.K. Raudya (1983) *Thin Solid Films* **102** 102.

[18] N.S. Murty, G.K. Bhagavat, S.R. Jawalekar (1982) *Thin Solid Films* **92** 347.