OXIDE/METAL/OXIDE TRANSPARENT ELECTRODES FOR PLASTIC ELECTRONICS AND PLASTIC SOLAR CELLS

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M. Girtan[1], R. Mallet[2] A. Stanculescu[3], S. Antohe[4], M. Kompitsas[5] L. Leontie[6]

[1]Photonics Laboratory, [2]SCIAM, Angers University, 2, Bd. Lavoisier, 49045, Angers, France,
[3]Materials Institute of Bucharest, Romania
[4]Faculty of Physics, Bucharest University, Romania
[5]Theoretical and Physical Chemistry Institute, Athens, Greece
[6]Faculty of Physics, "Al.I.Cuza" University, Iasi, Romania
mihaela.girtan@univ-angers.fr

LPHIA, Angers University, 2 Bd. Lavoisier, 49045, Angers, France,
mihaela.girtan@univ-angers.fr

LΦA Laboratoire de Photonique d'Angers

Introduction

Transparent conducting thin films are widely used in many thin films devices. Since now single thin films of In_2O_3:Sn, ZnO:Al or SnO_2:F deposited on glass substrate were typically used as transparent conducting electrodes. The progress, last years, in the fabrication of organic solar cells and organic light emitting diodes, constantly increase the interest for transparent conducting films on flexible substrates as PET or PES. One of the first inconvenient which rise at the replacement of glass substrates by plastic substrates, is that one that some of the usually transparent electrode preparation methods such as sol-gel, spray pyrolysis or chemical vapour deposition involving high deposition temperatures (400°C-500°C) cannot not be employed anymore. Thin films deposition on plastic substrates supposes deposition at lowé temperatures and, in this case, more suitable deposition methods are vacuum sublimation sputtering or pulsed laser deposition. The choice of oxide material is also important. At present, the most promising material as transparent electrode seems to be the Indium Tin Oxide (ITO). However the limited resources of Indium on earth and the expensive cost of this material impress the reduction of the quantities employed for films fabrication or even the replacement of ITO by other materials having equivalent properties. The thickness of ITO thin films used as transparent electrodes for optoelectronic devices ranges in general, between 150nm and 700nm. The reduction of the thickness under 150nm is not possible in the case of single oxide films due to the increase of the electrical resistivity with the thickness decrease (the classical size effect). Another inconvenient that should be also considered in the case of using plastic substrates, resides in the usual bent mechanical fragility of oxide films.

With all these requirements in mind, the realisation of transparent electrodes using oxide/metal/oxide multilayer structures has many advantages. First, in the case of ITO, one of the advantage is the reduction of the indium quantity by the reduction of thin films thickness from 150nm to a total of 50-60nm for both oxide layers. Second, the mechanical properties are considerably improved due to the ductile metallic interlayer. In the same time the optical and electrical qualities of electrodes are perfectly conserved and even improved if we talk about the electrical conductivity.

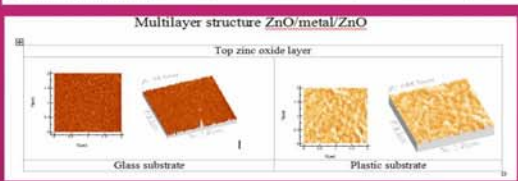
In this paper we present the physical properties of two types of multilayer structures: ITO/metal/ITO and ZnO/metal/ZnO deposited on both glass and PET substrates. The metallic interlayer was: Ag, Au, or Ag/Au

Results

Table I. Summary of the root mean square (RMS) and average (RA) roughness values of the oxide top layer of the multilayer structures oxide/metal/oxide deposited on glass and PET substrates.

Multilayer structure		Roughness of last (top) layer (nm)			
	Thickness (nm)	RMS values		RA values	
substrate		Glass	PET	Glass	PET
ITO/Ag/ITO	20/7/20	2.8	3.0	2.0	1.9
ITO/Au/ITO	20/8/20	1.4	1.9	0.9	1.5
ITO/Ag/Au/ITO	20/7/7/20	1.2	2.4	0.9	1.8
ZnO/Ag/ZnO	25/8/25	3.5	10.8	1.9	8.5
ZnO/Au/ZnO	25/8/25	1.4	5.7	0.9	4.6
ZnO/Ag/Au/ZnO	25/8/25	1.9	7.8	1.4	6.2

Multilayer structure ZnO/metal/ZnO



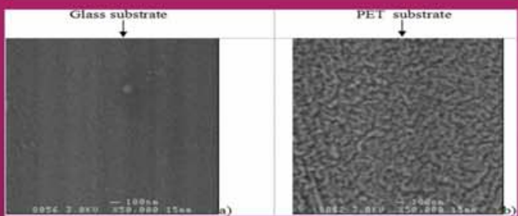
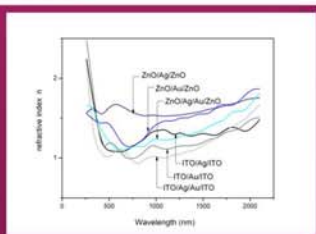
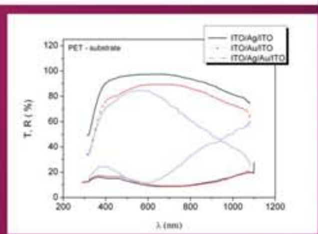
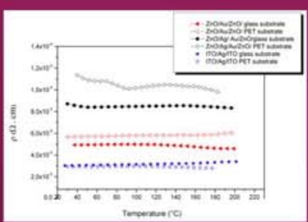


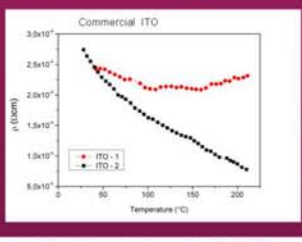
Table II. Fraser and Cooke and Haake figures of merit respectively calculated at 550nm transmittance for the multilayer structures oxide/metal/oxide deposited on glass and PET

Multilayer structure		Figure of merit ($10^{-3}\Omega^{-1}$) λ=550nm			
	Thickness (nm)	Fraser Cook		Haake	
substrate		Glass	PET	Glass	PET
ITO/Ag/ITO	20/7/20	59	39	21	29
ITO/Au/ITO	20/8/20	73	53	17	16
ITO/Ag/Au/ITO	20/7/7/20	125	127	24	28
ZnO/Ag/ZnO	25/8/25	77	46	7	4
ZnO/Au/ZnO	25/8/25	136	49	58	8
ZnO/Ag/Au/ZnO	25/8/25	174	83	26	15









Conclusion

Very good quality transparent conducting thin films structures (ρ=2·10-5Ω·cm, T ~ 90%) were prepared by sputtering and reactive sputtering. The morphological, optical and electrical properties were compared for the multilayer films ITO/metal/ITO and ZnO/metal/ZnO deposited both on glass and PET substrates. The influence of substrate nature is more pronounced in the case of zinc oxide films deposition. The Haake figures of merit for λ=550nm are comprised between 4·10-3Ω-1 and 29 ·10-3Ω-1 in function of the nature of the metallic interlayer Ag, Au or Ag/Au.The electrical properties stability with the temperature of oxide/metal/oxide structures is remarkable in comparison with the usual behaviour of single oxide films. These films are very promising for third generation flexible organic solar cells. Concerning the replacement of ITO with ZnO, from the figure of merit point of view results are comparables, however an inconvenient could rise from the fact that the roughness of zinc oxides films deposited on PET is more important than that of ITO films. Nevertheless, the roughness of indium tin oxide and zinc oxide films deposited on glass substrates are similar. In the same time, even in the case of ITO multilayer structures, the main advantages consist in the reduction of the films thickness from about 150-800nm to about 40-50nm and in a much better stability of the electrical resistivity to the temperature variations. The realization of a structure (oxide/metal) without a second oxide layer is not very suitable due to the fragility to scratch of the very thin metallic layer. The second thin oxide layer ensures a very good protective coating.