Web Summary Report

5th October 2011 – December 2013

(Phase I, II and III)

The aim of the project "Multifunctional zinc oxide thin films" is to explore and develop an original approach for the growth of new advanced multifunctional oxide thin films. Owing to its specific properties, low resistivity and high optical transparency in the visible range, highly desirable for technological applications, zinc oxide (ZnO) thin films have long been studied as an interesting alternative for indium tin oxide (ITO) and In_2O_3 thin films.

This project needed a perfect control of the growth of the oxide films, thus pulsed electron beam deposition method (PED) was used [1-3]. PED is an upcoming frontier growth technique with common features with pulsed laser deposition (PLD) of thin films [2, 4]. Even it is conceptually similar to the PLD, differs by the use of an intense pulsed electron beam (100 ns pulsed width, 100 A beam current and electron energies up to 15 keV) to ablate a target material instead of a laser beam. Due to its characteristics, this method is particularly well suitable to the growth of oxide films of complex compositions [1, 2]. Moreover the ability to easily control the substrate temperature and the deposition rate by PED permits to control the crystalline state of the oxide films, from amorphous to epitaxial films on single crystal substrates [3].

We have demonstrate in the three first Phases of the project (2001-2013) that by a precise control of the nature and concentration of dopants, the oxygen deficiency and structural defect density it is possible to tune the physical properties of doped and undoped ZnO thin films and to give them new functionalities.

The ZnO films properties can be enhanced or new properties can be obtained by the use of well adapted dopants. Transparent Nd doped ZnO thin films were grown by PED on Si and c-cut sapphire single crystal substrates at various oxygen pressures and substrate temperatures. The composition, surface morphology and structure of Nd doped ZnO thin films were investigated by means of Rutherford Backscattering Spectrometry, SEM and X-ray diffraction analyses. These films are smooth, dense, with the wurtzite phase. Epitaxial relationships between films and c-cut sapphire single crystal substrates were evidenced by asymmetric X-ray diffraction measurements. These results have been correlated with optical and electrical measurements.

The control of the film properties on different regions of a substrate during a single deposition process is an important achievement for multifunctional ZnO thin films. ZnO and In_2O_3 (considered as “model system”) thin films were grown by PED in the presence of an obstacle in the ablation plasma path and exhibited significant differences between the electrical properties of the region grown behind the obstacle and those of the adjacent regions [5]. The ratio ρ_{max}/ρ_{min} between the resistivity of the film region grown in the obstacle shadow and that of the adjacent regions is ~10^7 for In_2O_3 and ~10^2 for ZnO, so both films exhibit a considerably higher resistivity in the obstacle shadow region.

These results are encouraging for applications in transparent electronics requiring a single deposition process of a film with both conducting and highly resistive regions. Based on this study, we realized a self-assembled homojunction In_2O_3 transparent thin film transistor (TTFT), by downscaling both the obstacle size and the distance obstacle-substrate by 50 times [6, 7]. The resistivity of the active layer of this TTFT varies from 7×10^5 Ω·cm in the channel region to 10^{-3} Ω·cm in the source and drain regions.

The effects of oxygen deficiency on the physical properties of thin films have been also studied [2, 4]. As a result, a noticeable oxygen deficiency, i.e. about 15% of oxygen missing, was obtained [4]. Despite this oxygen deficiency, epitaxial oxide thin films were grown, with very specific transport properties. Actually, metallic or semiconductor behaviors were evidenced in the resistivity measurements as a function of temperature: a metal-insulator transition (MIT) or a metal-supraconducting transition were observed at low temperatures (T< 300K) [3, 4, 8]. Two different approaches have been used to interpret that MIT. For $ZnO_{1-\delta}$ the MIT can be described in the frame of the quantum corrections to conductivity (QCC) in disordered oxides. On the contrary, for $SrTiO_{3-\delta}$, $In_2O_{3-\delta}$, the MIT cannot be correctly fitted by the QCC model and the resistivity curve with temperature is better described in the frame of the electron localization which can be classically modeled by the variable range hopping model [3, 8].

Details about the results obtained in Phases I, II and III can be found in papers presented in the following section.

Dissemination

[1] M. Nistor, Rom.Rep.Phys. **64**, 1313 (2012)

[2] M. Nistor, F. Gherendi, N.B. Mandache, Applied Surface Science **258,** 9274 (2012)

[3] W.Seiler, M.Nistor, C.Hebert, J.Perrière, Solar Energy Materials&Solar Cells **116**, 34 (2013)

[4] E. Millon, M. Nistor, C. Hebert, Y. Davila and J. Perriere, J. Mater. Chem., **22**, 12179 (2012)

[5] F.Gherendi, J.Optoel. Adv. M. **15** (No. 11-12), 1463 (2013)

[6] F.Gherendi, M.Nistor,N.B.Mandache, J.Displ.Tech 9(9), 760 – 763 (2013)

[7] F.Gherendi, M.Nistor, S.Antohe, L.Ion, I.Enculescu and N. B. Mandache, Semicond. Sci. Technol. **28,** 085002 (2013); F.Gherendi, M.Nistor,N.B.Mandache, J.Displ.Tech **9** (9), 760 – 763 (2013)

[8] M. Nistor, J. Perrière, Solid State Communications **163,** 60 (2013),

and in 18 communications at international conferences.

In conclusion, the objectives of Phases I, II and III of this exploratory project were fully realized.