Voltage Induced Metal-insulator Transition in ZnO

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Introduction
Zinc oxide and its compounds are being studied as important materials for short-wavelength optoelectronic devices, and for potential applications in transparent electronics and spintronics. Some of us reported the observation of the Electric Pulse-Induced Resistance switching (EPIR) effect in N and Co co-doped ZnO [1] showing that this material exhibits memory properties and is therefore attractive for the next generation of electronic devices.

Experimental
Thin films of ZnO were fabricated by two methods: a) pure ZnO and S doped ZnO films were deposited by RF magnetron sputtering at RT in Ar atmosphere on SiO2/Si and on Si substrates and b) pure ZnO and Co doped ZnO films were grown on SiO2/Si substrates by PLD at 400 °C under 5 Pa of N2 using ZnO targets with a nominal Co content of 10% and 15%. A symmetric device was fabricated by depositing two coplanar Au disk-shaped contacts (diam. = 0.75 mm) by Ar-sputtering on the top surface. Leads were soldered using In. For electrical measurements we employed the two-probe method in the constant-voltage mode. The temperature dependence of the I-V curves were studied in the 25-300 K temperature range.

Results and Discussion
After exploring the I-V characteristics of the different samples we find that the N doped samples show a change in the resistance vs. temperature behavior. Fig. 1 shows the I-V characteristics for temperatures between 25 and 300K for a N-doped ZnO film. On the negative branch side of the I-V curve we see a change from semiconductor to a “metallic-like” behavior around -30V. The curves also show a temperature dependent hysteretic behavior. In the positive branch the conductivity shows a semiconductor behavior for all temperatures and voltages used here. The “metallic like” behavior is most easily seen in the inset, where a calculated R (@ -60V) vs. T plot is shown. It is hard to explain the presence of asymmetries in the I-V characteristic in symmetrical devices. Possible explanations are considered in terms of electrochemical reactions at the electrode-film interfaces [2,3]. The I-V curves are linear for low voltages (20 V) but switch to non linear with increasing voltage. We propose that the electric field bend the bands and excite carriers from traps to the conduction band. Below 50 K the behavior turns to semiconductor type, at this temperature the carriers recombine and the resistivity increases. This behavior is probably not a metal-insulator transition in a thermodynamic sense, but possibly related to a charge-carrier localization effect.

Conclusions
We found that N doped ZnO thin film behaves as a heavily doped semiconductor while stimulated by the electric field.

Acknowledgements
MJV thanks Fulbright Commission, CONICET (Argentina) and U.N.T.

References