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Charge and Spin-Based Electronics using ZnO Thin Films

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ZnO is an attractive semiconductor for charge and spin-based electronics. ZnO is an n-type II-VI compound semiconductor with a direct band gap of 3.35 eV. N-type doping is caused by the intrinsic defect levels approximately 0.05eV below the conduction band. The Hall mobility of ZnO single crystals at room temperature is on the order of 200 $cm^2V^{-1}s^{-1}$. For transparent transistor development, ZnO can be synthesized as thin films at low temperatures that are compatible with various substrates, including glass. Hall mobility for polycrystalline films ranges from 10-50 $cm^2V^{-1}s^{-1}$. Based on these characteristics, transparent field effect transistors (TFETs) using ZnO as an active channel layer are being explored. In addition, room temperature ferromagnetism has been observed in transition metal doped ZnO films, opening the possibility of developing spintronic technologies based on this material.

One of the major challenges in ZnO-based FET development is to control the carrier density in the active channel. As-deposited ZnO films tend to display a high carrier density, even for materials that are nominally undoped. A high carrier density yields a channel that will be conducting in the absence of applied gate voltage. Device functionality occurs via depletion of carriers with applied field. Hence, this is a depletion mode device. High channel carrier densities prove difficult to deplete. More preferable is an enhancement mode device, in which conductivity is induced via applied gate voltage. In this paper, the properties of thin-film FETs that utilize P-doped $Zn_{0.9}Mg_{0.1}O$ as the active channel materials are reported. Recently, it has been shown that phosphorus substitution introduces an acceptor level that reduces the electron density or, in some case, yields p-type behavior. A further reduction in carrier density can be achieved via Mg doping. In this case, Mg substitution increases the band gap, thus increasing the activation energy for defect-related donor states. The use of P and/or Mg doping yields an opportunity to tailor the channel conductance for enhancement mode operation. Figure 1 shows the transistor characteristics of a (Zn,Mg)O:P based FET device to be discussed.

In addition to spin-based electronics, diluted magnetic semiconductors offer the possibility of combining spin functionality into host semiconducting materials. For ZnO, theory predicts that room-temperature carrier-mediated ferromagnetism should be possible in manganese-doped p-type material, although Mn-doped n-type ZnO should not be ferromagnetic. We find room temperature ferromagnetism in Mn-doped ZnO films that are co-doped with either phosphorus or tin. Figure 2 shows the magnetization behavior for a P, Mn doped ZnO films. The properties of these films will be discussed in detail.

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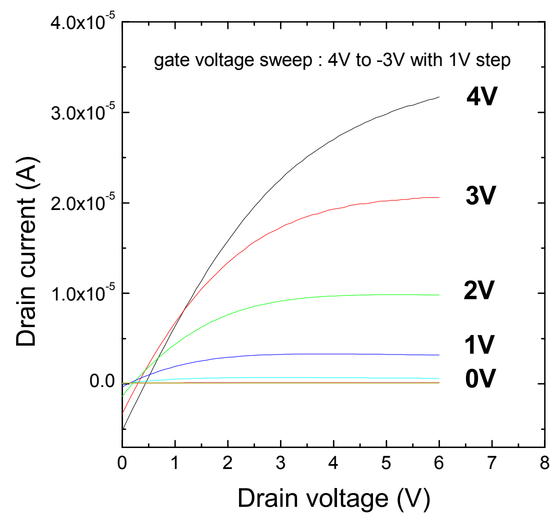

Fig. 1 I_D-V_{DS} characteristics of ZnO-based TFT with channel length of 20μm and channel width of 90μm

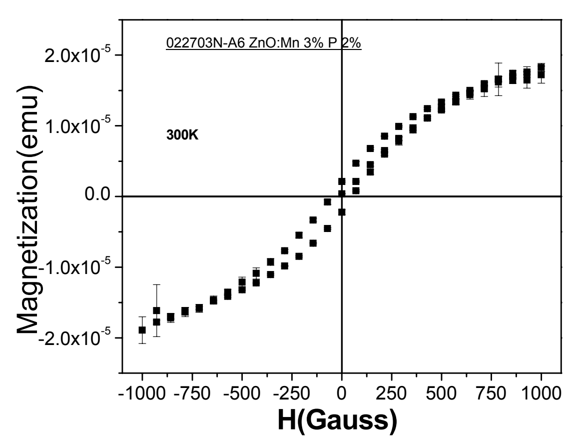

Fig. 2 Magnetization for ZnO film co-doped with Mn and P.