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Full Length Article

Probing of O_2 vacancy defects and correlated magnetic, electrical and photoresponse properties in indium-tin oxide nanostructures by spectroscopic techniques

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ABSTRACT

Indium-tin oxide (ITO) 1D nanostructures with tunable morphologies i.e. nanorods, nanocombs and nanowires are grown on c-axis (0 0 0 1) sapphire (Al_2O_3) substrate in oxygen deficient atmosphere through pulsed laser deposition (PLD) technique and the effect of oxygen vacancies on optical, electrical, magnetic and photoresponse properties is investigated using spectroscopic methods. ITO nanostructures are found to be enriched with significant oxygen vacancy defects as evident from X-ray photoelectron and Raman spectroscopic analysis. Photoluminescence spectra exhibited intense mid-band blue emission at wavelength of region of 400–450 nm due to the electronic transition from conduction band maxima (CBM) to the singly ionized oxygen-vacancy (V_O^+) defect level within the band-gap. Interestingly, ITO nanostructures exhibited significant room-temperature ferromagnetism (RTFM) and the magnetic moment found proportional to concentration of V_O^+ defects which indicates V_O^+ defects are mainly responsible for the observed RTFM in nanostructures. ITO nanowires being enriched with more V_O^+ defects exhibited strongest RTFM as compared to other morphologies. Current voltage (I-V) characteristics of ITO nanostructures showed an enhancement of current under UV light as compared to dark which indicates such 1D nanostructure can be used as photovoltaic material. Hence, the study shows that there is ample opportunity to tailor the properties of ITOs through proper defect engineering's and such photosensitive ferromagnetic semiconductors might be promising for spintronic and photovoltaic applications.

1. Introduction

The study of defect-induced d^0 ferromagnetism in various low-dimensional (1D/2D) metal-oxide nanostructures and thin-films has been drawn immense research attentions for novel spintronic and opto-spintronic applications [1,2]. The discovery of room temperature ferromagnetism (RTFM) in pure HfO_2 thin films [3] demonstrates an interesting physics indicating that the oxide semiconductors can exhibit FM without the presence of any d or f-electrons. Although, scientists have primarily attempted to prepare oxide-based dilute magnetic semiconductors [4–11] by dilute doping of transition metal ions (Co, Mn, Fe etc.) within semiconducting host. However, the magnetic properties of such transition-metal-doped O-DMSs remain quite controversial [4–11] still to date. On the other hand, reducing size or dimension of the material to nanosize ($\sim 10^{-9}$ m) scale, it is often advantageous to enhance many physical properties like optical, magnetic and electrical properties [12,13]. Such low-dimensional (1D/2D) nanostructures in the form of nanowires, nanorods and thinfilms are generally prone to be enriched with many surface defects, oxygen and cation vacancies [14–16] due to their low formation energy within nanoscale materials. The RTFM was reported in the pristine ZnO, TiO_2, In_2O_3 and SnO_2 nanostructures and thinfilms [6–11,15–18]. The origin of FM has been attributed to the different structural defects present in these oxide semiconductors. Based on the ab initio calculations for HfO_2 and CaO, Pemmaraju et al. [6] and Elfimov et al. [7] indicated that the cation vacancies can induce an almost localized magnetic moment on the oxygen atoms neighboring the vacancy. On the other hand, oxygen vacancies (V_O) have also been attributed to introducing RTFM in wide-band-gap oxide semiconductors such as ZnO, SnO_2 [3,8,10,18].

Sn-doped In_2O_3, commonly known as indium-tin oxide (ITO) is a promising n-type wide-bandgap ($\sim$3.5 eV) transparent metal-oxide semiconductor having high electrical conductivity and generally finds potential technological applications in solar cells, light

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