Solid State Communications 371 (2023) 115267

Contents lists available at ScienceDirect

Solid State Communications

journal homepage: www.elsevier.com/locate/ssc

Surface-disorder and cationic-site defect-induced ferromagnetism and correlated Raman vibrational modes in $Sn_{0.9}$ $In_{0.1}O_2$ nanocrystalline thin-films

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ARTICLE INFO

Communicated by: Zhao Liuyan

Keywords:
Oxide-nanomaterials and thin films
Defects
Ferromagnetism
Raman vibration modes
Photoluminescence

ABSTRACT

Exploration of magnetism in otherwise nonmagnetic wide-band oxides through defect-engineering has been become a new challenge to achieve the goal of room-temperature ferromagnetic semiconductor for potential applications in spintronics. In this backdrop, we report surface-disorder and cationic-site defect-induced FM in series of $Sn_{0.9}In_{0.1}O_2$ nanocrystalline thin films prepared using pulsed laser deposition different Argon (Ar) pressure. With the increase of deposition pressure, surface morphology of $Sn_{0.9}In_{0.1}O_2$ nanocrystalline thin-films changes as nanoclusters, nanofibres, nanoflakes and nanowires respectively, crystallite size decreases and surface disorder increases gradually. Raman, X-ray photoelectron and Photoluminescence spectroscopic analysis confirm the formation tin-vacancy (V_{Sn}) and associated combinational defects that significantly increase the ferromagnetic signal in In-doped SnO_2 thin-films. The substitution of trivalent In^{3+} in Sn site also cause serious lattice distortion which transform the Raman inactive modes A_{2g} and E_u modes into Raman active modes and thus appeared at 574 cm^{-1} and 354 cm^{-1} respectively. The nanowires of $Sn_{0.9}In_{0.1}O_2$ are found to possess highest concentration of V_{Sn} defects and therefore it exhibits strongest ferromagnetic moment (M_S) ~ 11.1 emu/cm^3 and highest Curie temperature (T_C) ~ 572 K. The gradual decrease in carrier concentration with the increasing deposition pressure suggests stabilization of hole-mediated V_{Sn}-induced room temperature FM in series of In-doped SnO_2 nanocrystalline thin-films.

1. Introduction

Defect-induced ferromagnetism (FM) in low-dimensional (1D/2D) otherwise nonmagnetic wide-band semiconducting oxide nanostructures has been recently drawn prime research attention due to potential applications in spintronics, magneto-optical and magneto-electrical devices [1–3]. During growth of oxide-based 1D or 2D nanotructures or thins-films in diverse atmosphere, many structural defects like cation vacancies, oxygen vacancies (V_O), interstitials and antisite defects and dislocations can stabilize within lattice. Among them, some type of defects can induce local magnetic moment within host semiconductors [4,5]. In fact, there are significant reports on the evidence of room-temperature FM in ZnO and TiO_2 based-oxides associated either with transition-metal doping or oxygen vacancy defects [6–12]. On the other hand, many theoretical studies [13–16] have suggested that the formation of cation-vacancy defects rather than V_O defects in similar oxides can be more effective to stabilize carrier-mediated room--temperature FM. Density functional theory (DFT) by Elfimov et al. [13] and Pemmaraju et al. [14], and later Osorio-Guillen et al. [15] has predicted that wide-band CaO thin-film can behave as pure ferromagnet with 5% Ca vacancies. Later, Zhang et al. [16] has shown experimentally that the Nb incorporation can help to stabilize Ti vacancy defects in pulsed-lased deposited Nb-doped TiO_2 thin film. Although they do not observed FM due to very low concentration of Ti vacancies and free carrier density. After that, Zn-vacancy induced FM is observed in different nonmagnetic element doped ZnO thin films [6,17], ZnO:Li nanorods [18] and also in our previous work on ZnO:K nanowires [9].

In this backdrop, tin dioxide (SnO_2) is an important transparent conducting oxide (TCO) which finds potential applications many field of science such as sensors, solar panel displays and other transparent electronic devices [19–21]. Unlike ZnO or TiO_2, it has been less explored as far as defect-modified magnetic behaviours are concern. DFT calculations by Gul Rahman et al. [22] have explained tin-vancacy (V_{Sn}) with proper defect-enginnering can generate large magnetic moment in SnO_2. They have also suggested that observation of unexpected gaint magnetic moment (7.5 ± 0.5) μ_B/Co in Co-doped SnO_2 films by Ogale et al. [23],

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https://doi.org/10.1016/j.ssc.2023.115267
Received 14 July 2022; Received in revised form 20 June 2023; Accepted 26 June 2023
Available online 5 July 2023

the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgement

Authors would like to acknowledge the support of Prof. K. Mandal, S. N. Bose National Centre for Basic Sciences Kolkata, India for providing sample preparation facility and Prof. P.M.G. Nambisan, Saha Institute of Nuclear Physics, Kolkata, India for fruitful discussions during the course of the work. The author is thankful to Dr. U. Manju, CSIR-Central Glass and Ceramic Research Institute, Kolkata, India for helping in XPS measurements. The author deeply acknowledge Dr. Gautam Dev Mukherjee, Indian Institute of Science Education and Research, Kolkata for providing the micro-Raman spectrometer (LABRAM HR from Horiba Jobin Yvon) facility and other laboratory facilities. The author is also thankful to Dr. B. N. Dev, Indian Institute of Cultivation of Sciences, Jadavpur, Kolkata, India for TEM facilities and fruitful suggestions. Auhors also thankful to Dr. A. Layek, Jadavpur University for his collaborative support during the course of work. Finally, the author acknowledge the support from the advanced laboratory facilities, Department of Physics, B. N. Mahavidyalya, Hooghly specially for the electrical characterization of the samples.

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