



Effects of MeV heavy ion irradiation on structural, morphological and optical properties of nanostructured SnO₂ thin films prepared by thermal evaporation



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ABSTRACT

We report on the effects of 8 MeV Si³⁺ ion irradiation on the structural, morphological and optical properties of nanostructured SnO₂ thin films, prepared by a simple thermal evaporation method. The structural and morphological evolution of nanostructured SnO₂ thin films upon MeV ion irradiation was studied by X-ray diffraction (XRD) and atomic force microscopy (AFM), while the optical properties of the thin films were characterized by Raman spectroscopy and photoluminescence spectroscopy (PL). XRD studies revealed the presence of nanocrystals of orthorhombic SnO₂ and cubic Sn in the as-deposited thin films. AFM studies revealed growth of SnO₂ nanoparticles in the films upon MeV ion irradiation. PL studies on the 8 MeV Si ion irradiated nanostructured SnO₂ thin films revealed strong enhancement in the intensity of UV and visible emissions from SnO₂ nanostructures.

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1. Introduction

Metal oxide semiconductor nanostructures have been the topic of intensive research due to their wide range of applications. Among various metal oxide semiconductors, tin dioxide (SnO₂), an n-type wide band gap semiconductor with high carrier mobility (250 cm²/V s) and high exciton binding energy (130 meV) [1], is considered to be a very promising candidate for applications in sensors [2–4], catalysts [5,6], transparent conducting electrodes [7], solar cells [8] and lithium ion batteries [9] due to its fascinating electrical and optical properties. SnO₂ nanostructures with different morphologies have been synthesized by different physical and chemical methods including thermal evaporation [10–12], physical vapor deposition [13], laser ablation [14], pulse laser deposition [15], chemical vapor deposition [16] and hydrothermal method [17]. Orthorhombic phase of SnO₂ nanostructures is relatively rare and has been synthesized under high pressure and oxygen deficient environment [18]. Orthorhombic SnO₂ has been synthesized by various methods by different groups [19–23] but the properties of SnO₂ nanostructures in orthorhombic phase are not well studied and synthesis of shape and size controlled SnO₂

nanostructures in pure orthorhombic phase is still a challenging task. High growth temperatures favor the formation of complex nanostructures with high crystallinity. Therefore, vapor phase deposition is a simpler route to obtain desired nanomaterials with high crystalline quality.

Ion irradiation is one of the most promising tools to engineer defects in solids, which in turn modify their structural, optical, electrical and magnetic properties [24–27]. Energetic ions moving in a solid transfer their energy to target nuclei and electrons in elastic and inelastic collisions, respectively within a very short interval of time. This leads to the deposition of very high energy localized within the solid, resulting in interesting modifications of the solid. Ion irradiation induced nanocrystallization, generation of ordered surface nanostructures, formation of latent tracks and associated changes in physical and chemical properties of different materials have been reported by various groups [28–30]. Ion irradiation has also been used to tailor the properties of metal oxide semiconductors such as TiO₂, ZnO, and SnO₂ [31–33], which have a wide range of applications. In an earlier paper [34], we have demonstrated that MeV heavy ion irradiation can be used for controlled fabrication of high density of SnO₂ nanorings through ordered self-assembly of SnO₂ nanoparticles which can find potential applications in nanotechnology. Sharma et al. [35] have reported growth of nanopillars in SnO₂ thin films by ion irradiation and studied its gas sensing properties.

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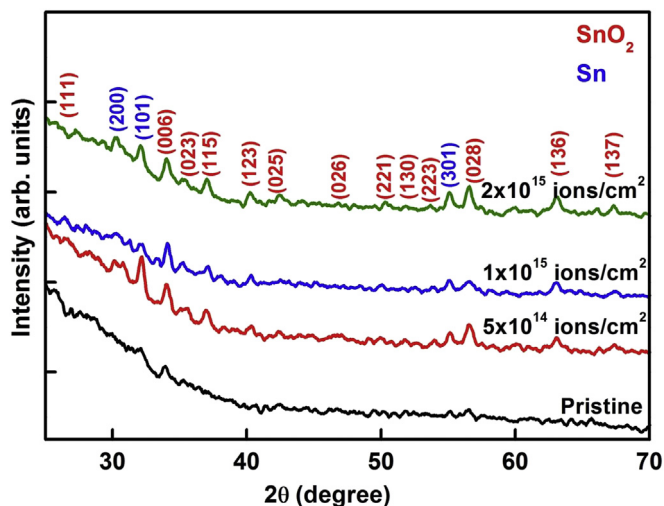


Fig. 1. XRD patterns from pristine SnO_2 thin film sample and samples irradiated with 8 MeV Si ions to fluence of 5×10^{14} ions/cm², 1×10^{15} ions/cm² and 2×10^{15} ions/cm².

In this paper, we report the effects of 8 MeV Si ion irradiation on the structural, morphological and optical properties of nano-structured SnO_2 thin films, prepared by a simple thermal evaporation method. We have demonstrated that MeV ion irradiation leads to growth of SnO_2 nanoparticles and results in significant enhancement in the UV and defect emissions from the nano-structured SnO_2 thin films.

2. Experimental details

Thin films of SnO_2 were deposited on thoroughly cleaned quartz and Si substrates using a simple thermal evaporation based vapor deposition method. In a typical synthesis, SnO_2 powder was grinded, pelletized and kept in a tungsten boat. Thin films of SnO_2 were deposited onto the substrates at a rate of 0.3 nm/s. The vacuum in the chamber before and during thin film deposition was 2×10^{-6} and 1×10^{-5} mbar, respectively. The as-deposited SnO_2 thin films were then irradiated with 8 MeV Si^{3+} ions to fluences varying from 5×10^{14} to 2×10^{15} ions/cm² using the 3 MV Pelletron accelerator facilities at Institute of Physics (IOP), Bhubaneswar. The morphological, structural and optical studies of the SnO_2 thin films and the irradiated samples were well characterized by atomic force microscopy (AFM), X-ray diffraction (XRD), Raman spectroscopy and photoluminescence spectroscopy (PL). Micro-Raman spectra were recorded by Horiba Jobin Yvon LabRam facility using a spot size of 1 μm and a wavelength of 532 nm. PL studies were carried out using 325 nm excitation from He–Cd laser.

3. Results and discussion

The crystal structures of the as-deposited and ion irradiated SnO_2 thin films were characterized by XRD. Fig. 1 shows the XRD patterns depicting the structural evolution of the SnO_2 thin films upon 8 MeV Si ion irradiation. The observed peaks marked (111), (006), (023), (115), (123), (025), (026), (221), (130), (223), (028), (136) and (137) are well indexed to the orthorhombic crystal structure of SnO_2 and closely match with the standard data (JCPDS

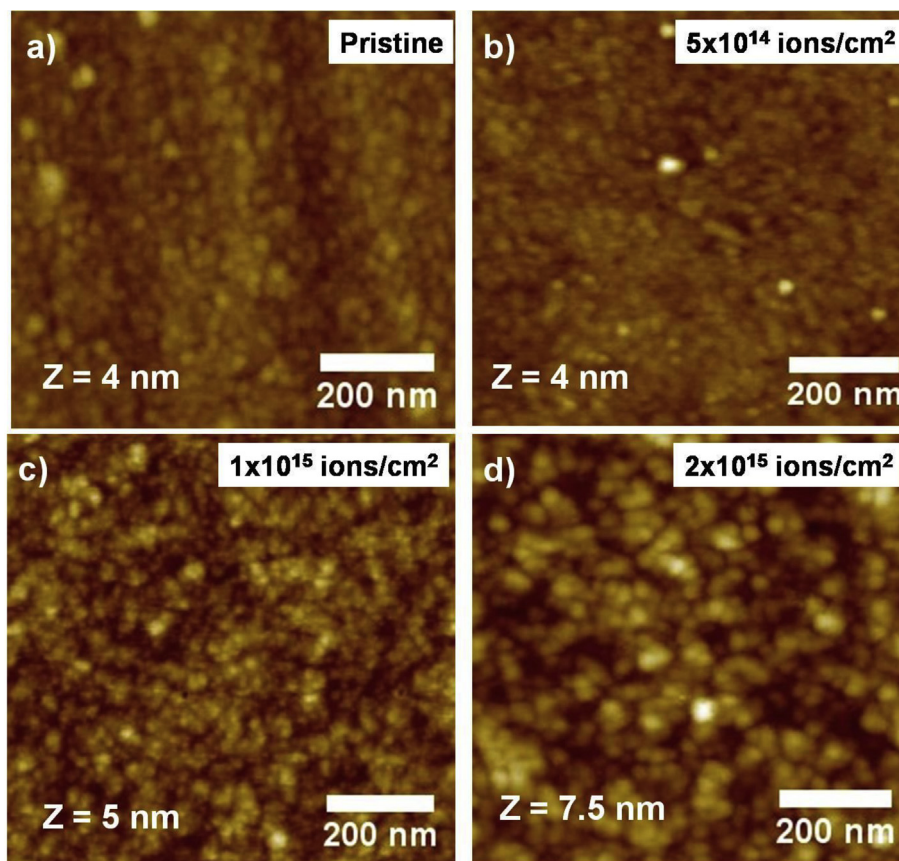


Fig. 2. AFM images of SnO_2 thin film samples (a) pristine, irradiated with 8 MeV Si ions to fluence of (b) 5×10^{14} ions/cm², (c) 1×10^{15} ions/cm² and (d) 2×10^{15} ions/cm². The scan size of all the images is $(1 \times 1) \mu\text{m}^2$ and the height scale z is indicated.

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