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Effect of hydrogen on electrical properties of ZnTe/Mn multilayer diluted magnetic semiconductor thin films

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In this article we have reported the role of hydrogen on ZnTe/Mn multilayer diluted magnetic semiconductor thin films grown by thermal evaporation method at pressure of 10^{-5} torr on simple as well as indium-tin-oxide (ITO) coated conducting glass substrates at room temperature. These samples have been vacuum annealed at constant temperature 400 K for one hour at base pressure of 10^{-5} torr. As deposited and vacuum thermal annealed samples have been separately hydrogenated by keeping these in a hydrogenation cell in which hydrogen gas was introduced for half an hour at different pressures (15-45 psi) at room temperature. Structural studies of as deposited and vacuum annealed ZnTe/Mn thin films have been investigated by X-ray diffractomerter. Current – voltage characteristics of both as deposited hydrogenated and vacuum annealed hydrogenated metal-semiconductor ZnTe/Mn thin films have been studied to see the role of hydrogenation. The surface topography of as deposited and vacuum annealed samples was confirmed by optical microscopy. This study confirms the formation of DMS thin films structure, uniform deposition, mixing and hydrogenation effect on electrical properties of ZnTe/Mn DMS thin films.

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Keywords: MLs DMS thin films, Hydrogenation, VTA, XRD, I-V characteristics and Surface topography.

1. Introduction

In recent years, II-VI compound semi conducting thin films have drawn much attention for their potential application in optoelectronics [1]. Zinc telluride (ZnTe) is an important semiconductor material for the development of various modern technologies of solid state devices (blue light emitting diodes, laser diodes, solar cells, microwave devices, etc.) [2,3]. It is a direct band gap semiconductor having band gap 2.26 eV at room temperature having zinc-blende structure with lattice constant of 6.1037 A^0 and melting point of 1295^0C [4]. Semiconductors and magnetic materials are two very important materials in the current electronic industries [5]. Diluted magnetic semiconductors (DMSs) in which transition metals (TMs) are doped into semiconductors exhibiting room temperature ferromagnetism (RTFM) have attracted much attention for their potential use in spintronic devices [6]. Recently, much attention and interest have been focused on the development of spintronics technologies. The use of carrier spins, in addition to carrier charges, of spintronics looks promising in the field of magnetic recording media [7]. The advantage of diluted magnetic semiconductor (DMS) based spin-electronic devices include enabling of instant-on computer, increased integration density, higher data processing speed, low electrical energy demand and compatibility of their fabrication processes with those currently used in industry [8]. Diluted magnetic semiconductors are expected to play an important role in interdisciplinary material science and electronics because charge and spin degrees of freedom accommodated into a single material exhibits interesting magnetic, magneto-optical, magneto-electronic and other properties [9, 10]. In recent years, II-VI compound semiconductors are attracting a great deal of attention because of their potential abilities in a wide spectrum of optoelectronic devices [11].

Hydrogen is omnipresent and easily incorporated in materials. Interstitial hydrogen is a fast diffuser. It can bind to native defects or to other impurities, often eliminating their electrical activity-a phenomenon known as passivation [12]. Electrical measurements such as current/voltage, capacitance/voltage and hall measurements, provides detailed information about the electric effects of hydrogen. In our article we have reported the role of hydrogen in structural and electrical [13] and optical properties [14] of CdTe/Mn BLs DMS thin films. In the present study the structural, electrical, morphology study and effect of hydrogen on thermally evaporated ZnTe/Mn MLs thin films have been investigated.

2. Experimental details

2.1 Sample preparation

For deposition compound zinc telluride powder with 99.995 % purity and elemental Mn granules with 99.98% purity were purchased from Alfa Aesar, Jonson Matthay Company, U.S.A. Thin films of ZnTe/Mn metal-semiconductor junction have been prepared by thermal evaporation method using vacuum coating unit (HIND HIGH VACUUM system) at a constant pressure of 10^{-5}

torr on ITO coated conducting glass substrates. Tantalum sheets were used as source boats. Compound ZnTe powder and elemental Mn were placed in separate source boat in vacuum system. Indium-tin-oxide glasses as well as simple glass substrates were placed in the substrate holder above the boats. The source to substrate distance was kept 15 cm. First we have deposited ZnTe layer and later Te to get ZnTe/Mn metal-semiconductor junction structure. These thin films have been grown by maintaining substrates at room temperature (RT). The thickness of ZnTe/Mn thin films was 400 nm (150 nm ZnTe/ 100 nm Mn/ 150 nm ZnTe) measured by quartz crystal thickness monitor (HINDHIVAC THICKNESS MONITOR MODEL DTM-101) as well as gravetric method.

2.2 Vacuum thermal annealing (VTA)

Vacuum thermal annealing of ZnTe/Mn thin films has been performed in a vacuum of 10^{-5} torr by using vacuum coating unit for mixing to get homogeneous structure and interdiffusion of ZnTe and Mn layers, where samples were kept on a heater at constant temperature 400 K for one hour. The temperature of heater was measured by using CIE-305 thermometer.

2.3. Hydrogenation

Prepared as deposited and annealed ZnTe/Mn thin films have been hydrogenated by keeping these separately in hydrogenation cell, where hydrogen gas was introduced at different pressures (15-45 psi) for 30 minutes and termed as deposited hydrogenated and annealed hydrogenated samples respectively.

2.4. X-ray diffraction

The X-ray diffraction (XRD) patterns of as deposited and vacuum annealed DMS thin films have been recorded with the help of PANalytical X'pert PRO MPD PW3040/60 X-ray diffractometer using CuK_{α} as a radiation source of wavelength λ=1.540598A^0. The tube was operated at 45 KV, 40 mA with the scanning speed of 0·090 (2θ)/sec. The XRD patterns of all films were taken from 20° to 80° (2θ). The peaks of the XRD patterns have been searched by computer programming using Powder X Software.

2.5. I-V characteristics

Transverse I-V characteristics of as deposited hydrogenated and vacuum annealed hydrogenated samples have been recorded using Keithley-238 high current source measuring unit in the voltage range of -1.0 to +1.0 volts with increasing step of 0.1 volt. For I-V characteristics, electrode contacts were made using silver (Ag) paste across the junction. I-V outputs of the junction were monitored with the help of SMUSweep computer software. All the measurements have been performed at room temperature.

2.6. Optical microscopy

The optical micrographs have been observed with the help of Labomed optical microscope at 10x magnification having resolution of the order of 1μm and the microscope was kept in reflection mode. The micrographs are stored in computer through standard software (PixelView). Recorded two-dimensional (2-D) optical micrographs have been converted in three –dimensional (3-D) images with the help of Scanning Probe image processor computer program.

3. Results and discussion

Fig. 1(a) and (b) show the XRD pattern of as deposited and vacuum thermal annealed ZnTe/Mn thin films on glass substrate, which reveals the nanocrystalline structure of ZnTe and metallic Mn. It is found that the diffraction peaks at 2θ angles of 25.20^0, 41.85^0, 49.56^0 and 65.53^{0}corresponds to the (111), (220), (311) and (331) planes of the cubic zincblende structure of ZnTe [27] and 2θ angles of 34.20^0, 37.65^0, 51.56^0, 54.50^0 ,61.80^0, 64.20^0 and 78.54^0 corresponds to the (211),(321), (422), (321), (400), (331) and (511) planes of cubic structure of Mn.

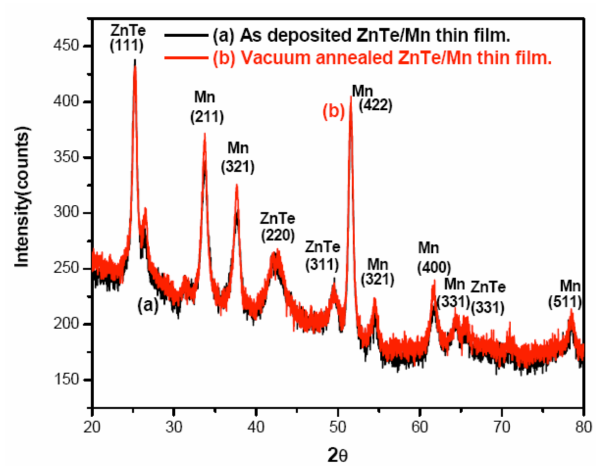

Fig. 1. X-ray diffraction patterns of (a) as deposited and (b) vacuum annealed ZnTe/Mn MLs thin films.

Fig. 1(b) shows changes in the X-ray diffraction spectra of vacuum annealed ZnTe/Mn thin film indicating the peak intensity has been increased due to annealing. It is suggested that the intensity of all the diffraction peaks has been increased due to possibility of grain growth and some limited grain growth has been occurred during annealing due to mixing of these multilayer of ZnTe and Mn.

Fig.2 shows I-V characteristics curves for (a) as deposited and (b) vacuum annealed thin film of ZnTe/Mn junction, in which (a) shows the partially straight line for both positive and negative ranges of voltage, indicating the ohmic behavior of the junction due to the free flow of Mn electrons across the junction, whereas (b) shows the partially semiconducting nature of the junction due to the annealing effect which causes the mixing or interdiffusion of metal -semiconductor thin film junction.

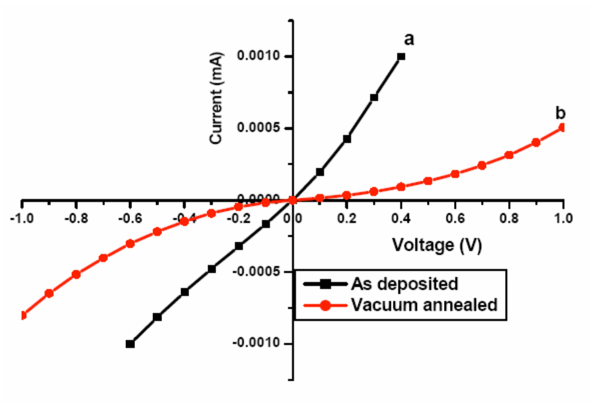

Fig.2 I-V characteristics curve for (a) as deposited and (b) vacuum annealed thin film of ZnTe/Mn MLs thin films.

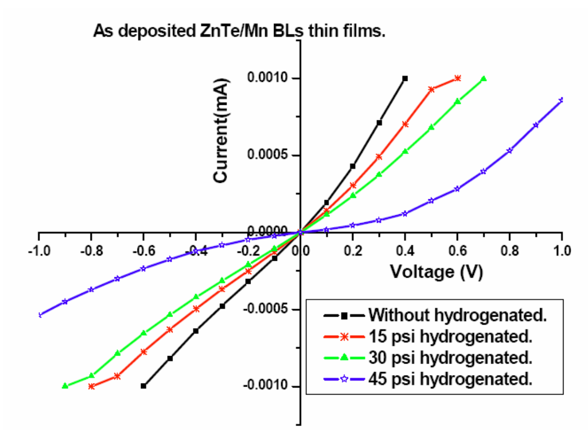

Fig.3 I-V characteristics curve of as deposited hydrogenated thin film of ZnTe/Mn MLs thin films.

Fig. 3 shows I-V characteristics curves of as deposited hydrogenated thin films of ZnTe/Mn junction have been found to be partially ohmic to partially semiconducting nature with increasing pressure of hydrogenation it may be suggested that hydrogen passivated defects at the interface causing the block of charges to free flow across the metal-semiconductor junction.

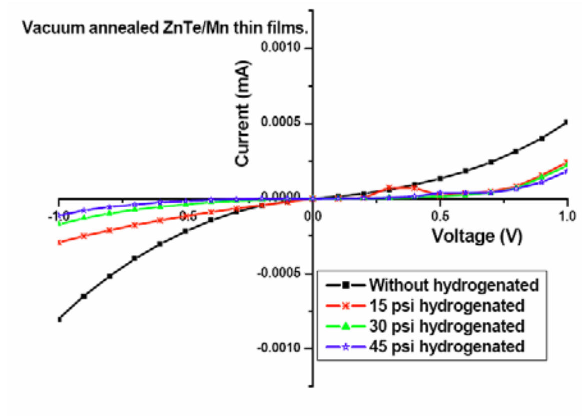

Fig. 4. I-V characteristics of vacuum annealed hydrogenated thin film of ZnTe/Mn MLs thin films.

Fig. 4. Shows that I-V characteristics of vacuum annealed hydrogenated thin films of ZnTe/Mn metal-semiconductor junction have been found to be semiconducting nature and current decreases with increasing pressure of hydrogenation due to the hydrogen interaction with metal and semiconductor. Hydrogen interacts with metal and semiconductor and takes electrons from conduction band of metal as anionic model.

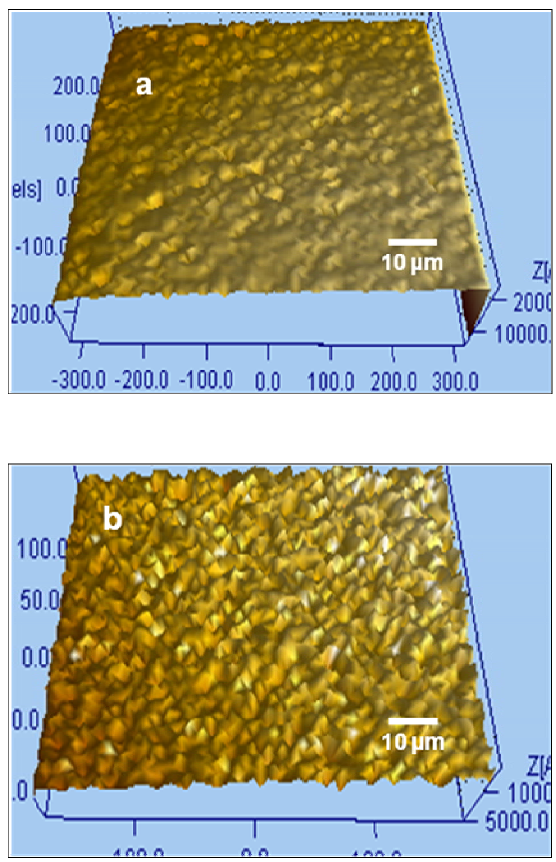

Fig. 5. Surface topography of (a) as deposited and (b) vacuum annealed ZnTe/Mn thin films with 3-D images.

Fig. 5(a) shows the optical micrograph of as deposited ZnTe/Mn thin film with 3D image and fig. 5(b) shows the optical micrograph of annealed ZnTe/Mn thin film with 3d image indicating the uniform deposition of thin film and proper mixing of ZnTe/Mn thin films. The surface roughness of ZnTe/Mn thin films has been found to be increased due to annealing indicating the improvement in crystalinity. The scale for both figures is 10 μm.

4. Conclusion

It may be concluded from the above study that structural characteristics shows ZnTe/Mn MLs DMS thin films have been deposited using vacuum coating unit and crystalinity nature of thin film increases due to annealing. I-V characteristics of as deposited and annealed ZnTe/Mn thin films show that the current has been found to be decreased with increasing pressure of hydrogenation due to the electronic passivation of host impurities induced by hydrogen in DMS thin films. The surface topography confirms the uniform deposition and proper mixing of these thermally evaporated ZnTe/Mn MLs DMS thin films.

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