Materials Science in Semiconductor Processing 88 (2018) 1–9

Contents lists available at ScienceDirect

Materials Science in Semiconductor Processing

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

Growth, characterization and photoconduction properties of $Sb_{0.1}Mo_{0.9}Se_2$ single crystals grown by DVT technique

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ARTICLE INFO

Keywords:
Crystal growth
$Sb_{0.1}Mo_{0.9}Se_2$ crystal
Structural properties
Photo-current
Photo responsivity
Detectivity and EQE

ABSTRACT

The present investigation deals with the preparation of antimony doped molybdenum di-selenide ($Sb_{0.1}Mo_{0.9}Se_2$) single crystals and its application for detection of UV–Visible radiation. The chemical composition of the crystals grown by direct vapor transport (DVT) technique is confirmed by Energy Dispersive Analysis of X-rays (EDAX), while the morphological analysis is carried out using optical microscopy and Scanning Electron Microscopy. The grown crystals are characterized by powder X-ray diffraction technique to evaluate the structural properties of the material and are compared with that of the pure $MoSe_2$ crystals grown under similar conditions. The XRD analysis revealed the hexagonal structure of the crystals. The indirect optical band gap of 1.39 eV, Urbach energy and steepness parameter were determined by UV–Visible spectroscopy. The ability of pure and Sb doped $MoSe_2$ crystals to be used as detectors of UV, Visible and IR radiations are studied by their pulsed photoresponse on exposure to a polychromatic source at varying intensities of illumination. Laser source (670 nm) having an intensity of $3\,mW\,cm^{-2}$, UV radiation (320 nm) having an intensity of $20\,mW\,cm^{-2}$ and IR radiation having an intensity of $120\,mW\,cm^{-2}$ were used in the measurements. The effect of biasing voltage on the photoresponse has also been analyzed. The excellent detection properties of the grown crystals are revealed from the responsivity, specific detectivity and external quantum efficiency (EQE) of pure and Sb doped $MoSe_2$ crystals. The effect of doping is clearly seen in the improvement of the detection properties of the crystals.

1. Introduction

Photosensitive solid state devices have great importance owing to their use as sensors and detectors in research and for commercial purposes; this has raised the need for various new photo sensitive materials with tailored properties. This requirement can be well fulfilled by thin 2D layered transition metal di-chalcogenide (LTMDCs), materials have been sought after for decades due to their exotic applications in the fields of optoelectronics, photonics and photovoltaic electronics as FETs, transducers, super capacitors, bio-sensors and NEMS [1–17]. These materials are usually of "MX_2" type where; M(= Mo, W, etc.) represents a transition metal sandwiched between two chalcogen atoms X(=S, Se). These materials are preferred over graphene due to the similarities in their structure and also considering the various growth techniques available in addition to layer thickness dependent band gap [18–21]. Layered semiconductor materials such as MoS_2, $MoSe_2$ and WSe_2 exhibit great potential towards fabrication of devices with improved characteristics including high mobility ($> 100\,cm^2\,V^{-1}\,s^{-1}$) and large photo responsivity (~ 500 A/W) to name a few; while their energy band gap falls between 1 and 2 eV [22–26] making them most prominent among similar class of materials for future electronic as well as photosensitive applications. Another fascinating property of these materials is the exhibition of quantum confinement effect [27,28] which causes indirect to direct band gap cross over on going from bulk to monolayer. Earlier reports suggest quantum confinement effect to be the main reason for the large photo responsivity of layered $MoSe_2$ semiconductor materials which exhibits detection properties from ultraviolet to near infrared region of electromagnetic spectrum in the bulk form rather than in a monolayer [29,30]. However, the physical and chemical properties of such materials can be intentionally altered by doping with impurities for desired applications. These impurities tend to enhance the electrical, optical and magnetic properties of the LTMDC materials [31–36]. The large photo responsivity of layered $MoSe_2$ is the sole reason for the efforts put in the present investigation to prepare Sb doped $MoSe_2$ crystals ($Sb_{0.1}Mo_{0.9}Se_2$) and to study its response under monochromatic, polychromatic, ultraviolet and IR sources. The variation in the morphological, structural and optical properties of the grown crystals due to doping is also studied and reported here in detail.

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https://doi.org/10.1016/j.mssp.2018.07.026
Received 25 May 2018; Received in revised form 9 July 2018; Accepted 17 July 2018
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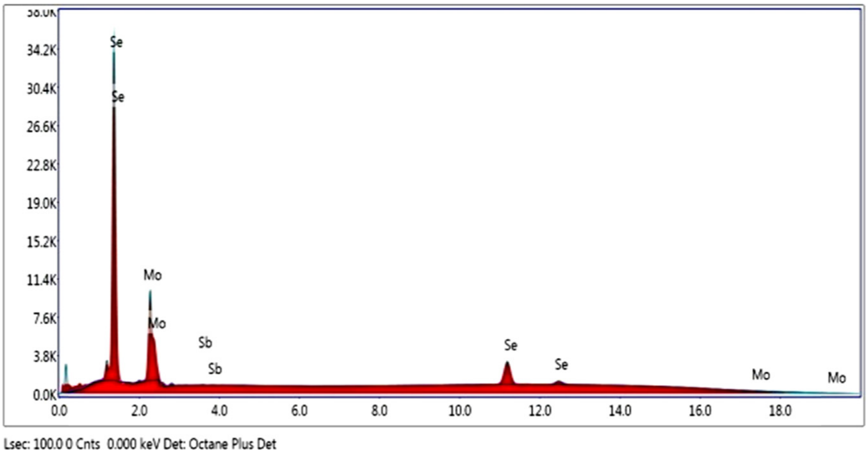

Fig. 1. EDAX spectra of $Sb_{0.1}Mo_{0.9}Se_2$ crystal grown by DVT technique.

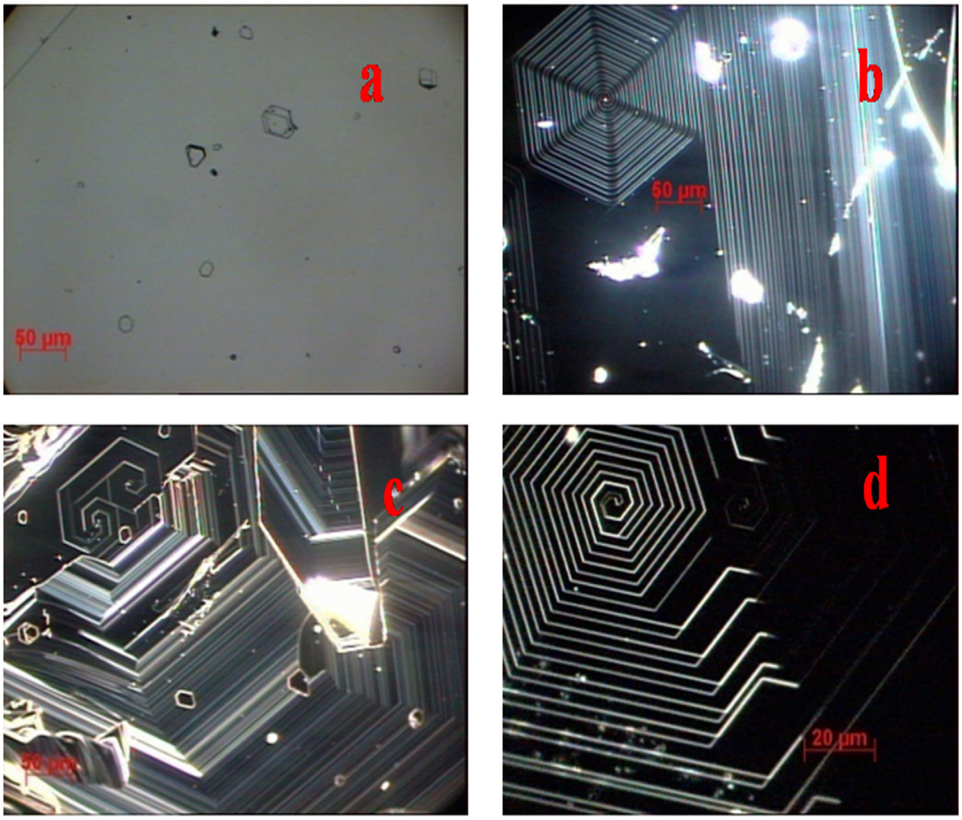

Fig. 2. Optical micrograph of $Sb_{0.1}Mo_{0.9}Se_2$ crystal (a) flat region on the surface (b) helical spiral on the surface (c) two close by screw dislocations observed on the surface and (d) The Frank-Read dislocation.

2. Materials and methods for growth of $Sb_{0.1}Mo_{0.9}Se_2$ crystals

Antimony doped molybdenum di-selenide ($Sb_{0.1}Mo_{0.9}Se_2$) single crystals were grown by direct vapor transport (DVT) technique [37–40]. Pure and analytical grade elements such as antimony (Sb), molybdenum (Mo) and selenium (Se) (Alfa Aesar, U.K) used as precursors, were taken in proper stoichiometric proportion (10 g) in a quartz ampoule which was later sealed after evacuating to 10^{-5} Torr. The ampoule thus sealed was then loaded in a dual zone horizontal furnace controlled by programmable temperature controllers “TAIE FY700” having an accuracy of ± 1 K. The temperatures at the source zone (SZ) and growth zone (GZ) were raised to 1353 K and 1333 K respectively with an increment rate of 24 K/h. The temperatures were maintained thus for 100 h and then gradually cooled to room temperature at the rate of 12 K/h. The temperature gradient of 20 K and a holding time of 100 h provide sufficient time for the reactions to occur in vapor phase and also ensure the growth of large sized crystals at the growth zone. The crystals thus obtained after growth are shiny thin plate like in appearance.

3. Characterization techniques

The confirmation of the chemical composition of the grown crystals was made by subjecting them to Energy Dispersive Analysis of X-rays (EDAX) using Philips FESEM XL 30. The surface topography of the grown crystals were studied by optical microscope (Carl Zeiss Jena) and Scanning Electron Microscope (SEM) Philips FESEM XL 30, while their structural properties were studied by powder X-ray diffraction (XRD)