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Characterization of the nanosandwiched Ga_2S_3/In/Ga_2S_3 interfaces as microwave filters and thermally controlled electric switches

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ABSTRACT

In this work, an indium layer of 50 nm thicknesses is sandwiched between two 500 nm thick Ga_2S_3 layers. The effect of indium nansandwiching on the composition, structure, morphology, light absorbability, capacitance and reactance spectra, and temperature dependent electrical conductivity of the Ga_2S_3 films are investigated by means of X-ray diffraction, scanning electron microscopy, energy dispersion X-ray spectroscopy, Raman spectroscopy, visible light spectrophotometry, impedance spectroscopy and current voltage characteristics. While the nansandwiched films are observed to exhibit an amorphous nature of structure with indium content of Owing to the nucleation mechanisms that take place during the film growth, the accumulation of some unit cells in groups to form grains should be a significant reason for the existence of many different sizes of grains in the nanosandwiched films (Alharbi and Qasrawi, 2016). O, the Raman spectra displayed three vibrational modes at 127.7, 145.0 and 274.3 cm^{-1}. It was also observed that the indium insertion in the structure of the Ga_2S_3 shrinks the energy band gap by 0.18 eV. The nanosandwiched films are observed to exhibit a semiconductor −metal (SM) transition at 310 K. The SM transition is associated with thermal hysteresis that exhibited a maximum value of 16% at 352 K. This behavior of the nanosandwiched films nominate it for use as thermally controlled electric switches. In addition, the impedance spectral analysis in the range of 10–1800 MHz has shown a capacitance tunability of more than 70%. The measurements of the wave trapping property displayed a bandpass/reject filter characteristics above 1.0 GHz which allow using the Ga_2S_3/In/Ga_2S_3 thin films as microwave resonator.

1. Introduction

The Ga_2S_3 compound has recently been widely considered as a result of its technological applicability. It has been employed as optical resonators and second harmonic generators [1]. It can also find it is position as promising smart capacitive switches, Plasmon devices and as wavetraps [2]. The GaAs/Ga_2S_3 interfaces are reported to be suitable for high −power radiation sensing [3]. Owing to its shorter wavelength transparency, the Ga_2S_3 single crystals are also considered as a competitor to pure and doped GaSe in mid-IR and THz applications [4]. Surface morphology, elemental stoichiometry, chemical

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states and stability, and crystallinity studies on gallium sulfide which was synthesized by the atomic layer deposition, using hexakis (dimethylamido) digallium and hydrogen sulfide revealed a self-limiting growth process of GaS_x in the temperature range of 125–225 °C [5,6]. Particularly, the growth per cycle is reported to decrease linearly with increasing temperature. The S/Ga ratio exhibited values between 1.0 and 1.2 in the temperature range of 125–200 °C and decreased to 0.75 at 225 °C [5]. It was observed that the growth of these films on single-walled carbon nanotube powders can perform as an excellent electrochemical anode material for use in lithium-ion batteries. Tests on these electrodes have yielded a stable capacity of ≈575 mA/g at a current density of 120 mA/g in the voltage window of 0.01–2.00 V [6].

Early works on the Ga_2S_3 thin films concerned information about the effect of doping processes on the optical performance of this compound. Particularly, it was observed that the Mn doped Ga_2S_3 single crystals prepared by the chemical transport reaction method displayed a dominant emission bands at 1.81 eV and other three weak emission bands at 2.34, 2.14 and 1.54 eV [7]. In our recent works [2,8], we have concentrated on the properties of the Ga_2S_3 in thin film form. The thin films of Ga_2S_3 deposited onto glass and onto Yb, Au and Al metallic thin film substrates were observed to be highly sensitive to the type of substrate. Promising types of plasmonic, metal-semiconductor and metal-semiconductor-metal rectifying devices were fabricated. Here in this work, we aim to report, the results of the nanosandwiching of an indium layer of 50 nm thicknesses between two layers of Ga_2S_3. Particularly, the effects of indium nanosandwiching on the structural, optical and electrical properties of the Ga_2S_3 are studied. The associated thermal hysteresis during the heating and cooling of the samples are reported and discussed. In addition, the alternating current transport dynamics through the sandwiched films is considered in detail.

2. Experimental details

The physical vapor evaporation technique is employed to prepare a 500 nm thick of Ga_2S_3 thin films onto ultrasonically cleaned glass slides from the 99.99% pure Ga_2S_3 powder (Alfa Aeser) under vacuum pressure of 10^{-5} Torr. The resulting fresh films were used as substrates to evaporate 50 nm thin layers of high purity (99.999%) indium. The indium coated Ga_2S_3 films are reused as substrate for the evaporation of another 500 nm thick Ga_2S_3 thin films. The thicknesses of the films were measured with the help of a thickness monitor attached to the system Norm VCM 600 vacuum evaporation system. The nanosandwiched Ga_2S_3/In/Ga_2S_3 films were subjected to X-ray diffraction, scanning electron microscopy, Raman spectroscopy, visible light spectroscopy and impedance spectroscopy analysis using Miniflex 600 diffractometer, Joel JSM 7600 F scanning electron microscope equipped with energy dispersion X-ray (EDX) analyzer, high resolution micro-Raman spectrometer (Thermoscientific DXR), evolution 300 spectrophotometer that is equipped with VEEMAX II reflectometer and 4291 B RF Impedance/Material Analyzer, respectively. The I–V characteristics data were recorded at different temperatures in the range of 300–400 K using a Keithley 230 programmable voltage source and Keithley 6485 picoammeter.

3. Results and discussion

The X-ray diffraction patterns from the top surface of the Ga_2S_3, Ga_2S_3/In and Ga_2S_3/In/Ga_2S_3 interfaces are displayed in Fig. 1(a). The figure illustrates an amorphous structure of the films before and after the sandwiching of indium similar to that of the not sandwiched Ga_2S_3 films [8] indicating that the 50 nm thick indium metal insertion between two 500 nm thick Ga_2S_3 layers does not alter the structure. For the Ga_2S_3/In double layer an intensive peak which is assigned to the tetragonal indium being oriented in the (101) direction is observed (PDF Card No.: 00-005-0642). Coating the indium 50 nm thick layer with 500 nm thick Ga_2S_3 forces this intensive peak to disappear.

To reveal more accurate information about the crystalline nature of the films we have subjected the Ga_2S_3/In/Ga_2S_3 interface to scanning electron microscopy analysis. The image which is shown in Fig. 1(b) represent a 30,000 magnification for the top surface of the films being recorded at an accelerating voltage of 2.0 kV. The image reflects very dense, randomly distribute and spherically shaped particles. Some rarely observed regions exhibit particles of larger sizes. When the image was enlarged 60,000 times (appears in Fig. 1(c)), those particles which are shown in red colored dashed circles exhibit size of ∼ 100 nm. Another group of particles which are also shown in blue dashed circles exhibited size values of ∼ 20 nm. Most of the other remaining particles which are very dark colored in the image of Fig. 1(c) are of 7–10 nm size. Owing to the nucleation mechanisms that take place during the film growth, the accumulation of some unit cells in groups to form grains should be a significant reason for the existence of many different sizes of grains in the nanosandwiched films [8]. On the other hand, when the Ga_2S_3/In/Ga_2S_3 interfaces were subjected to energy dispersion X-ray spectroscopy an elemental atomic contents of 40.7% and 59.3% of Ga and S were detected for the bottom layer. The EDS spectrum of the mapped elements of the Ga_2S_3/In/Ga_2S_3 is illustrated in the inset of Fig. 2(a). For the top layer, the Ga, S and In atomic contents were found to be 41.37% and 56.11% and 2.52%, respectively. Thus, the indium as a doping agent represents only ∼2.52% of the composition. The elemental distribution through the nanosandwich sample as observed from the EDS mapping which are illustrated in Fig. 2. The figure indicate a very dense presence of Ga (Fig. 2(b)) and S (Fig. 2(c)) compared to indium (Fig. 2(d)). The mapping of the indium which is shown in Fig. 2(d) is plotted on blue colored background to allow observation of the indium through the samples. The indium distribution is shown by while color on the blue background.

The Raman spectra for the Ga_2S_3/In/Ga_2S_3 interface are displayed in Fig. 1(d). The spectrum was recorded in the frequency range of 100–3000 cm^{-1}. However, because the spectra did not display any sharp patterns above 300 cm^{-1} it was not shown in the figure. One sharp very intensive peak appears at frequency of 127.7 cm^{-1}. The intensity of this Raman shift is 4650.