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Sb_2S_3 thin films: effect of PEI polymer substrate on physical properties

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Abstract: The aim of this work is to highlight the substrate effects on physical properties of antimony trisulphide (Sb_2S_3) thin films grown by simple chemical bath deposition. Sb_2S_3 thin films were deposited on glass and flexible Polyetherimide (PEI) substrates using similar deposition conditions. X-ray diffraction results indicate that both Sb_2S_3/glass and Sb_2S_3/PEI thin films are polycrystalline with orthorhombic structure. It was found that their texture and structural parameters are strongly dependent on the substrate. In fact, Sb_2S_3 growth on polymer substrate leads to an enhancement in surface roughness (RMS = 33 nm for Sb_2S_3/glass, and 116 nm for Sb_2S_3/PEI) and superhydrophobic character. This makes Sb_2S_3/PEI sought to be used in self-cleaning applications

Keywords: Sb_2S_3 thin films, PEI flexible substrate, Self-cleaning

1. Introduction

Sb_2S_3 is one of interesting metal chalcogenides. In fact, Sb_2S_3 thin films are widely used for various applications in the semiconductor industry for making infrared detectors, diodes, high-reflecting dielectric films, microwave devices, switching devices, absorber layer in different hetero-junction photovoltaic structures and photocatalysts [1]. This considerable attention is due to its suitable band gap, high absorption coefficient, relatively non-toxic and earth-abundant constituents, simple composition (binary compound), and long-term stability (a natural mineral: stibnite). The growth, structure, and properties of a deposited thin film depend significantly on a number of factors, such as the nature of the substrate, substrate temperature, deposition rate. As known, the physical properties of thin films are affected obviously by the process parameters such as the substrate nature [2]. Using thin films deposited on polymer flexible substrates received a great interest in progressing flexible electronic devices such as solar cell planer [3]. Flexibility and light weight are two great advantages to using plastic substrates [4].

In this work, PEI flexible polymer and glass substrates are employed for growth of Sb_2S_3 thin films by simple CBD technique. The effect of substrate nature on the physical properties was investigated. Our study was especially focused on the microstructure, surface morphology and hydrophobicity properties.

2. Results and Discussion

Fig. 1 shows the XRD patterns of the Sb_2S_3 thin films grown glass as well as on PEI substrates.

The XRD pattern of the Sb_2S_3/PEI sample showed broad band-related to the amorphous structure of the PEI polymer. The labeled peaks in XRD were compared to the standard JCPDS powder diffraction data set (78-1347). This analysis revealed that these samples are polycrystalline with orthorhombic structure. No other peaks related to impurities are observed which proves the high purity of Sb_2S_3 binary phase. It is clear that the substrate nature affects significantly the general texture and notably the preferred orientation. Hence, the preferential growth orientation of the polycrystalline Sb_2S_3 thin films can be understood from the texture coefficient $TC_{(hkl)}$ calculation using the following relation:

$$TC_{(hkl)} = \frac{I_{(hkl)} / I_{0(hkl)}}{N^{-1} \sum I_{(hkl)} / I_{0(hkl)}} \qquad (1)$$

where $I_{(hkl)}$ is the measured intensity for *(hkl)* diffracting plan, $I_{0(hkl)}$ is the corresponding intensity for randomly oriented sample taken from the JCPDS card and N is the number of observed diffraction peaks. The variation of the texture coefficient of all Sb_2S_3 thin films is shown in insert Figure 1. The change in crystallite preferred orientation for (a) and (b) thin films can be explained by the difference between the morphology of substrate surface. Notably, the contact angle measurements of PEI and glass substrate show that the PEI substrate (Ө =76°) is more hydrophobic than the glass one (Ө =50°) (figure 2). The variation of the hydrophobicity is due to the difference in adhesion forces (Van Der Wall's forces) between water and the solid surfaces. Indeed, it is noted that the PEI substrate has the lowest adhesion work with higher adhesion force (118,8 10^{-3} N/m) compared to glass one (96, 3 10^{-3} N/m), which is related to the difference in both composition and morphology of substrate surfaces. The polymer PEI substrate inherently has a low surface energy, namely, a hydrophobic character that results in poor adhesion. Consequently, the grown samples show different preferential orientations due to the surface energy of the substrate [5].

The substrate nature affects also the microstructural parameters of Sb_2S_3 thin films such as the crystallite size and structural defects. Using Debye Scherrer's formula, the crystallite sizes are found to be 138 nm and 63 nm for the Sb_2S_3/glass and Sb_2S_3/PEI, respectively. Also, the structural defects are computed for Sb_2S_3/glass and Sb_2S_3/PEI 7.2 $10^{-3}nm^{-2}$ and 0.2 $10^{-3}nm^{-2}$, respectively. We can assume that the films has the larger crystallite size has the lower structural defects.

Figure 3 displays 3D AFM images (10 µm× 10 µm) of Sb_2S_3/glass and Sb_2S_3/PEI thin films, along with the contact angle images.

The average RMS roughnesses are found to be 33 nm and 116 nm for Sb_2S_3/glass and Sb_2S_3/PEI, respectively. It is observed that using PEI substrate causes higher roughness than the glass substrate. Indeed, the surface of the polymer is more irregular than the glass surface causing, as a consequence, the different observed morphologies of Sb_2S_3 thin films. We can assume that the structural variations such as the texture and microstructural parameters reveal a significant variation in the morphology of thin films. The variation in the morphology causes a variation on contact angle measurement of Sb_2S_3 thin films. The static contact angles of Sb_2S_3/glass and Sb_2S_3/PEI films are found to be 66 ° and 162° respectively. As it is known the surface roughness is assumed to be among principal a factor which impinges surface wettability [6], which is in agreement with AFM observations. We can note that the Sb_2S_3/glass has a hydrophilic surface however the Sb_2S_3/PEI has a superhydrophobic one. This superhydrophobic character of Sb_2S_3/PEI surface thin films makes this material good candidate for self-cleaning surface devices.

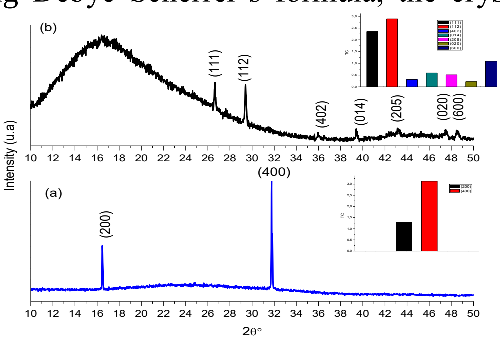

Figure 1.XRD patterns:Sb_2S_3/PEI (a) and Sb_2S_3/glass (b)

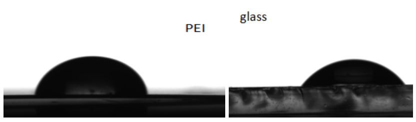

Figure 2. Contact angle measurements of PEI and glass substrate

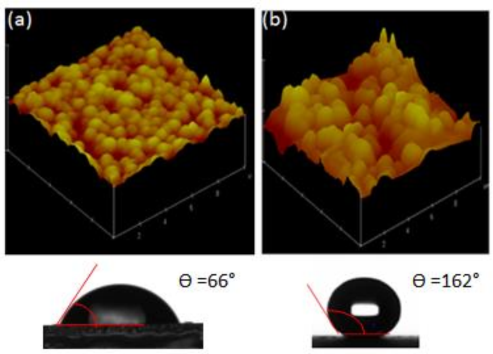

Figure 3. 3D AFM images and contact angle measurements of Sb_2S_3/PEI (a) and Sb_2S_3/glass (b)

3. Materials and Methods

Antimony sulphide thin films were prepared on glass substrates and PEI polymer substrate by simple chemical bath deposition. The bath for Sb_2S_3 was prepared as follows: $SbCl_3$ was dissolved acetone, (1 M $Na_2S_2O_3$ aqueous solution was added. We used the deposition temperature of 60 °C for 35 min. More details were reported elsewhere [7]. The thickness of the films is determined by double weight method. Calculations for film thickness were found to be 600 nm. The crystal structure of Sb_2S_3 films was determined by X-ray diffractometer analysis X Pert PromPD with radiation (λ=1.54Å). The surface morphology and roughness of the samples were analyzed using atomic force microscopy(AFM).The wettability measurements have been made using a contact angle meter (Micro-Drop analysis DSA 100 M) at room temperature.

4. Conclusions

Sb_2S_3 films were deposited on two types of substrate: glass and PEI flexible polymer by simple CBD technique with 600 nm of thickness. It was found that the substrate nature affect the growth of Sb_2S_3 notably the texture and the orientation. The microstructural parameters are also affected which influenced the morphologies Sb_2S_3 thin films. The grown process on different substrate is dependent on the chemical composition and the morphology of substrate surface. The contact angle measurement shows the poor adhesion of PEI substrate. The morphology of surface substrate affects the growth orientation, the texture and the microstructural parameters. The morphological properties and RMS values are substrate dependant. The Sb_2S_3 deposited on PEI shows a super hydrophobic surface which presents a good candidate for self-cleaning devices.

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