Photovoltaic structure:

$AgSbSe_2$ was chosen as the absorber layer for PV structure because of the good electrical and optical properties. Figure 6 shows the J-V characteristics of the PV structure: Glass/ITO/CdS/$AgSbSe_2$/Ag. This structure was illuminated from the CdS side using a tungsten halogen lamp. From the J-V curve, V_{oc}= 370 mV and J_{sc}=0.5 mA/cm^2 are obtained.

CONCLUSIONS

Thin films of $AgSb(S,Se)_2$ and $AgSbSe_2$ were formed by heating $Sb_2S_3/Ag_2Se/Ag$ multilayered precursor films in close contact with selenium thin film deposited for 1 h and 3 h respectively. From the studies on electrical and optical properties of these thin films, it is evident that by varying Ag and Se layer thickness in the precursor thin films, $AgSbSxSe_{2-x}$ thin films of appropriate electrical and optical properties can be obtained which will improve PV characteristics and performance. The advantage of selenization through chemical bath deposited Ag_2Se or Se thin films ensure a non- toxic and cost effective PV technology using this material.

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Structural Properties of CdTe Thin Films for Solar Cell Applications Deposited on Flexible Foil Substrates

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ABSTRACT

Cadmium telluride (CdTe) is a leading thin film photovoltaic (PV) material due to its near ideal band gap of 1.45 eV and its high optical absorption coefficient. The typical CdTe thin film solar cell is of the superstrate configuration where a window layer (CdS), the absorber (CdTe), and a back contact are deposited onto a glass slide coated with a transparent electrode. Substrate CdTe solar cells where the above listed films are deposited in reverse order are not common. In this study, the growth of CdTe thin films deposited on foil substrates by the close-spaced sublimation (CSS) has been investigated for the purpose of fabricating substrate based CdTe solar cells. The CdTe films were deposited at substrate temperatures (T_{SUB}) in the range of 300 to 600°C, and source temperatures (T_{SRC}) in the 600 to 650°C range. The effect of the substrate-source temperature variations on the growth rate, film structure and morphology were studied using XRD and SEM. It was found that for low substrate temperature and as the growth rate increases, grain size was the same but the films appeared to be more uniform and more densely packed with less or no pinholes. The growth rate increased as the source temperature increased. The substrate temperature clearly influences the grain growth and the preferred orientation. As the substrate temperature increased the growth rate decreased and the grain size varied from 2 to 6 μm. XRD analysis showed that with the increase in substrate temperature film orientation changes from preferential along the (111) direction to a mix of (111) (220) and (311).

INTRODUCTION

CdTe has long been recognized as an ideal material for thin film photovoltaics because of it's near ideal band-gap energy of 1.5eV, high absorption coefficient and the variety of available deposition techniques. The close spaced sublimation (CSS) is one of the most promising methods to deposit high quality CdTe films due to the large grain size, high material utilization and speed of deposition. There are various reports of the CdTe/CdS solar cells with efficiencies exceeding 15%, prepared by CSS [1, 2].

CdTe thin film solar cells are usually manufactured on glass substrates. Producing thin film solar cells on flexible metal foils offers several advantages over the glass based devices. Solar cells on thin metal foils can provide higher mechanical durability, are lighter and flexible making them suitable for space and terrestrial applications. Flexible solar cells with conversion efficiencies exceeding 7% have been developed on metal foil substrates [3].

The growth of CdTe thin films deposited on flexible foil substrates by CSS has been investigated in order to study their structural properties for solar cell applications. The effect of substrate-source temperature variation and the growth rate on the structure and surface morphology of CdTe films were analyzed. The films were characterized using SEM and XRD.

EXPERIMENTAL

Flexible stainless steel foil substrates were cleaned in an ultrasonic bath with acetone, methanol and de-ionized water. This procedure ensures that the metal foils are free of any contaminants and dust particles. A molybdenum layer (typically 4000Å in thickness) was deposited. Samples were then transferred into the CdTe-CSS system. The system consisted of two heated graphite blocks, one containing the CdTe source, and the other supporting the substrate. The source and substrate graphite blocks were heated by halogen lamps. Temperatures were measured using thermocouples inserted in the graphite blocks. For this study an inert ambient was used and was the same for all experiments. To investigate effects on CdTe morphology, the substrate temperature was varied from 300°C to 600°C at three different source temperatures of 600, 630, and 650°C and two different pressures. All samples were measured with X-Ray diffraction (XRD) and scanning electron microscopy (SEM) to study their structure and morphology.

RESULTS AND DISCUSSION

For each sample the growth rate was experimentally calculated using film thicknesses obtained from SEM cross-section images. Results show that the growth rate increased as the source temperature increased for films deposited at the same substrate temperature which was also reported by S.N Alamri [8]. Figure 2 shows the growth rate for different source temperatures. The growth rates were in the 1μm to 10μm per minute range. It is clear that really fast deposition rates can be achieved which is really important for a high throughput process. As the substrate temperature increases for a given source temperature the growth rate decreases. This maybe attributed to the fact that as the substrate temperature increases the sticking coefficient decreases, re-evaporation of CdTe increases, which in turn reduces the growth rate. Figure 1 shows SEM micrographs of CdTe films deposited at a source temperature of 650°C and with substrate temperatures of 450, 500 and 550°C respectively.

Figure 1. SEM micrographs of CdTe films prepared at different substrate temperatures of (a) 450°C, (b) 500°C and (c) 550°C. Source temperature was constant at 650°C.

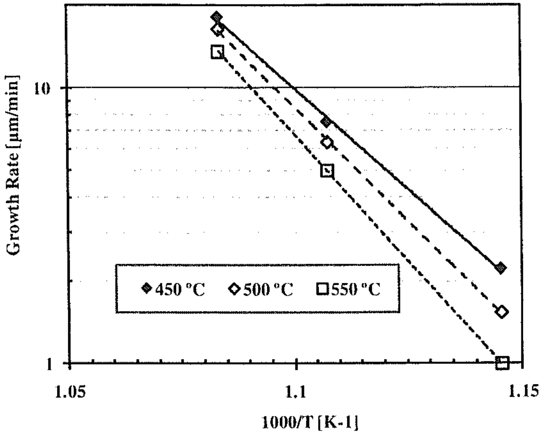

Figure 2. Growth rate versus $1/T_{SRC}$ at three different substrate temperatures of 450°C, 500°C and 550°C.

The film deposited at the lower substrate temperature appears to be the more uniform than the others with an average grain size of 3μm. It can also be seen that the films deposited at higher substrate temperatures exhibit significant variation in grain size, with large grains ~6μm, surrounded by smaller ones ~2μm. Despite the non-uniformities all samples appear densely packed and pinhole free a requirement for thin film solar cells. From the cross-section SEM pictures at figure 3 it appears that the grains extend through the whole film thickness.

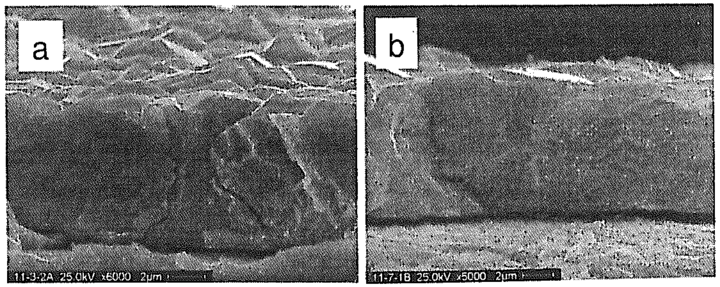

Figure 3. (a) SEM cross-section of CdTe at T_{SUB} 450°C and T_{SRC} 600°C. (b) SEM cross-section of CdTe at T_{SUB} 500°C and T_{SRC} 650°C.

To investigate changes in texture all samples were characterized using XRD. Figure 4 shows the XRD spectra of four CdTe samples deposited at substrate temperatures of 400, 450, 500 and 550°C. The source temperature was kept constant. The trend shown in figure 4 was the same for all source temperatures investigated in this work (630℃ and 650℃).

It can be seen from figure 4 that substrate temperature influences the preferred orientation of the grains. For the lowest substrate temperature of 400°C there is a very strong peak at (1 1 1) orientation along with a few other peaks with intensities below 1% of the intensity of the strongest peak. As the substrate temperature increases there is shift from the (1 1 1) orientation to a mix (1 1 1), (2 2 0) and (3 1 1) orientations as reported also by G.P.Hernandez [4].

The texture coefficient is a measure of the preferred orientation of crystallites along a crystal plane (h k l). A value of unity indicates random grain orientation, whereas a value greater than unity indicates preferred orientation of the crystallites in that direction. The texture coefficient *Pi* was calculated using equation 1 [5, 6]:

$$Pi = \frac{N(Ii/Iio)}{\sum_{N}(Ii/Iio)}, \qquad (1)$$

where *Ii* is the XRD intensity of the reflections from plane i, *Iio* is the corresponding intensity of the powder sample and N is the number of planes considered for analysis. The degree of orientation of the sample as a whole has been evaluated from the standard deviation σ, equation 2, of all the values calculated from *Pi* of each film [7]:

$$\sigma = \sqrt{\frac{\sum_{N}(Pi - Pio)^2}{N}}, \qquad (2)$$

where *Pio* is the texture coefficient of the powder sample. The value of σ was used to compare the degree of preferential orientation among the different samples. Values of standard deviation close to zero indicate that the sample has random orientation. The results for the texture coefficient and the standard deviation are given in table I.

Table I. Texture coefficient and standard deviation values for CdTe films deposited on flexible foil.

T_{SRC}	T_{SUB}	Texture Coefficient									
℃	℃	1 1 1	2 2 0	3 1 1	4 0 0	3 3 1	4 2 2	5 1 1	4 4 0	5 3 1	σ
600	400	7.57	0.00	0.08	0.09	0.10	0.23	0.92	0.00	0.00	2.34
	450	4.60	0.35	0.43	1.01	0.51	0.45	1.07	0.21	0.37	1.30
	500	2.93	0.75	1.02	1.37	0.84	0.67	0.92	0.49	0.00	0.77
	550	2.17	0.88	1.21	1.32	0.78	0.85	0.83	0.37	0.60	0.49
630	450	3.71	0.57	0.53	1.23	0.63	0.53	0.99	0.34	0.49	0.99
	500	2.69	0.69	0.94	1.41	0.72	0.72	0.86	0.38	0.60	0.65
	550	2.57	0.88	1.20	1.08	0.75	0.83	0.96	0.45	0.28	0.62
650	450	4.60	0.37	0.42	1.05	0.52	0.53	0.98	0.24	0.29	1.30
	500	3.25	0.57	0.74	1.40	0.57	0.59	0.81	0.35	0.72	0.84
	550	2.62	0.75	1.05	1.10	0.83	0.85	0.99	0.51	0.31	0.62

From table I it can be seen that the degree of preferential orientation has a dependence on the substrate temperature. For low substrate temperatures of 400 and 450℃ the value of σ is greater or close to one indicating that the sample as a whole has a significant orientation. As the substrate temperature increases the σ value decreases showing that the samples are oriented randomly as reported also by G.P.Hernandez [4]. From the texture coefficient though we can see that in all the films the (1 1 1) and (4 0 0) are the preferred orientations.

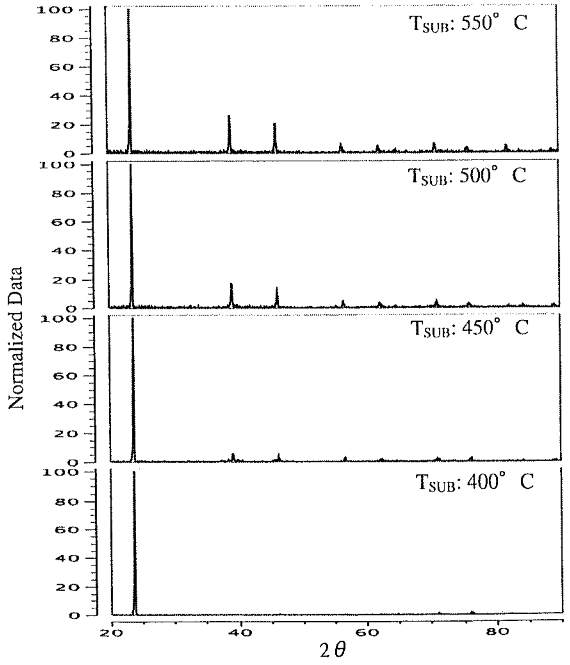

Figure 4. Normalized XRD-patterns of four films deposited at the same source temperature T_{SRC} of 600 ℃ but with different substrate temperatures.

CONCLUSIONS

The growth rate increased as the source temperature increased. The substrate temperature clearly influences the grain growth and the preferred orientation. As the substrate temperature is increased the growth rate decreases and the films are less uniform with grain sizes ranging from 2 to 6 μm. XRD analysis showed that with the increase in substrate temperature the orientation of the grain growth goes from a (111) plane to a mix of (111) (220) and (311). Further studies are being done to study the growth of ZnTe films on flexible foils and also the growth of CdTe on ZnTe films.

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High Optical Absorption of Indium Sulfide Nanorod Arrays Formed by Glancing Angle Deposition

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ABSTRACT

Indium (III) sulfide has recently attracted much attention due to its potential in optical sensors as a photoconducting material and in photovoltaic applications as a wide direct bandgap material. Optical absorption properties are key parameters in developing highly photosensitive photodetectors and high efficiency solar cells. We show that indium sulfide nanorod arrays produced by glancing angle deposition techniques have superior absorption and low reflectance properties compared to conventional flat thin film counterparts. We observed an optical absorption value of approximately 96% for nanorods, in contrast to 80% for conventional amorphous-to-polycrystalline thin films of indium sulfide. A photoconductivity response was also observed in the nanorod samples, whereas no measurable photoresponse was detected in conventional thin films. We give a preliminary description of the enhanced light absorption properties of the nanorods by using Shirley-George Model that predicts enhanced diffuse scattering and reduced reflection of light due the rough morphology.

INTRODUCTION

Indium (III) sulfide (In_2S_3) has promising properties for photovoltaic and optoelectronic device applications due to its wide bandgap, photosensitivity and photoconductivity [1,2,3], stable chemical composition and physical characteristics at ambient conditions. [2,3,4,5] It is intrinsically an n-type [6,7]semiconductor in the vicinity of 2.0 eV bandgap [1,12,15]. However, there is still controversy on whether it is a direct [8,9] or indirect[10,11] bandgap material. Also, for the environment, it is free of highly toxic heavy metals, such as cadmium [15,16,17]. Various synthesis methods for indium sulfide have been utilized, like, CVD[15], chemical bath deposition, chemical transport reaction [1], sputtering [15], spray pyrolysis [13,14], and thermal evaporation [13,14]. Most of the previous studies on indium sulfide have focused on the effects of crystal structure, doping, annealing, and stoichiometry [2,1,3,15,16,12,20], but there have been limited studies about the effects of nanostructuring on optical and electrical characteristics. Nanorod arrays have recently attracted attention due to their high optical absorption . Previously, various groups utilized surface textured morphologies in order to decrease the index of refraction and enhance the anti-reflection and subsequent trapping of light, using methods such as anisotropic etching, lithography, and glancing angle deposition (GLAD) [21,22]. In this study, we focused on the effect of nanorod morphology on the light absorption, transmittance, and reflectance characteristics of In_2S_3 materials. We show that by utilizing nanorod morphology produced by GLAD, it is possible to achieve a significant increase in the absorption compared to with conventional flat thin films. Together with the absorbance, the significant enhancement in the photoconductivity of nanorods is believed to be due to the enhanced random multiple scattering events caused by strong diffusion of light.

EXPERIMENT

We deposited arrays of indium sulfide nanorods in a custom designed vacuum thermal evaporation GLAD system. The sample size was 1"x1". The source material used was 99.99% pure Cerac In_2S_3 in powder form. Depositions were carried out at room temperature under 7.5 x 10^{-6} torr base pressure. A carbon crucible was used for evaporation and to avoid flash evaporation, the crucible was heated gradually and rate was monitored using a Sigma