CdTe thin films have been deposited by thermal evaporation in vacuum on slide glass substrate and on Cu thin film layer coated slide glass substrate without heating substrate. From XRD analysis, CdTe thin films obtained on both type substrates are polycrystalline belonging to cubic structure with a preferential orientation of (111) plane. However, a better preferential orientation of (111) plane was observed on CdTe films deposited on Cu thin film layer. Surface morphology of the as-deposited films was investigated by SEM technique. Energy gap values of the as-deposited films with different substrates were evaluated from the optical transmission spectra. The dark sheet resistance and sheet resistance under illumination by using ELH halogen lamp were performed on the as-deposited films at room temperature. The activation energy value was also obtained from the sheet resistance measurements as a function of temperature.

Keywords: CdTe thin films, XRD, SEM, Optical transmission, Electrical properties

T. Gaewdang: kgthitin@kmitl.ac.th

1Department of Applied Physics, Faculty of Science, King Mongkut's Institute of Technology Ladkrabang, Bangkok, 10520.
INTRODUCTION

CdTe has gained considerable interest as one of the most promising II-VI semiconductors as a solar cell absorber layer because of its direct band gap (1.5 eV), large absorption coefficient and sharp optical absorption edge. CdS/CdTe solar cells represent one of the leading candidates for polycrystalline thin film solar cells with the highest conversion efficiency for laboratory scale at 16.5\% [1,2]. The basic requirements are uniform CdTe film thickness around 2 \( \mu \)m with high absorption coefficient to absorb maximum solar radiation, low density of defects, morphological uniformity over large area with larger grains size (>0.5 \( \mu \)m), large diffusion length (0.2 \( \mu \)m) for minority carriers with p-type and resistivity < \( 10^3 \) \( \Omega \) cm, sharp interface, high stoichiometry without Te segregation, free of pinholes and voids with crystallographical orientation (111) cubic plane. CdTe in thin form can be grown by variety of techniques like closed space sublimation, sputtering, hot wall vacuum evaporation, molecular beam epitaxy and electrodeposition. Among the growth techniques for large area and low cost deposition for CdTe thin films, the thermal evaporation method is often preferred due to large possibility to modify the deposition conditions. In the present work, CdTe thin films were prepared by vacuum evaporation on different substrates. Structural, optical and electrical properties of the as-deposited films were also investigated.

METHODOLOGY

CdTe thin films were deposited on thoroughly pre-cleaned substrates by using thermal evaporation in vacuum better than \( 1x10^{-5} \) mbar. The substrates were soda lime glass of dimensions 25x12x1 mm\(^3\) and a Cu thin film layer deposited on soda lime glass. CdTe and Cu element using as starting material with 99.999 \% was supported by Aldrich. Cu thin film layer was also deposited on soda lime glass by vacuum evaporation. The crystal structure of these films was checked by X-ray diffraction technique with a Bruker D8 Advance with CuK\(_{\alpha}\) (\( \lambda = 1.5418 \) \( \text{Å} \)) radiation. The grain size was also calculated for different films using Scherrer's formula [3]. Grain size and surface morphology were revealed in accordance to scanning electron microscopy (SEM). The optical transmission spectra were measured with a spectrophotometer in the 700-1000 nm wavelength range at room temperature. The energy gap value was deduced from the optical transmission spectra. Sheet resistance was measured by direct current with two-probe method using Keithley 236 current/voltage source meter in darkness and under illumination of ELH halogen lamp. The contacts were made with silver paint, which showed ohmic over a wide range of voltage.
RESULTS AND DISCUSSION

The films obtained by this method were smooth, uniform, adherent pinhole free and dark-red in color. The CdTe films deposited on glass substrate with evaporation time 10 min show cubic structure with a preferential orientation of the (111) diffraction plane (Fig.1a). However, a less preferential orientation of the (111) plane was observed on CdTe films deposited on Cu thin film layer (Fig. 1b). From a full width at half maximum (FWHM) of (111) diffraction plane of the CdTe films deposited on glass substrate and on Cu thin film layer, grain size value about 100 nm and 1 μm was evaluated by using Scherrer’s formula [3]. Fig. 2 shows surface morphology of the CdTe films deposited on both type substrates. From SEM micrographs, the grain size of the both types of CdTe films is good agreement with the one obtained from Scherrer’s formula.

The optical transmission spectra were measured with a spectrophotometer in the 700-1000 nm wavelength range at room temperature. The absorption coefficient (α) was calculated using the expression: \[ T = 100 \exp(-\alpha d) \] where \( d \) is the thickness of the films and \( T \) is the percentage of transmittance. The plot \((\alpha h\nu)^2\) versus photon energy \((h\nu)\) are found to be straight lines, thus supporting the interpretation of direct rather than indirect energy gap. The energy gap values for CdTe films deposited on slide glass substrate and on Cu thin film layer are 1.51 and 1.50 eV respectively (Fig. 3). Generally, the accepted energy gap value of CdTe bulk crystal at room temperature is close to 1.5 eV. The energy gap value of our films, slightly higher than the one obtained in single crystal, is due to the quantum size effect [4]. From electrical measurements, the dark sheet resistance of the CdTe films deposited on slide glass substrate and on Cu thin film layer is 2.5 x 10⁹ and 28.548 Ω-cm respectively (as shown in Table 1). The dark sheet resistance value of the CdTe films deposited on slide glass substrate is very high cause of native defects and grain boundary scattering which is good agreement with those reported elsewhere [5]. In contrast, the one of the CdTe films deposited on Cu thin film layer is rather low cause of Cu dopant. Sheet resistance was also measured under illumination conditions using ELH halogen lamp. The sheet resistance value of the both type films slightly decreases under illumination condition (Table 1). The photosensitivity of our films may be due to the effect of photogenerated carrier and/or intergrain barrier height reduction [6].

The activation energy of the dark sheet resistance was found, using the equation: \[ R = R_0 \exp(E_a/kT) \] and plotting \( \ln(R/R_0) \) vs. 1000/T (Fig. 4), where \( R \) in sheet resistance at temperature \( T \), \( R_0 \) is sheet resistance at room temperature (300 K), \( k \) is the Boltzmann’s constant, and \( E_a \) is the activation energy. The activation energy of the CdTe films deposited on slide glass substrate and on Cu thin film layer is found to be 450 and 5 meV respectively. The first value is believed to be related to isolated
Cd vacancy defect in the films. The second one is associated with $\text{Cu}^+\text{V}_{\text{Cd}}^-$ and/or $\text{Cu}^+\text{Cu}_{\text{Cd}}^-$ complexes [7]. We plan to reduce sheet resistance by CdCl$_2$ treatment for efficient CdTe solar cell in near future. The present work constitutes an intermediate step towards the development of low cost CdS/CdTe thin film solar cells.

![XRD patterns of CdTe thin films deposited on slide glass substrate (a), and on Cu thin film layer (b).](image1)

**Fig. 1** XRD patterns of CdTe thin films deposited on slide glass substrate (a), and on Cu thin film layer (b).

![SEM micrographs of CdTe thin films deposited on slide glass substrate (a), and on Cu thin film layer (b).](image2)

**Fig. 2** SEM micrographs of CdTe thin films deposited on slide glass substrate (a), and on Cu thin film layer (b).
Fig. 3 The plot $(\alpha h\nu)^2$ versus photon energy $(h\nu)$ of CdTe thin films deposited on slide glass substrate (a), and on Cu thin film layer (b).

Fig 4. ln$(R/R_0)$ versus $1000/T$ of the CdTe thin films deposited on slide glass substrate.

Table 1 Some important parameters of CdTe thin films deposited on slide glass substrate and on Cu layer coated slide glass substrate.

<table>
<thead>
<tr>
<th>Thin Film Configuration</th>
<th>Lattice Constant (Å)</th>
<th>Grain size (nm)</th>
<th>Energy Gap (eV)</th>
<th>$R_s$ (Ω/sq)</th>
<th>$E_a$ (meV)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Darkness</td>
<td>Illumination</td>
</tr>
<tr>
<td>CdTe/glass</td>
<td>6.427</td>
<td>100</td>
<td>1.51</td>
<td>$2.5 \times 10^3$</td>
<td>$2.5 \times 10^3$</td>
</tr>
<tr>
<td>CdTe/cu/glass</td>
<td>6.731</td>
<td>1000</td>
<td>1.50</td>
<td>28.55</td>
<td>28.50</td>
</tr>
</tbody>
</table>
CONCLUSION

CdTe thin films have been deposited by thermal evaporation in vacuum on slide glass substrate and on Cu layer coated slide glass substrate without heating substrate. From XRD analysis, CdTe thin films obtained on both type substrates are polycrystalline belonging to cubic structure with a preferential orientation of (111) plane. However, a better preferential orientation of (111) plane was observed on CdTe films deposited on Cu thin film layer. From SEM micrographs, grain size of the CdTe films deposited on slide glass substrate and on Cu thin film layer about 100 nm and 1 μm was observed. The dark sheet resistance and sheet resistance under illumination by using ELH halogen lamp were performed on the as-deposited films at room temperature. The activation energy values of the films deposited on slide glass substrate and on Cu thin film layer, evaluated from the Arrhenius plot of the sheet resistance versus inverse temperature, were found to be 450 and 5 meV respectively. These values are believed to be related to isolated Cd vacancy defect and Cu$^{+}$-V$_{Cd}$ and/or Cu$^{+}$-Cu$_{Cd}$ complex states respectively. The present work constitutes an intermediate step towards the development of low cost n-CdS/p-CdTe thin films solar cells.

ACKNOWLEDGEMENTS

We would like to thank Assoc.Prof.Dr. T. Wongcharoen and Asst.Prof.Dr. C. Poo-Rakkiat for valuable discussions and C. Chityuttakarn for vacuum system installation. This work was supported by Faculty of Science, KMITL.
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