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CdS Thin Films Prepared by RF Magnetron Sputtering in Ar Atmosphere

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CdS thin films were prepared using rf planar magnetron sputtering in Ar atmosphere. Different deposition temperatures between 150 and 250 °C and different rf powers between 30 and 130 W were used. The films had hexagonal structure with crystallites oriented in the ⟨100⟩ direction. The increase of deposition temperature caused an increase in the crystallite size (from 380 to 450 Å) and a decrease in the resistivity (from 3.87 to 0.95 Ω cm). The increase in the rf power (from 30 to 130 W) caused a decrease in the grain size (from 480 to 320 Å) and an increase in the resistivity (from 0.51 to 2.05 Ω cm) above 70 W. The average optical transmission in the visible region of the spectrum ranged between 71 and 86%. The quality of the films as window layers for solar cell applications was investigated.

1. Introduction

CdS thin films have received a growing interest over the past three decades due to their electro-optical properties that are suitable for applications in the field of optoelectronic devices, particularly solar cells [1] and photodetectors [2]. Several methods have been used for the preparation of such films (e.g. evaporation [3], chemical path deposition [4], electro-deposition [5], screen printing [6]). On the other hand, the use of rf sputtering for the preparation of CdS films has received relatively little attention [7 to 9] despite the known advantages of this method in (i) producing films that are closely stoichiometric, (ii) being cheep and (iii) being scalable to production of large area.

The effect of various preparation parameters (e.g. deposition temperature, rf power, argon gas pressure) on the properties of the CdS films, prepared by diode rf sputtering in argon atmosphere, has been studied previously [7, 9]. The rf planar magnetron sputtering technique has been used for the preparation of CdS thin films in $Ar{-}H_2$ atmosphere [10], or in Ar atmosphere in the course of the study of CdS/CdTe solar cells [11]. However, to our knowledge, there has been no previous investigation of the effect of the preparation variables on the properties of films prepared be rf planar magnetron sputtering in Ar atmosphere. The effect of film thickness on the structural, electrical and optical properties of such films has been described in a previous report [12]. Here we report on the variations of those properties with the deposition temperature and the rf power.

2. Experimental

The films were sputtered from CdS targets of purity 99.999% provided by E-Vac Products. The sputtering was performed in the chamber of a sputtering system type Edward

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306 which uses a planar magnetron source. The chamber was evacuated to a pressure of 10^{-5} Torr before admitting pure Ar gas (purity 99.999%) at a pressure of 5 to 6 mTorr. Before deposition, conditioning of the target was carried out by sputtering for 10 min while the substrate was covered by a shutter. This ensures normalization of initial sputtering conditions. The substrates were microscopy glass. They were chemically cleaned and, before sputtering, they were further cleaned in the chamber by glow discharge. The substrate was heated using a radiant heater (quartz–halogen lamp) and the substrate temperature was measured using chromel–alumel thermocouple. The film thickness was measured using Tencor Instruments Alpha Step 200 Profiler. Ohmic contacts for electrical measurements were prepared by evaporation of indium spots (200 nm thick) on the film. The conductivity was measured using the Van der Pauw method. The transmission measurements were carried out using a spectrophotometer type Cary 5E. XRD spectra were obtained using an X-ray diffractometer type Siemens D5000, which uses the Cu Kα line ($\lambda = 1.5406$ Å) with Bragg-Brentano measurement geometry. The resolution in angle of the diffractometer was 0.050°.

3. Results and Discussions

Two sets of CdS thin films were prepared. The first set includes films prepared at different deposition temperatures between 150 and 250 °C using a constant rf power of 50 W. The second set includes films prepared at 220 °C using different rf powers between 30 and 130 W.

3.1 Effect of substrate temperature

XRD studies showed that the films have hexagonal structure, without cubic phase. The spectrum (Fig. 1) shows strong enhancement of the 002 peak indicating a preferential orientation of the crystallites along the ⟨100⟩ direction. The mean crystallite size was calculated using the formula

$$d = K\lambda/D \cos\theta\,, \tag{1}$$

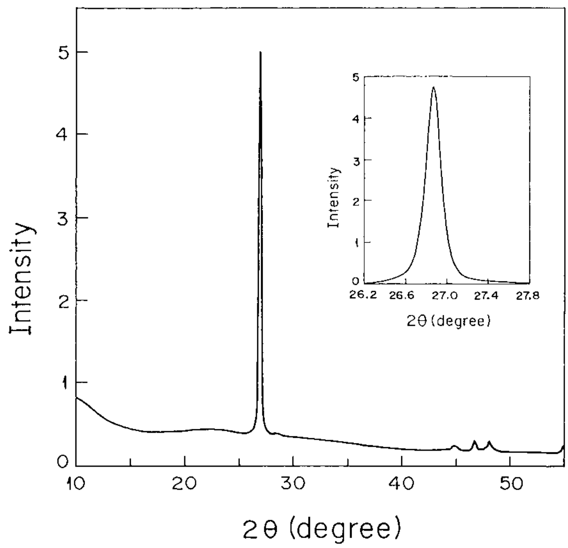

Fig. 1. Typical RDF spectrum (intensity in arbitrary units) for CdS thin films showing the enhancement of the (002) peak. Inset: the (002) peak enlarged for the calculation of the grain size using Eq. (1)

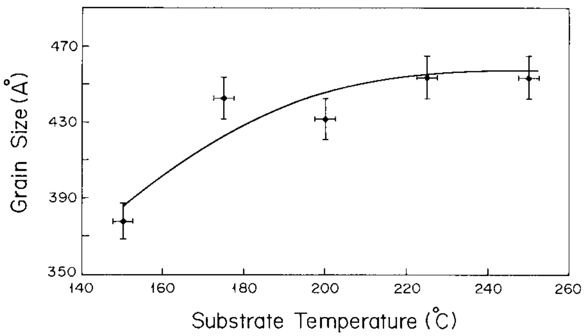

Fig. 2. Crystallite size as a function of substrate temperature for CdS films prepared using rf power of 50 W. The films thickness is 462 ± 35 nm

where K is a constant with value ranging from 0.70 to 1.70 depending on both the crystallite shape and the way in which d and D are defined [13]. It has been shown that the definition of d as the effective thickness of the crystallite in the direction perpendicular to the reflecting planes leads to values of K in the neighbourhood of 0.90, provided D is defined as the full width at half maximum (FWHM) of the diffraction peak [13]. λ is the Cu Kα wavelength.

The accuracy of the mean crystallite size measurements using Eq. (1) has been discussed [13] and measured [14] previously. The inaccuracy was found to be about 5 to 10% at maximum for the size range measured here. The grain size was calculated from the FWHM of the 002 peak using Eq. (1). The smallest line width observed was 0.18°, much wider than that for single crystals. Therefore the FWHM of the 002 peak was taken as a measure of the broadening of the peak. The calculated crystallite size varies between 380 and 450 Å and increases with the increase of substrate temperature T_s (Fig. 2). This indicates that the process of grain formation is thermally activated.

All the prepared films were n-type with carrier mobility less than 5 cm^2/Vs. Fig. 3 shows the resistivity ϱ as a function of substrate temperature T_s for films prepared using rf power of 50 W. As T_s increases from 150 to 250 °C, ϱ decreases from 3.9 to 0.95 Ω cm. Martil et al. [7] observed much higher values of ϱ and an increase of ϱ from 10^2 Ω cm at 100 °C to 10^8 Ω cm at 240 °C. The disagreement between those observations and the results in Fig. 3 may be due to a higher degree of compensation in the samples studied by Martil et al. It is to be noted that Martil et al. [7] used a diode rf sputtering technique which does not involve magnetic field effects as for the case of the rf magnetron sputtering technique used here.

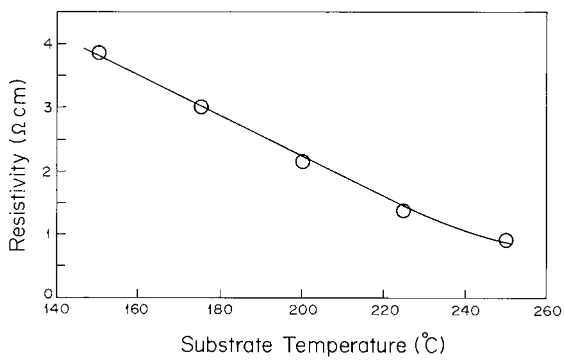

Fig. 3. Electrical resistivity as a function of substrate temperature for films prepared using rf power of 50 W. The films thickness is 462 ± 35 nm

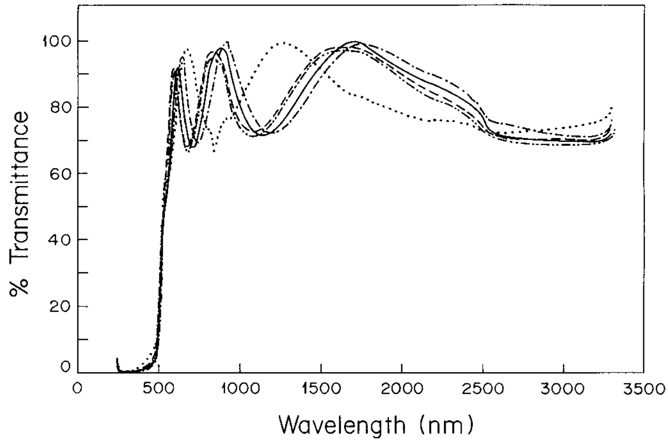

Fig. 4. Optical transmission spectra of CdS films of thickness 462 ± 35 Å prepared at different substrate temperatures, (——) 150 °C, (– – –) 175 °C, (······) 200 °C, (– · –) 225 °C, (– ·· –) 250 °C

The transmittance of the films was measured as a function of wavelength in the range 400 nm $< \lambda <$ 3400 nm. The results are shown in Fig. 4 for films of thickness 462 ± 35 nm. The spectra exhibit interference peaks with average transmittance in the visible of 83% to 86%.

3.2 Effect of rf power

The XRD patterns the films did not show noticeable variations with the rf power. The films had hexagonal structure with preferential orientation of crystallites along the ⟨100⟩ direction. The grain size calculated form Eq. (1) is shown as a function of rf power *P* in Fig. 5. The grain size ranges between 320 and 480 Å and decreases with the increase of *P*. This is to be expected since the sputtering rate increases appreciably with the increase of *P*. Fig. 6 shows the dependence of sputtering rate on rf power.

The resistivity ϱ of the films ranges between 0.35 and 2.13 Ω cm. It is nearly constant up to about 70 W and increases with the increase of *P* above that value (Fig. 7). This increase of ϱ is consistent with the observed decrease of grain size with *P*. As the grain size decreases the grain boundary scattering of current carriers is enhanced which leads to a lower mobility and a higher resistivity.

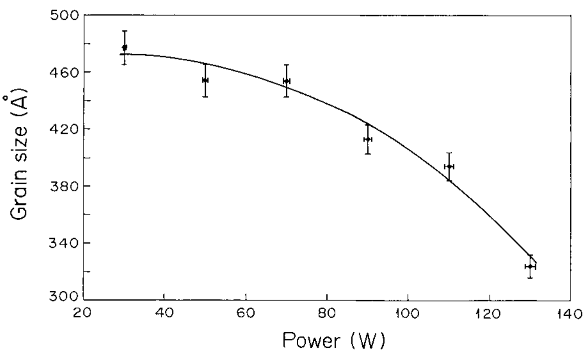

Fig. 5. Dependence of the crystallite size on rf power for CdS films prepared using substrate temperature of 220 °C. The film thickness is 453 ± 15 nm

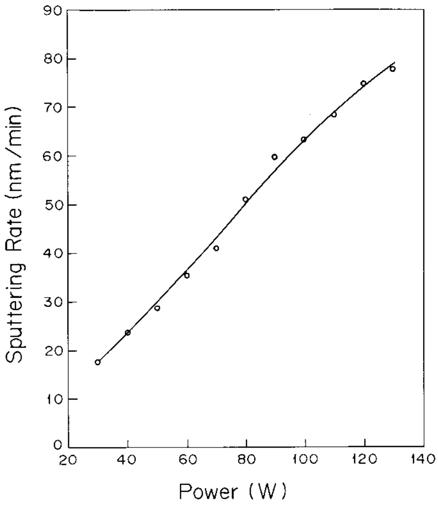

Fig. 6. Dependence of the sputtering rate on rf power for films prepared at 220 °C

The average transmittance in the visible varies between 72% and 86% depending on the value of *P*. However, no trend between the average transmittance and *P* was observed. The film thickness was 453 ± 15 nm.

3.3 Figure of merit

The figure of merit is a measure of the quality of the films with respect to photovoltaic applications [15]. It is defined as

$$\Phi = T_a^{10}/R_s ,$$

where T_a is the average transmission in the visible, R_s is the sheet resistance. The highest value of Φ $(= 10^{-5}\,\Omega^{-1})$ was obtained for $T_s = 220\,°C$ and $P = 70$ W. To the author's knowledge this is the highest value of Φ reported for as grown undoped CdS films prepared by the sputtering technique.

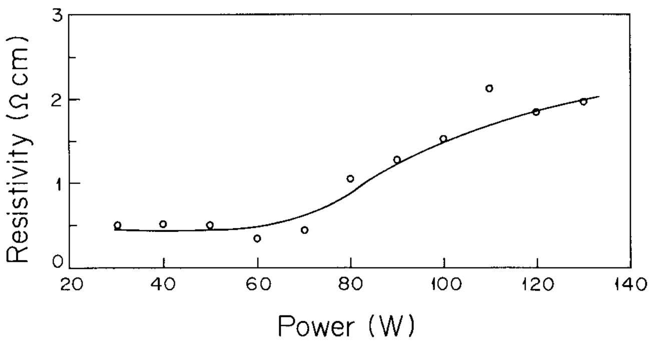

Fig. 7. Dependence of the electrical resistivity on rf power for films prepared using substrate temperature of 220 °C. The film thickness is 453 ± 15 nm

4. Summary

The technique of rf magnetron sputtering was used to prepare CdS thin films using different deposition temperatures and rf powers. The films were polycrystalline with hexagonal structure and with crystallites preferentially oriented along the 100 axis. With increasing substrate temperature the grain size increases and the resistivity decreases. The increase in the rf power causes a reduction in the grain size and an increase in the resistivity above 70 W. The best value of the figure of merit ($\Phi = 10^{-5}\ \Omega^{-1}$) is the highest reported on as grown undoped CdS thin films prepared by sputtering.

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