Bull. Mater. Sci., Vol. 20, No. 8, December 1997, pp. 1085–1087. © Printed in India.

Depth profiling of CdS homojunction using AES analysis

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MS received 31 July 1997; revised 17 October 1997

Abstract. Top layer of spray pyrolyzed *n*-type CdS has been converted into *p*-type by diffusion of copper which resulted in the formation of homojunction. This is achieved by annealing CdS/Cu bilayer film. The nature of diffusion of copper atoms into CdS has been studied using auger electron spectroscopy (AES).

Keywords. Cadmium sulphide; spray pyrolysis; AES.

1. Introduction

Cadmium sulphide (CdS) thin films have potential application in optoelectronics. These films can be prepared in large area by simple and low-cost processes viz. spray pyrolysis technique (Chamberlin and Sakarman 1966) and chemical bath deposition technique (Kaur *et al* 1980). Moreover it forms heterojunctions with a number of materials like Cu_xS (Norian and Edigton 1981), CdTe (Arita *et al* 1991), $CuInSe_2$ (Schwartz *et al* 1991) etc. Normally the conductivity of as-prepared CdS thin films will be *n*-type (Chopra and Das 1983). Kashiwaba *et al* (1992) recently reported the *p*-type characteristics of copper-doped CdS thin films prepared by vacuum evaporation. Later, Sunny Mathew *et al* (1995) reported the *p*-type characteristics of copper-doped CdS thin films deposited using spray pyrolysis technique, and, with the help of techniques like XRD, XPS and optical absorption, they confirmed that compounds like Cu_xS have not been formed owing to diffusion of copper atoms into the CdS film.

Keeping the idea of device fabrication, we fabricated a homojunction in spray-pyrolized CdS films and the results are reported elsewhere (Varkey and Vijayakumar 1997). We have studied the nature of copper diffusion into CdS film using auger electron spectroscopy (AES) and the results are reported in this paper.

2. Experimental

Transparent and conducting SnO_2 thin films were prepared by spraying an alcoholic solution of stannic chloride ($SnCl_4 \cdot 5H_2O$) over a very clean glass plate kept at 500°C with compressed air as the carrier gas. Thickness of SnO_2 films coated were ~ 500 nm and this was the lower electrode for the device. This layer had an optical transmission of 80% and a resistivity of $25 \times 10^{-6}\ \Omega$m.

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CdS thin films were prepared by spray pyrolysis technique on SnO_2-coated glass substrate. Solutions of cadmium chloride (0·02 M) and thiourea (0·02 M) were prepared and mixed in the ratio 1:1 by volume. This was sprayed on to the SnO_2-coated glass substrate kept at 300°C. The spray rate was kept at 15 cc per min, which ensured uniform thickness. Thickness of the film was about 1·3μm, and the type of conductivity of the CdS film was found to be *n*-type. High pure copper (99·999%) was deposited on the as-prepared *n*-CdS film by vacuum evaporation at room temperature in a high vacuum coating unit at a pressure slightly less than 1×10^{-5} torr. Thickness of the copper layer was about 400 nm. These samples with the copper layer on top surface were annealed in vacuum (10^{-4} torr) at temperatures in the range 100°C–300°C for 45 min. The heating and cooling rates were kept at 2°C/min in all the cases.

Due to annealing the copper deposited on top of *n*-CdS diffused into it. Electrical connection to the top layer was given by depositing indium (thickness ~ 500 nm) using vacuum evaporation.

3. Results and discussions

AES analysis of a sample annealed at 300°C is shown in figure 1, which shows that thickness of copper layer on the top surface of the annealed sample is very feeble and the copper concentration increases and reaches a maximum value at about a depth of 100 nm on CdS film and thereafter the concentration of copper decreases rapidly. This result agrees with the earlier VASE analysis in which it was shown that the diffusion of copper into CdS layer is not homogeneous (Sunny Mathew *et al* 1995). Further, the AES analysis shows that there is a layer of *n*-CdS at the bottom without any trace of copper. This result supports our earlier work of fabricating a homojunction on CdS thin films. From the figure we can see that the depth of free *n*-type CdS layer is about

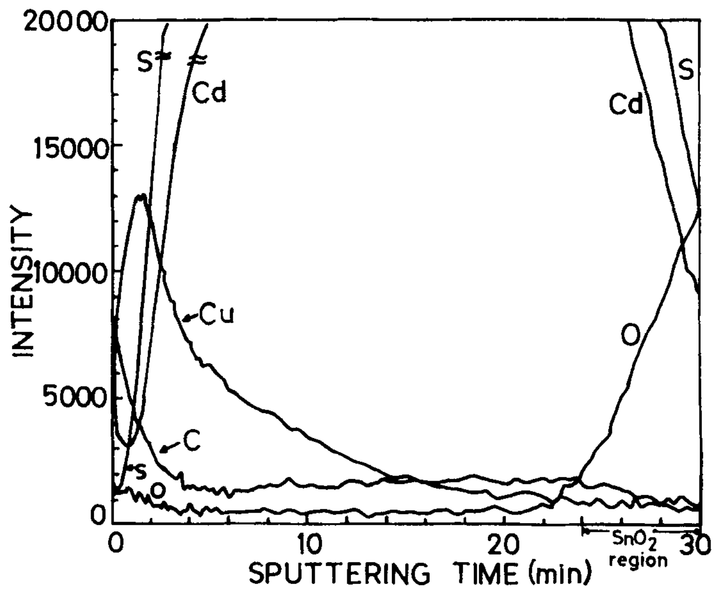

Figure 1. AES depth profile of p-CdS/n-CdS/SnO_2 sample analysed.

500 nm and the depth of copper diffused *p*-CdS layer is about 800 nm, since the sputtering rate is 50 nm/min for CdS. The percentage of copper atoms diffused is calculated to be 25%. This is in agreement with the earlier work (Kashiwaba *et al* 1992).

We fabricated a solar cell using this homojunction. Glass coated with conducting transparent layer (SnO_2) was used as the substrate in this case so that the SnO_2 layer will act as the lower electrode of the cell. Evaporated indium over the *p*-type CdS formed act as the top electrode. Illumination of 60 mW/cm^2 was given through SnO_2 side. This gave an open circuit voltage of 200 mV and short circuit current density of 5 mA/cm^2 and the efficiency of the cell is calculated to be 0·73%.

We have done the AES analysis of the homojunction for optimizing *p*-CdS layer and *n*-CdS layer which may improve the efficiency of the cell. Also uniform distribution of copper atoms may increase the cell efficiency. Works are in progress in achieving better efficiency. Even if the efficiency is low, this technique can be used for making a tandem solar cell in which CdS forms top layer over another *p*-type material like $CuInSe_2$.

4. Conclusion

CdS/Cu bilayer has been annealed for diffusing copper into CdS layer. This resulted in the formation of a *p*-type CdS at the top layer. Depth profile of copper diffused CdS layer is analysed using AES technique. It is observed that copper atoms have not diffused fully upto the bottom layer of CdS. At the bottom, there remains a layer of *n*-type CdS. This supports the formation of a homojunction.

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