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Photoconductivity in vacuum deposited cadmium selenide thin films

B V Rajendra, V B Kasturi & G K Shivakumar
Department of Physics, National Institute of Technology, Surathkal, Srinivasnagar 575 025, India

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Photoconductivity has been studied in cadmium selenide thin films prepared by thermal evaporation in vacuum. Attempts have been made to correlate the photoresponse with the deposition conditions. It has been observed that as-grown films, irrespective of the cadmium content, are not photosensitive and that baking in air, especially above 723 K, leads to considerable improvement in the photoconducting properties of cadmium selenide films.

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Cadmium selenide has been investigated for many years due to its potential use in photoconductive devices, photovoltaic solar cells and electro photographic photoreceptors. The suitable direct band gap (1.70 eV) of the material encouraged many researchers to study the growth of its thin films for use in device fabrication. The electrical properties of these films depend mainly on the impurity concentration and the sensitization of the films. A few studies have been reported on the photoconducting properties of pure and doped cadmium selenide films[1-13], but with widely varying results. The lack of agreement on the results may be traced to the non-uniformity of growth conditions. The performances of polycrystalline cadmium selenide thin film devices were observed to depend critically on the preparation conditions and subsequent heat treatment[14]. Structural studies of cadmium selenide films deposited onto different substrates were reported by Chaudhuri *et al.*[15] Wurtzite hexagonal phase has been reported by various workers[16] for films deposited onto glass substrate at temperature below 470 K. Photoconductivity of cadmium selenide films and the effect of defect structure were studied by Sakalas[17]. Electrical and photoelectrical properties for cadmium selenide films and crystals were also reported by a few groups[1-3,7,18-20]. Photoelectrical and optical properties of cadmium selenide films deposited onto glass substrates by the hot wall evaporation technique has been reported by Mondal *et al.*[21]

The present paper reports an analysis of the photoconductivity of cadmium selenide thin films as a function of deposition and post-deposition conditions of sample preparation.

Experimental Procedure

Thin films of pure cadmium selenide (250-300 nm thickness) were prepared by thermal evaporation onto corning glass substrates at temperature in the range 300-523 K in a residual air pressure of 10^{-5} torr. Stoichiometric powder of cadmium selenide (purity 99.999% obtained from Research Organic/Inorganic Chemical Corporation USA) was taken as the source material and molybdenum boat source was used for the evaporation. The details of the composition and structure of the films deposited at different substrate temperature have been described elsewhere[16]. The films were deposited at the required temperature and then cooled to room temperature before examination. Baking was carried out in an oven heated to the required temperature. The duration of baking was uniformly two hours for all samples.

Electrical measurements were carried out with a Keithley 614 electrometer using ohmic aluminum contacts. Spectral dependence of the photoconductivity were measured under light illumination varying between 0.1 and 1 W m^{-2} in the spectral region 400-900 nm.

Results and Discussion

Detailed experiments were carried out to study the photoconductivity in cadmium selenide thin films prepared under various growth conditions. The parameters selected for the analysis include the deposition temperature and the temperature of baking in air. It has been observed that cadmium selenide thin films deposited at various substrate temperatures in the range 300-523 K have a weak photosensitivity (Table 1). There is a marginal increase in its

Table 1—Effect of substrate temperature on the photosensitivity of cadmium selenide films

Sample number	Substrate temp., K	(R_d / R_{ill})
GB11	300	1.01
GB10	373	1.06
GB07	453	1.33
GB01	523	1.12

Table 2 –Effect of baking in air on the photosensitivity of cadmium selenide films

Sample number	Baking temp., K	(R_d/R_{ill})
PH22	373	1.59
PH07	473	1.65
PH31	573	3.81
PH36	673	18.22
PH27	723	167.74
PH23	773	241.94

sensitivity with increase in substrate temperature[21]. Lack of sensitivity of the as-deposited films is attributed to the presence of excess cadmium and also the invariance of carrier concentration on illumination. A recent study[16] has revealed that cadmium content in as-deposited films decreases with increase in substrate temperature. Detailed analysis of the composition of the films has been done using energy dispersive analysis of X-rays. It has been observed that increase in substrate temperature results in a decrease in cadmium content in the films. The films have excess cadmium when deposited at temperature in the range 300-453 K and are deficient in cadmium at higher substrate temperatures. This is attributed to the increased re-evaporation of cadmium from the films at elevated temperatures. Hence, the weak photoresponse of the films cannot be related to the cadmium content. However, photosensitivity has been found to increase when the films are baked in air (Table 2). This has been explained as due to the creation of opposite type of charge carriers with the oxygen acting as an acceptor impurity[2,3,7,22].

A study of the spectral sensitivity of the films shows a broad peak in the excess conductivity in the red region. Hence, all further studies were carried out with an incident radiation of wavelength 620 nm. Table 3 shows the effect of baking the films in air. The baking has been carried out in air by maintaining the sample at the required temperature for a period of two hours. It is observed that baking in air produces drastic reduction in the decay constant thereby improving the speed of response of the samples. It has

Table 3—Effect of baking temperature on the decay constant

Sample number	Baking temp., .K	Decay constant (τ), μs
PH46	300	2200
PH46	373	1000
PH47	473	400
PH37	573	180
PH37	673	100
PH29	723	90
PH23	773	80

also been observed that the decay constant decreases marginally with increase in the deposition temperature. These results are in contrast to the reported decrease in the photosensitivity of cadmium selenide films on baking in the air above 50°C (ref. 11).

The rise and decay of photoconductivity has been studied as a function of substrate temperature and the temperature for baking. It has been observed that the rise in photoconductivity is faster than the decay for all the samples studied. The rise and decay may be described by the power law,

$$\Delta R \propto t^{-m}$$

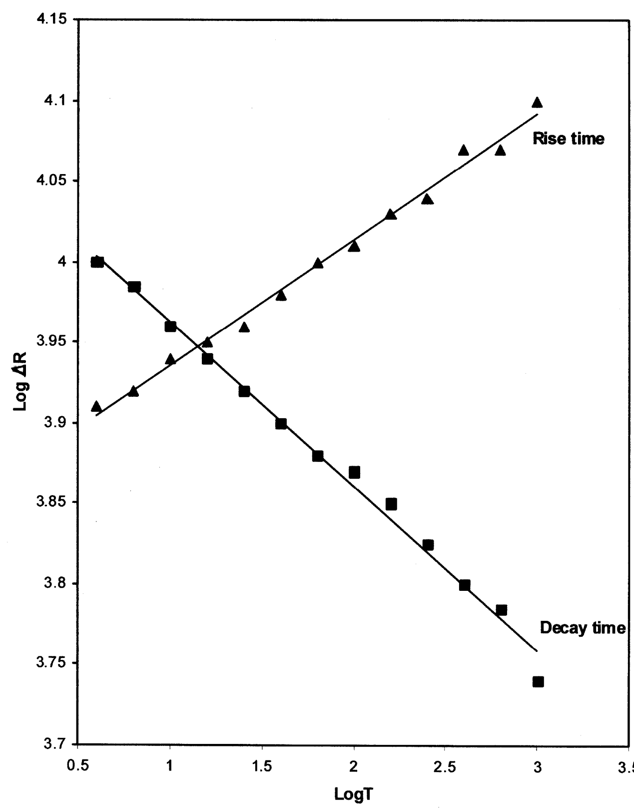

Fig. 1—Plot of log ΔR versus log t for a typical cadmium selenide film deposited at 453 K

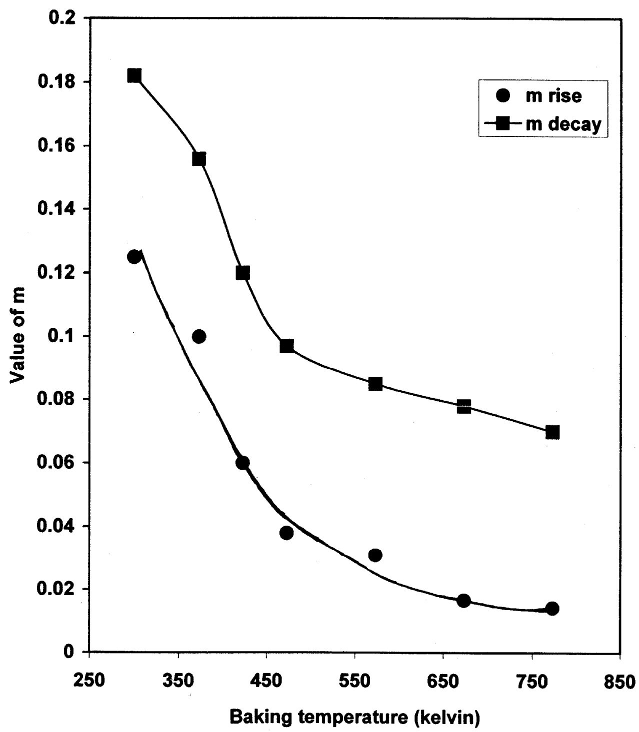

Fig. 2—Effect of baking temperature on the value of *m*

where ΔR is the change in the resistance at any instant of time t. The value of the constant m is evaluated by making a plot of log ΔR against log t (Fig. 1). Effect of baking temperature on the value of m is shown in Fig. 2. It is observed that the films baked at elevated temperatures show smaller values of m. The numerical value of m is always less than unity and decreases as the baking temperature is increased. Further, the value of m is lower for the rise than for the decay of photoconductivity indicating that the photoconductive decay is a slower process compared to the rise. The decay of photocurrent with time may be used to evaluate the trap depth E_{tr} below the bottom of the conduction band and also the probability of escape of an electron from the trap. The variation of photocurrent with time is given by

$$I(t) = I_0 \exp(-pt)$$

where p is the probability of escape of an electron from the trap, expressed in s^{-1} and given by

$$p = S \exp(-E_{tr} / kT)$$

where S is a frequency factor assumed to be 10^{10} s^{-1}. The trap depth E_{tr} and probability factor p, computed for films deposited at various substrate temperature are 0.77 eV and 2.58×10^{-2} s^{-1} respectively. The results are in contrast to those reported by Buragohain and Barua[11] but are comparable with the data reported for cadmium selenide single crystals.

Conclusions

Detailed and systematic study of photoconductivity in cadmium selenide thin films indicates that as-deposited thin films are not suitable for device applications. Interestingly the photosensitivity has been found to be independent of the film composition. Elevated temperatures of baking increase the sensitivity and speed of response of the deposits which is attributed to the incorporation of oxygen in the films. The photoconductivity decay and rise characteristics of the films indicate that the decay of photoresponse is slower than the rise in photoconductivity.

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