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The optoelectronic properties of CdSe:Cu photoconductive detector

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Abstract

Photoconductive CdSe doped with (1–5 wt%) of Cu was fabricated using the vacuum evaporation technique for thin-film preparation followed by vacuum annealing at 350°C under an argon environment for doping with copper. The electrical and detection properties as a function of Cu content were studied. It was found that the gain coefficient was increased with an increase in the Cu impurity concentration and better results were obtained for a CdSe:Cu detector of 5 wt% concentration, which showed a gain coefficient of up to 8.87×10^3 for white illumination ~ 1000 Lux. This value is much greater than the published value for pure CdSe film, possibly due to the sensitizing action of Cu centers. Additional weak but well resolved features were observed in the high-energy region of the curve depicting gain coefficients as a function of wavelength characteristics. These peaks were attributed to the 3D transition of Cu from deep levels in the valence band. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: CdSe:Cu; Responsivity; Gain coefficient

1. Introduction

CdSe is a well-known semiconductor used in applications such as photoconductors, photovoltaic cells, and other optoelectronic devices. Impurity doped CdSe crystals were found to have new quasiline impurity photoconductivity spectra due to the localized positions of impurity levels above the valence band and below the conduction band of CdSe [1]. An increase in photosensitivity of pure CdSe was found under 600 W/m^2 illumination [2] and annealing in air at temperatures of 200–450°C. High photosensitivity was observed for CdSe films deposited at room substrate temperature

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under illumination with white light as well as with monochromatic light over the 400–750 nm region. A conclusion is therefore reached concerning the existence of compensated donor and acceptor defects in the as-deposited state [3].

Various deposition techniques have been used for the preparation of CdSe doped with impurity atoms [4–6]. In the present work copper atoms were introduced into prepared CdSe films by dipping them in a chemiplating solution of CuCl. This method has previously been used for doping CdSe single crystals. We report here the first successful experiment for doping CdSe films with copper.

2. Experiment

CdSe as a thin film, 1 μm in thickness, was deposited on a glass substrate (7.6 \times 2.6 cm) using a BALZERS-OE-8 evaporating unit. High-purity 99.999% aluminum was deposited on the CdSe film to act as ohmic contacts. Copper atoms of a different weight percent were introduced into the CdSe lattice by dipping the film in a CuCl solution, complemented by annealing using a vacuum furnace and flowing argon gas. The experimental layout is shown in Fig. 1. Different temperatures (100–350°C) were used in the doping process for a period of 2 h. The doped CdSe films prepared by this method showed similar characteristics to the CdSe single crystals doped with impurity atoms. The photocurrent and spectral response were measured by a detector test system DSR-500 supplied by Optronic Laboratories.

3. Results and discussions

3.1. *I-V* characteristics

Fig. 2 shows the *I-V* characteristics of CdSe:Cu for 1, 2, 3 and 5 wt% Cu content in the CdSe lattice. As expected, the behavior is linear. Furthermore, the photocurrent increases with increasing bias voltage and illumination intensity (Fig. 3). The low intensity of illumination causes trapping by the Cu centers inside the band gap of

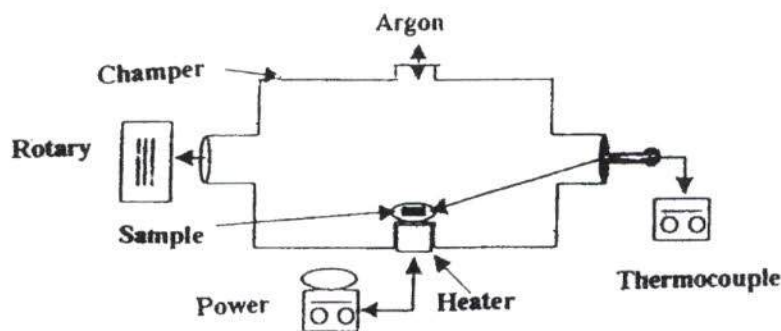


Fig. 1. The experimental layout for doping CdSe with Cu impurities.

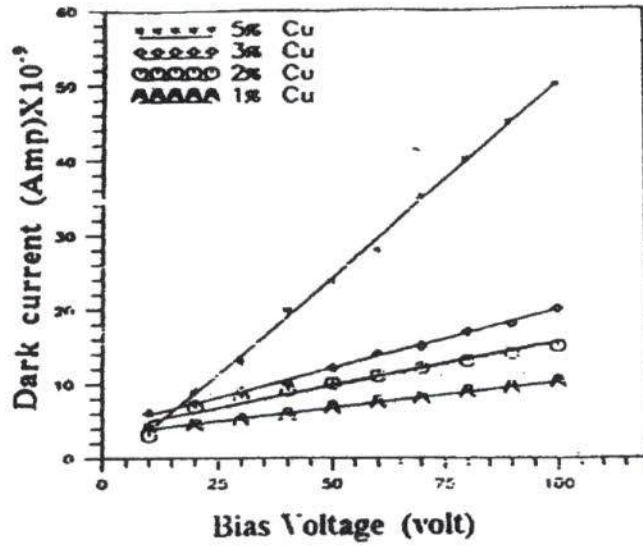


Fig. 2. *I-V* characteristics of CdSe:Cu at 1, 2, 3 and 5 wt% of Cu.

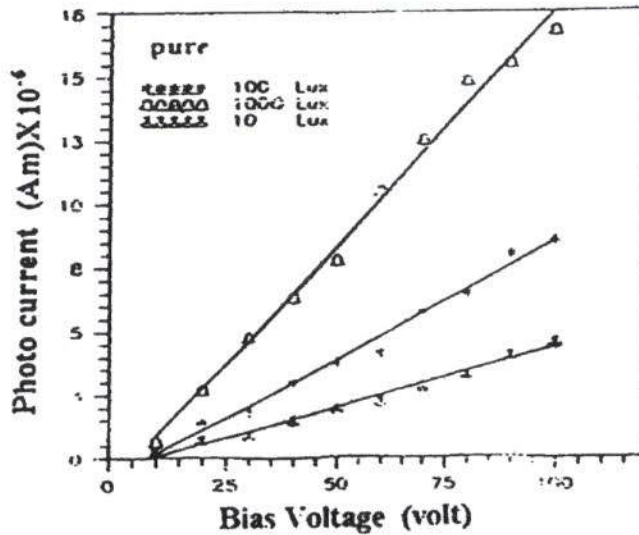


Fig. 3. Photocurrent bias voltages and illumination intensities.

the CdSe. At higher intensities (>1000 Lux), further increases in the photocurrent were observed due to saturation of the trapping centers, which reduces their activities as free carrier traps. The increase in Cu content from 1 to 5 wt% is shown to improve the crystal structure of the CdSe film compared to pure CdSe. This effect had been observed by others [7] for thin-film CdSe doped with In.

3.2. Gain coefficient and responsivity

The gain coefficient was $G=I_p/I_d$, the photocurrent to dark current ratio for CdSe and CdSe doped with Cu (1, 2, 3 and 5 wt%). Fig. 4 shows the measured G value as a function of wavelength for the cases of 3 and 5 wt% of Cu. The maximum G value obtained in the present work was 8.87×10^3 with an illuminance of 1000 Lux and bias $V=10$ V, which is higher than the corresponding G value for pure CdSe by 25 times. Further, the value of G obtained here is much higher than values published by others. However, a value of $G=60$ was obtained by Glew [8] for CdSe prepared by the sputtering method, while Metha and Sharama [11] obtained $G=300$ for a Schottky-type CdSe. For a CdSe single crystal [9] a value of $G=2 \times 10^3$ has been obtained. The higher gain value reported in the present work for CdSe:Cu compared with that published by others can be explained in terms of the cross section of holes and electrons. The Cu atoms possess a trapping cross section for holes which is relatively greater than that for electrons ($\sigma_p/\sigma_n \approx 10^5$), which clearly indicates that the Cu centers act as a photoconductivity sensitizer [10]. This is not surprising since it also acts as a sensitizing center in a similar semiconductor CdS [11]. It is clear from Fig. 4 that an additional weak but well resolved structure appears in the high-energy region.

The peaks are located at 2.34 and 2.21 eV, which means at 0.63 and 0.5 eV lines below the top of the valence band. Such peaks correspond to 3D transition of Cu from deep levels in the valence band [6]. Such levels are formed due to the interaction between metal contacts and the semiconductor surface. The peaks are not clearly resolved in the responsivity and quantum efficiency measurements as shown in Figs.

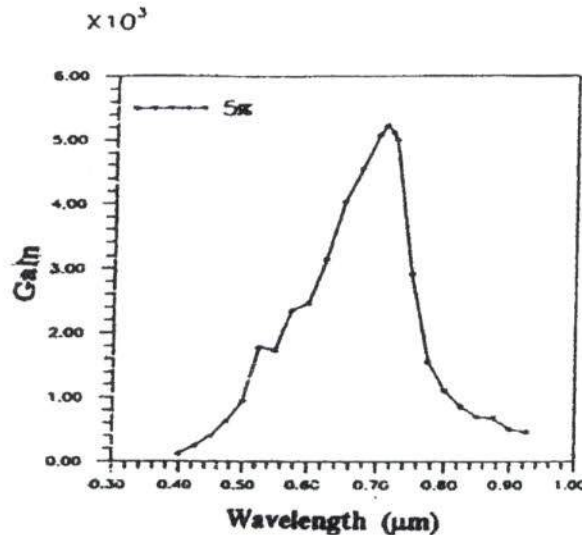


Fig. 4. Gain coefficients versus wavelength for CdSe doped with 5 wt% of Cu.

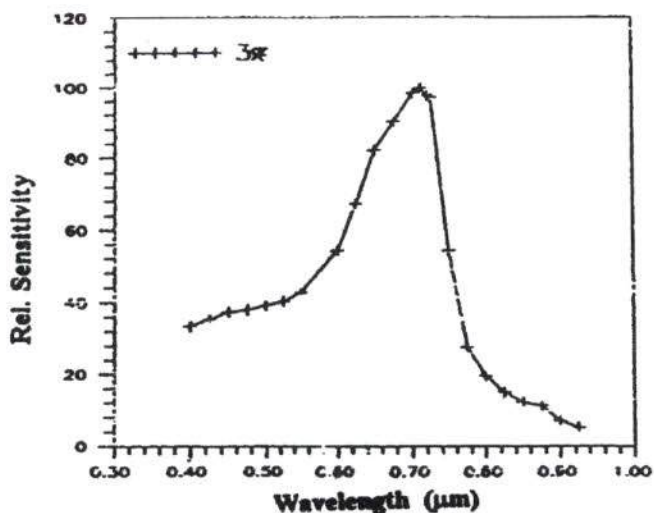


Fig. 5. Spectral response for the CdSe:Cu detector at 3 wt% of Cu.

5 and 6, respectively. However, we observe the continuum spectral response in the region between 0.5 and 0.65 eV, which gives further and clear evidence for the existence of deep Cu levels below the top of the valence band of CdSe.

4. Conclusions

It can be concluded that the technique used in the present work for doping CdSe with Cu atoms, by vacuum evaporation followed by vacuum annealing under an

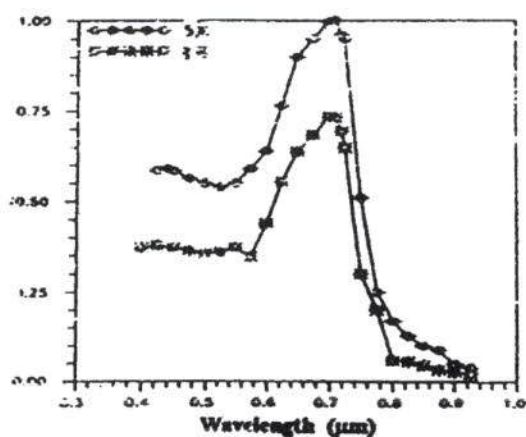


Fig. 6. Quantum efficiency of the CdSe:Cu detector at 3 and 5 wt% of Cu.

argon environment, is successful and capable of yielding quality films. The high gain coefficient, $G=8.87 \times 10^3$, reported here is due to the sensitizing action of Cu centers. The features observed in the curve of gain as a function of wavelength along with the continuum detected in the responsivity curve in the region 0.5–0.6 eV, are a result of transitions from deep levels of Cu localized below the top of the valence band, due to interactions between metal contacts and the semiconductor surface.

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