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Investigation of Photoconductivity in Pr-doped ZnS Powder Prepared by Simple Heat Treatment Technique

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Abstract. In the present work, we have investigated photoconductivity properties in Pr-doped ZnS powders. ZnS: Pr powder has been prepared by simple heat treatment technique at temperature of 800 °C. I-V characteristics i.e. voltage dependence of photocurrent under UV illumination (λ=365 nm) exhibits non-Ohmic (r < 1) behavior at low as well as high voltage regimes. The crystallite size of ZnS:Pr corresponding to main XRD peak is estimated as 37.25 µm. The micro strain is calculated as 0.46.

Keywords: ZnS, Pr, XRD, Photoconductivity.

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INTRODUCTION

The increase in electrical conductivity due to photons is known as photoconductivity. Photoconductivity is considered to be an important tool for providing information regarding the nature of the photoexcitations. Photoconductivity studies are important because of the applications in image intensifiers, xerography, thin film electronics etc. A good photoconductive device requires not only efficient charge separation but also efficient transport of charge carriers to the electrode [1, 2]. It is well known that the rise and decay curves of photocurrent are governed by the trapping states or recombination centers lying in the forbidden energy zone of a photoconductor. Therefore these curves can be used to understand the nature and distribution of traps and recombination centers [3-4]. Photoconductivity in powder has been investigated by many workers [5-10]. Nair et al. [11-13], Bhushan et al. [14-16] have worked on photoconductivity of rare-earth doped ZnS and CdSe.

In this work we have studied the photoconductivity effects of ZnS: Pr prepared by heat treatment technique. Perhaps, there is no report on photoconductivity of ZnS: Pr so far. However there are reports on electroluminescence (EL) and photoluminescence (PL) of ZnS: Pr [17, 18].

EXPERIMENTAL SECTION

Sample Preparation

For the preparation of samples, pure (luminescent grade) zinc sulphide is taken as the starting material. Aqueous solution of praseodymium oxide was added to ZnS with proper proportion of Pr₂O₃. The mixture was then thoroughly pulverized and slowly dried up at about 800°C. The mixture was powdered and put in carbon capped quartz tube. It was then fired at a temperature of 800 °C for 30 minutes in cylindrical furnace under controlled atmospheric conditions.

Instrumentation

For photoconductivity and dark conductivity measurements, a cell was formed by spreading a thick layer of powdered samples in between two Cu electrodes etched on a Cu plate (PCB), having a spacing of 1 mm. The powdered layer was pressed with transparent glass plate. This glass plate has a slit for providing illumination area of 0.25 cm². In this cell type device, the direction of illumination is normal to field across the electrodes. The cell was mounted in a dark chamber with a slit where from the light is allowed to
fall over the cell. The visible photo-response was measured using a commercial bulb of 300 W as a photo-excitation source. A stabilized dc field (50 V/cm to 500 V/cm) was applied across the cell to which a digital dc nano-ammeter, NM-121 (Scientific Equipment, Roorkee) for the measurement of current and RISH Multi 15S with adapter RISH Multi SI 232 were connected in series. The light intensity over the cell surface was changed by varying the distance between slit and light source. Before measuring photoconductivity of the sample, the cell is first kept in dark till it attains equilibrium.

RESULTS AND DISCUSSION

Structural Study

X-ray diffraction (XRD) Spectra

Figure 1 shows the XRD pattern of ZnS and Pr doped ZnS phosphors. XRD patterns indicate formation of cubic (zinc blende structure). No additional peak is found in ZnS:Pr which may be due to low concentration of Pr [13]. The crystallite size of Pr doped ZnS particles were calculated using Debye-Scherer’s (DS) formula: $D = \frac{0.91 \lambda}{\beta \cos \theta}$, where $\beta$ is the full width at half maxima (FWHM) in radians, $\lambda$ is the X-ray wavelength and $\theta$ is the Bragg’s angle. For the estimation of micro strain ($\mu$), we have used the following relation: $\mu = (\beta \cot \theta)/4$. The crystallite size calculated for the main peak is 37.25 µm and the micro strain ($\mu$) calculated for the main peak is 0.46.

![FIGURE 1. X-ray diffraction (XRD) patterns of undoped and ZnS:Pr powder.](image)

Photoconductivity study

Voltage dependence of photocurrent

Figure 2 shows variation of photo current with applied voltage on an ln-ln scale. The ln ($I_{pc}$) versus ln ($V$) curves are straight lines having segments with different slopes. Thus the variation of photo-current may be represented by power law i.e. $I \propto V^r$ where $r$ is the slope of a straight line. Variation of photocurrent with the applied voltage is found to be sub-linear for low voltage as well as high voltage. At high voltage the value of $r$ is increased as compared to that at low voltage. Sub-linear behaviour may be attributed to the formation of non ohmic contacts not replenishing the carriers being captured by the electrodes.

![FIGURE 2. Voltage dependence of photocurrent at different light intensity](image)

Rise and decay curves

Figure 3 shows time-resolved rise and decay photocurrent of ZnS:Pr. As the light is switched on the photocurrent rises and attains a stable value. The rise in photocurrent is due to generation of electron-hole pairs as a result of absorption of photons. When the light is switched off the photocurrent sharply decreases. The decay takes place mainly due to the direct recombination of free electrons with holes in large cross-section recombination centres without any trapping process involved [9-11]. The $p$-values corresponding to different exponentials have been calculated by the relation, $I = I_0 \exp (-pt)$, where $p$ is the probability of escape of an electron from the trap per second and its value is different for different line sections, $I_0$ is the current at the moment the light is interrupted and $I$ is the current at any instant of time.

The probability of an electron escaping from a trap is also given by the relation $[3, 4]: p = S(\exp (-E/kT))$, where $k$ is the Boltzmann constant, $T$ is the absolute
temperature and $S$ is the frequency factor and is of the order of $10^9$.

The trap depth ($E$) is calculated by the relation, $E = kT \ln(S - \ln(I/I_0)/t))$. The calculated value of trap depth is 0.50 eV.

![FIGURE 3. Rise and decay photocurrent curve of ZnS:Pr powder](image)

**CONCLUSIONS**

The XRD pattern exhibits cubic (zinc blend) structure of ZnS. Variation of photocurrent with the applied voltage is found to be sub-linear ($r<1$) for higher as well as lower voltages. The time response of Pr-doped ZnS sample shows sharp rise and decay of photocurrent indicating the fast generation and recombination of electron and hole pairs. The calculated value of trap depth is 0.50 eV. The crystallite size of ZnS:Pr corresponding to main XRD peak is estimated as 37.25µm. The micro strain is calculated as 0.46.

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**REFERENCES**