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Photoresponsive measurements on $InAs_{0.3}Sb_{0.7}$ infrared detector

M RAJA REDDY, B SRINIVASULU NAIDU and
P JAYARAMA REDDY

Department of Physics, Sri Venkateswara University, Tirupati 517 502, India

Abstract. This paper presents a study of responsivity of $InAs_{0.3}Sb_{0.7}$ infrared detector. Thin films of $InAs_{0.3}Sb_{0.7}$ semiconducting compound were prepared by vacuum evaporation on glass and mica substrates held at 473° K under a pressure of 10^{-6} torr with deposition rate of 20 A°/sec. The isothermal annealing process was employed to improve the quality of the films. The responsivity variation with blackbody temperature (333° K to 673° K), detector temperature (80° K to 303° K) and frequency (10 Hz to 10 kHz) was measured. The experimental set-up and the results are presented and discussed.

Keywords. Thin films; photoresponsivity; semiconductor; infrared detector.

1. Introduction

For the fabrication of the infrared detectors in the wavelength range 3 μm to 12 μm, the III–V ternary alloy system $InAs_{1-x}Sb_x$ is of particular interest (Clawson *et al* 1972; Wieder and Clawson 1973; Andrews *et al* 1975; Chenug *et al* 1977; Gertner *et al* 1979; Bubalac *et al* 1980). Previous studies (Raja Reddy *et al* 1984a, b, c) carried out by us on the preparation and characterization of $InAs_{1-x}Sb_x$ films revealed that films with x between 0·6 and 0·8 have favourable properties as infrared detector, since these films showed maximum mobility and minimum optical energy gap among the compositional range investigated. Hence in the present study the photoconductive properties of the solid solutions of $InAs_{0.3}Sb_{0.7}$ prepared by thermal evaporation are reported.

2. Experimental

2.1 *Film preparation and characterization*

$InAs_{0.3}Sb_{0.7}$ films were prepared from homogeneously mixed 5 N pure InAs and InSb compounds. The films (1 μm thick) were deposited onto glass by discrete evaporation technique using a vacuum coating technique (Balzers Automatic 510E) and freshly cleaved mica (surface smoothness: average atomic value 1·73 μm) substrates at a pressure of 10^{-6} torr. The thickness and deposition rate of the films were monitored using a calibrated quartz crystal thickness monitor (QM101). The source temperature (1700°K), substrate temperature (473° K), thickness (1 μm) and the deposition rate (20 Å/sec) were controlled by a built-in microprocessor.

The composition of the films analysed by EDAX technique showed that the films were stoichiometric. The films were found to be polycrystalline from the selective area diffraction pattern taken with Philips TEM. The carrier concentration and Hall mobility were measured using van der Pauw technique. The as-deposited films

(T_s = 473° K) were *p*-type with a carrier concentration of $4{\cdot}8 \times 10^{18}$ cm^{-3} and Hall mobility, 110 cm^{2}V^{-1}sec^{-1}. These films did not exhibit any photoresponse, probably due to the low mobility of charge carriers, high carrier concentration and *p*-type conduction.

The films were annealed at 700° K in arsenic vapour at 1 atm pressure, to compensate the native acceptors. After annealing, the films were found to be *n*-type with carrier concentration $6{\cdot}2 \times 10^{17}$ cm^{-3} and mobility $1{\cdot}4 \times 10^3$ cm^{2}V^{-1}sec^{-1} and exhibited good photoresponse.

2.2 *Photoconductive measurements*

The annealed $InAs_{0{\cdot}3}Sb_{0{\cdot}7}$ films with dimensions 0·2 cm × 0·2 cm × 1 μm were used for photoconductive measurements. The electrical contacts were provided by evaporating indium and attaching silver leads using indium solder.

The blackbody photoconductive response of the films was measured using the experimental set-up shown in figure 1. A blackbody (Model 11-210) obtained from M/s Barnes Engineering Company, USA was used as a radiation source. A variable mechanical chopper (Barnes Model 11-200/201-10A and 10C) placed between the source and the sample film, modulated the radiation frequency in the range 10 Hz to 10 kHz. The film sample was mounted in a specially designed cryostat and the temperature was controlled by a temperature controller (Specac 20-100) with an accuracy of ±1°K in the temperature range, 80°K to 303°K. A CaF_2 infrared transmitting window was fixed to the cryostat with 90° field of view. The film sample i.e. the detector was connected in series with load resistor and a bias power supply. The signal voltage (V_s) developed across the detector due to the incident radiant power from the blackbody was measured using a lock-in amplifier (Princeton Applied Research, model 124A) with a plug-in (PAR 184) pre-amplifier.

The measurements were repeated by varying the blackbody temperature from 333° K to 673° K, maintaining the detector always at 80° K.

The spectral response of the detector was measured using a monochromator (M/s Central Electronics Limited, New Delhi, model HM104) with interchangeable

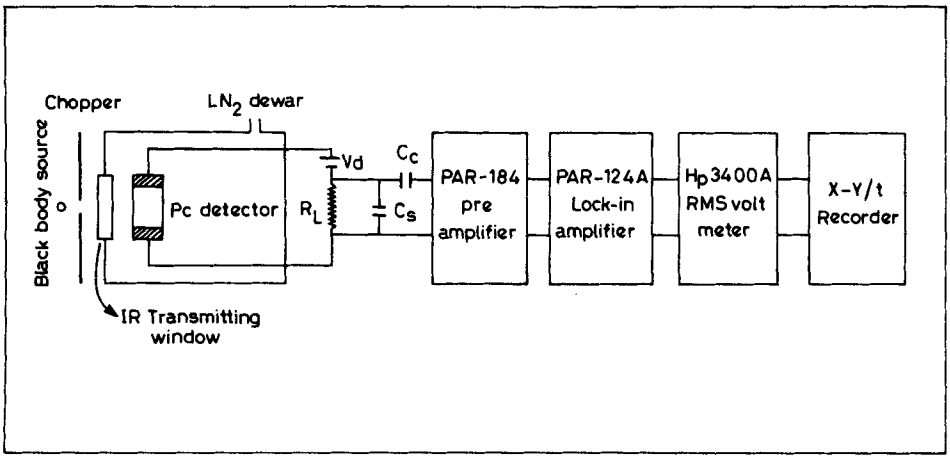

Figure 1. Experimental set-up for photoconductive measurements.

gratings in the wavelength range 2 μm to 10 μm. The detector temperature was varied from 80°K to 303°K.

The noise voltage of the detector in the frequency range 10 Hz to 10 kHz was measured using a voltmeter (Hewlett Packard 3400A RMS) with a full scale accuracy of $\pm 1\%$.

The photoresponsivity (R) of the detector, was determined using the relation,

$$R = V_s/H\,A \tag{1}$$

where H is the irradiance on the plane of the detector and A is the effective area of the detector.

In order to specify the effect of noise on the performance of the detector, an area independent figure of merit, D^*, was evaluated using the relation (Kruse *et al* 1962)

$$D^* = (1/H)(V_s/V_n)(\Delta f/A)^{1/2}, \tag{2}$$

where V_n is the noise voltage and Δf the electrical bandwidth.

3. Results and discussion

The variation of blackbody photoresponse with its temperature is shown in figure 2. The responsivity slowly increases with increasing blackbody temperature and then saturates beyond 500° K. The initial increase is due to the increase of photon flux density. The blackbody temperature was therefore fixed at 500° K for studying responsivity and detectivity.

From the measured spectral response of the detector, D^* was calculated and plotted against wavelength. D^* showed a maximum around 8 μm (figure 3). Further, the detectivity was high at 80° K and decreased as the temperature increased. This may be due to the substantial increase of the thermally generated charge carriers which overshadow the photogenerated charge carriers resulting in the decrease of signal-to-noise ratio.

The variation of detectivity with frequency and temperature is shown in figure 4. It is observed that the detectivity is frequency-dependent up to about 200 Hz and then

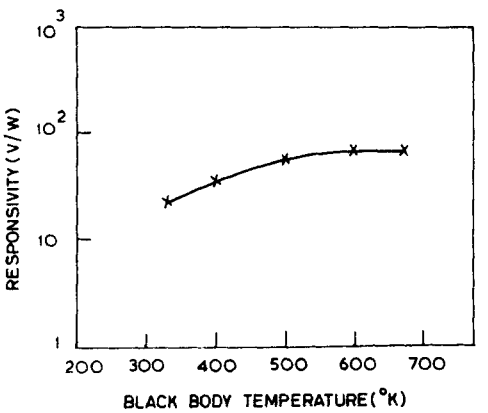

Figure 2. Variation of photoresponse with blackbody temperature.

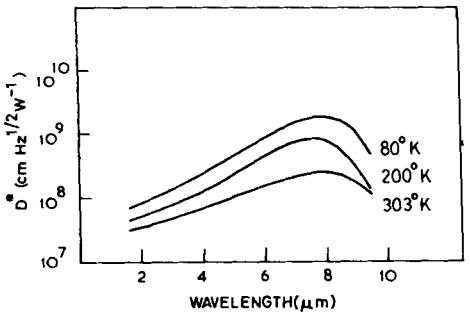

Figure 3. Variation of detectivity (D^*) with wavelength.

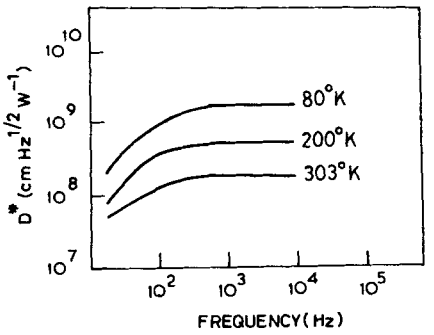

Figure 4. Variation of detectivity (D^*) with frequency.

becomes independent. At low frequencies the detectivity is generally limited by $1/f$ noise arising due to the presence of potential barriers at the electrical contacts, surface or interior (Hanafi and van der Ziel 1978) of the sample. In the present case, the potential barriers appearing at the electrical contacts were taken as negligible, because the contacts used were perfectly ohmic. Also, the surface states contribution to $1/f$ noise was reduced by depositing antireflecting layer (polystyrene) on the surface of the detector, i.e. the low value of $1/f$ noise (figure 4) was mostly due to the interior potential barriers of the semiconducting film which was polycrystalline in nature. At frequencies > 200 Hz, the detectivity is limited by amplifier or generation-recombination (g-r) noise. Because of the use of a low noise amplifier and a proper design of the electronic circuit, the amplifier noise may be taken as negligible in the present study. The g-r noise is generally proportional to the minority carrier density and is dependent on the nature of conduction and the quality of the films. In the present film samples (i.e. detectors), even after annealing, there are likely to be some uncompensated native defects which act as recombination centres, contributing significantly to the g-r noise and limiting the detectivity. The performance of the detector however, can be improved by preparing films free from impurities and defects and having a low minority carrier concentration. The g-r noise decreases with increasing temperature (figure 4), because the majority carrier concentration increases at higher temperatures.

4. Conclusions

$InAs_{0.3}Sb_{0.7}$ films were deposited on glass and mica substrates held at 473° K using discrete evaporation at a pressure of 10^{-6} torr. As-deposited films were p-type and did not exhibit photoresponse. The films were annealed in arsenic ambient to convert them to n-type. The annealed films exhibited high mobility and good photoresponse. The photoresponse of annealed n-type films were studied as a function of frequency, wavelength and detector temperature. The performance of the detector was limited by $1/f$ noise at low frequencies (< 200 Hz) and then g-r noise at higher frequencies. The detector showed maximum detectivity ($2{\cdot}78 \times 10^9$ cm $Hz^{1/2}$ watt^{-1}) at 80° K around 8 μm. The performance of the detector may be improved by preparing epitaxial films free from defects and impurities.

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