Photoacoustic characterization of CuSe metal chalcogenide semiconductor using phase signal analysis

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Open photoacoustic cell analysis has been done on CuSe metal chalcogenide semiconductor to obtain thermal and carrier transport properties. The thermal diffusivity, carrier diffusion coefficient, surface recombination velocity and recombination lifetime of the CuSe were determined from the photoacoustic phase signal-frequency analysis. The experimental results show that the surface recombination velocity decreases with the increasing of CuSe sample thickness. The results indicate an increasing trend of band-to-band recombination lifetime in conjunction with the increasing of sample thickness.

I. INTRODUCTION

Copper selenide (CuSe) is an interesting semiconductor compound with various applications in solar cells, super ionic conductors, photo-detectors, photovoltaic cells and Shottky-diodes [1,2]. The attraction of copper selenide also lies in the feasibility of producing ternary material, $CuInSe_2$ by incorporating indium into this binary compound [3]. Thermal conductivity and thermal diffusivity are very important physical parameters in device modelling. In semiconductor material characterization, two of the most important parameters are the bulk recombination lifetime and the surface recombination velocity. Their knowledge allows the optimization of semiconductor device design and a direct control of the semiconductor material manufacturing process [4]. The photoacoustic (PA) technique has been recognized as an important tool for studying thermal and transport properties of semiconductor [5-7]. Our current research efforts are directed towards characterizing thermal and carrier transport properties of the CuSe metal chalcogenide semiconductor using phase signal analysis.

II. MATERIAL AND METHODS

The experimental set-up used for the PA measurements corresponding to the open photoacoustic cell (OPC) configuration [8,9] is shown in Fig. 1. In this configuration, the sample is attached on the front sound inlet of an electret microphone (Brüel & Kjaer 4192). The surface of the sample was irradiated by He–Ne laser (05-LHR-991) beam modulated by a mechanical chopper (SR 540). A relatively large irradiated area was used in order to exclude the effects of lateral diffusion in measured samples. The generated photoacoustic signal was amplified by a low-noise preamplifier (SR 560), and analyzed by a lock-in amplifier (SR 530). The whole set-up was controlled by a PC where the PA signal was recorded as a function of the light modulation frequency, *f*.

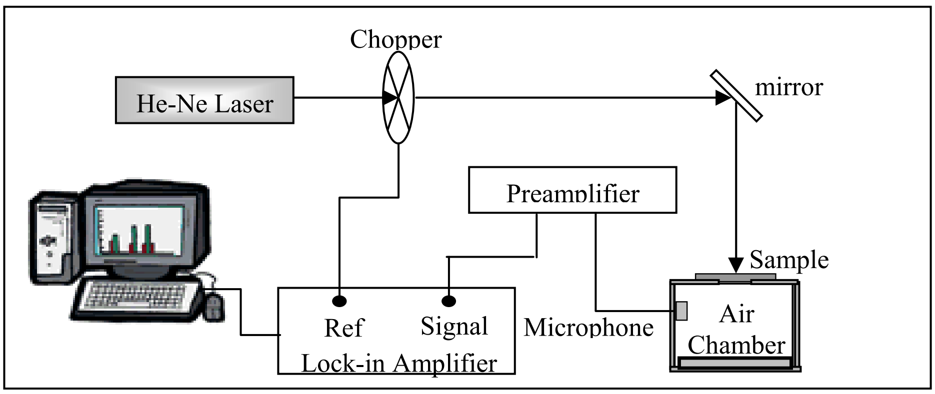


FIG. 1. Experimental setup for OPC detection technique.

The thermal and carrier transport properties of the CuSe samples were obtain from experimental data by using photoacoustic phase fitting technique equation [10]:

$$\phi = \phi_o + \tan^{-1}\left(\frac{(aD/\upsilon)(\omega\tau_{eff} + 1)}{(aD/\upsilon)(1 - \omega\tau_{eff}) - 1 - (\omega\tau_{eff})} \right) \quad (1)$$

(1)

where $\tau_{eff} = \tau[(D/\alpha_s) - 1]$, $a = (\pi f/\alpha_s)^{1/2}$ and ϕ_o is the initial phase angle, D is the carrier diffusion coefficient (cm²/s), υ is the surface recombination velocity (cm/s), α_s is the thermal diffusivity (cm²/s), τ_{eff} and τ is the effective recombination lifetime and the surface band to band recombination lifetime respectively.

III. RESULTS AND DISCUSSION

The PA phase signal is very sensitive to the change of carrier transport process in the sample. This is clearly illustrated in Fig. 2 where the bulk recombination process is dominant at the descending frequency range, while the surface recombination process is dominant at the ascending frequency range. The minimum of this graph corresponds to the breaking frequency or characteristic frequency, f_c. Fig. 3 shows the characteristic frequency as a function of sample thickness.

Fig. 4 shows the best phase fitting of the experimental data to the phase equation (1) for CuSe sample with thickness, L = 0.0456 cm and L = 0.0830 cm respectively. The solid line in this figure represents the best fit of the theoretical model to the data. The experimental and theoretical curves are in good agreement indicating the validity of our approach.

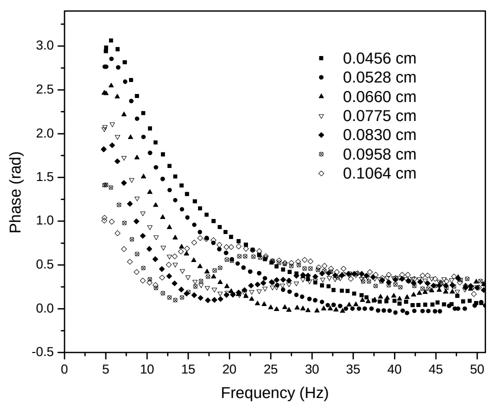


FIG. 2. Phase signal versus chopping frequency for CuSe at different thickness.

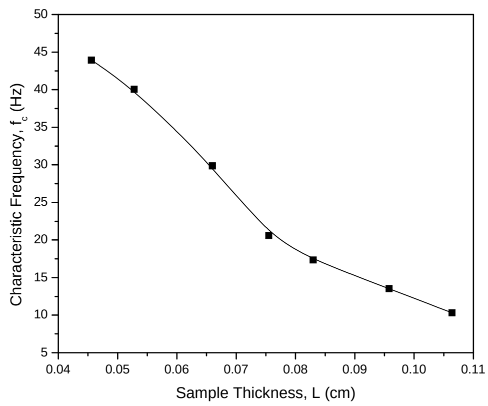
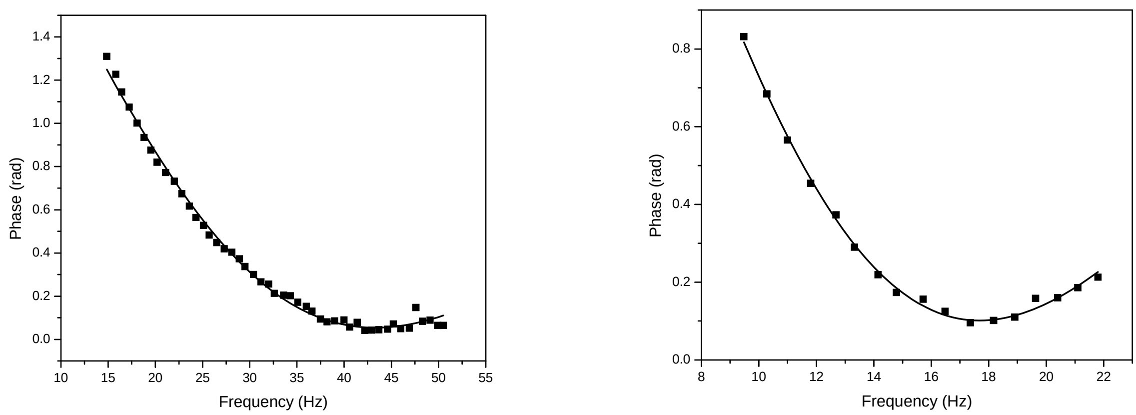


FIG. 3. Characteristic frequency as a function of sample thickness.



(a) (b)

FIG. 4. Phase signal as a function of frequency for CuSe at (a) L = 0.0456 cm and (b) L = 0.0830 cm.

From the fitting, values of carrier diffusion coefficient, surface recombination velocity, thermal diffusivity and the surface band to band recombination lifetime were obtained.

Figs. 5 and 6 reveal the thermal diffusivity and diffusion coefficient values for CuSe sample at different thickness. Thermal diffusivity obtained from phase fitting is 0.01126 cm^2/s and this value is very close as compared to the thermal diffusivity value (0.01125 cm^2/s) measured by photoflash method [11]. The diffusion coefficient of CuSe sample determined from the fitting is around 2.421 cm^2/s. The thermal diffusivity exhibits the same characteristic as the diffusion coefficient in which it does not depend on sample thickness and surface quality. The consistency of this parameter is attributed to its temperature dependent on the characteristic of the semiconductor materials [12].

The surface recombination velocity and band to band recombination lifetime of CuSe samples as indicated in Fig. 7 describe the dependence of these parameters on thickness. The experimental results show that the surface recombination velocity decreases from 225.97 cm/s to 103.56 cm/s with increasing thickness of CuSe sample. Surface recombination process i.e., surface recombination velocity decreases as the sample thickness increases due to the recombination of carriers on the trapped sample surface and consequently the excess carriers have a higher diffusion lifetime for the thicker sample [13]. These non-radiative recombination processes are the most important parameters in the investigation of semiconductor material. From the plot, the lifetime was found to be between 4.38 μs and 18.30 μs. The graph displays an increasing trend of band-to-band recombination lifetime in conjunction with the increasing of sample's thickness. The reason may be due to the absorption of light energy in the thicker samples which would increase the phonon scattering that lead to the increase of band-to-band recombination lifetime.

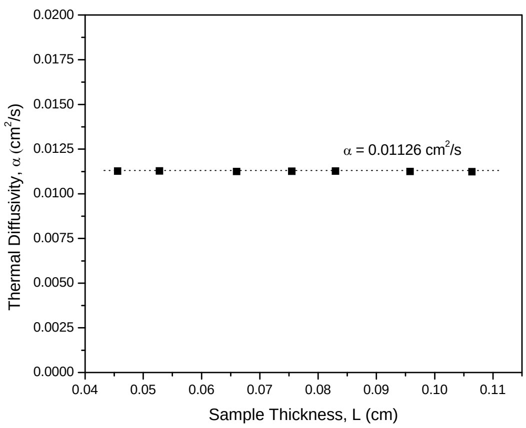


FIG. 5. Thermal diffusivity as a function of sample thickness.

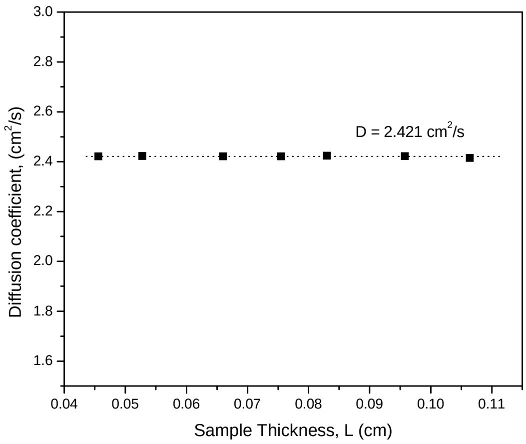


FIG. 6. Diffusion coefficient as a function of sample thickness.

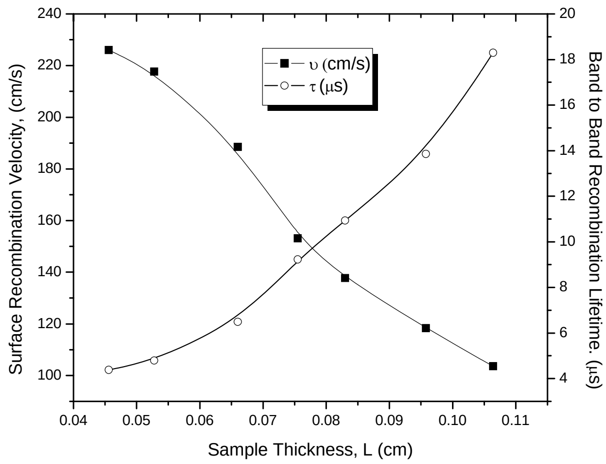


FIG. 7. Surface recombination velocity and band to band recombination lifetime as a function of thickness for CuSe sample.

IV. CONCLUSION

The thermal and carrier transport properties of CuSe metal chalcogenide were characterized using open photoacoustic cell technique. The thermal diffusivity and diffusion coefficient was determined to be 0.01126 cm^2/s and 2.421 cm^2/s respectively. It was found that surface recombination velocity decreases from 225.97 cm/s to 103.56 cm/s as the sample thickness increases, while the band to band recombination lifetime increases from 4.38 to 18.30 μs as the sample thickness increased from 0.0456 to 0.1064 cm.

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