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Photoacoustic spectroscopy of thin films of As_2S_3, As_2Se_3 and $GeSe_2$

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Abstract. Photoacoustic spectroscopy (PAS) is one of the important branches of spectroscopy, which enables one to detect light-induced heat production following the absorption of pulsed radiation by the sample. As_2S_3, As_2Se_3 and $GeSe_2$ exhibit a wide variety of photo-induced phenomena that enable them to be used as optical imaging or storage medium and various electronic devices, including electro-optic information storage devices and optical mass memories. Therefore, accurate measurement of thermal properties of semiconducting films is necessary to study the memory density. The thermal conductivity of thin films of As_2S_3 (thickness 100 μm and 80 μm), As_2Se_3 (thickness 100 μm and 80 μm) and $GeSe_2$ (thickness 120 μm and 100 μm) has been measured using PAS technique. Our result shows that the thermal conductivity of thicker films is larger than the thinner films. This can be explained by the thermal resistance effect between the film and the surface of the substrate.

Keywords. Thermal conductivity; thermal resistance; semiconducting thin films.

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1. Introduction

The photoacoustic effect [1] is an effective method of determining thermal parameters of various materials when the PA signal is measured as a function of chopping frequency. The suitability of the photoacoustic (PA) technique lies in the fact that it can be applied irrespective of the physical state of the sample, i.e. solid, semisolid, liquid, gel etc. [2,3]. As_2S_3, As_2Se_3 and $GeSe_2$ exhibit many properties, including a high refractive index, and excellent transmission at infrared wavelengths. Thus these are very promising glasses for ultrafast all-optical switching. Semiconducting thin films have potential application in optoelectronis. However, the thermal properties were not widely investigated compared to the optical and electrical properties [4,5]. In this work we report that the thermal conductivity of thin films of As_2S_3, As_2Se_3 and $GeSe_2$ changes with the thickness of the film.

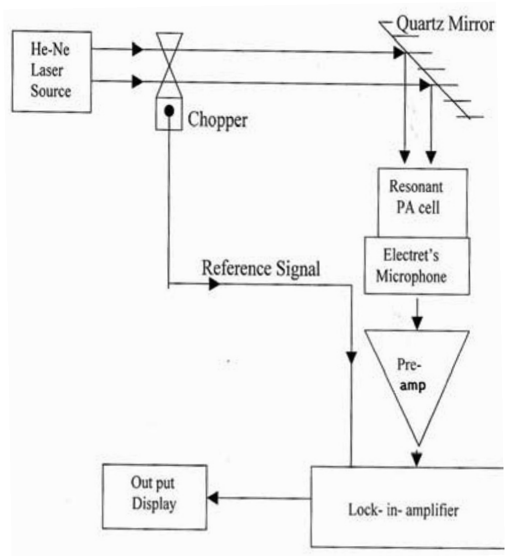

Figure 1. Schematic diagram of PAS measurement.

2. Experimental set-up

Thin films of As_2S_3, As_2Se_3 and $GeSe_2$ were prepared by the thermal deposition of As_2S_3, As_2Se_3 and $GeSe_2$ onto transparent slides under a pressure of $\sim(1–2)\times10^{-7}$ Torr at a rate of $\sim$3 nm/s. The measurements are taken at room temperature. The experimental apparatus for PAS measurements is shown in figure 1. A He–Ne laser (wavelength 632.8 nm) is used as a light source. The light beam was modulated by a mechanical chopper (Model Sr 540, Stanford, USA) and directed to the sample compartment of the PA cell through the quartz window. The PA signal produced is processed by using a pre-amplifier and a lock-in amplifier.

3. Results and discussion

The log–log plots of the variation in photoacoustic signal with chopping frequency for As_2S_3 (thickness 100 μm and 80 μm), As_2Se_3 (thickness 100 μm and 80 μm) and $GeSe_2$ (thickness 120 μm and 100 μm) are shown in figure 2. Thermal diffusivity can be evaluated using the relation $\alpha = t_f^2 f_C$, where t_f is the thickness of the examined sample and f_C is the characteristic frequency. The measurement of α allows us to determine thermal conductivity (κ) by the relation $\kappa = (\rho \propto c)$. Here ρ is the density and c is the specific heat. The specific heat of As_2S_3, As_2Se_3 and $GeSe_2$ are 0.247 J/K g, 0.429 J/K g and 0.308 J/K g [6] and the densities of these thin films are 3.46 g/cm^3, 4.75 g/cm^3 and 4.56 g/cm^3 respectively [7]. The values of thermal conductivity are tabulated in table 1.

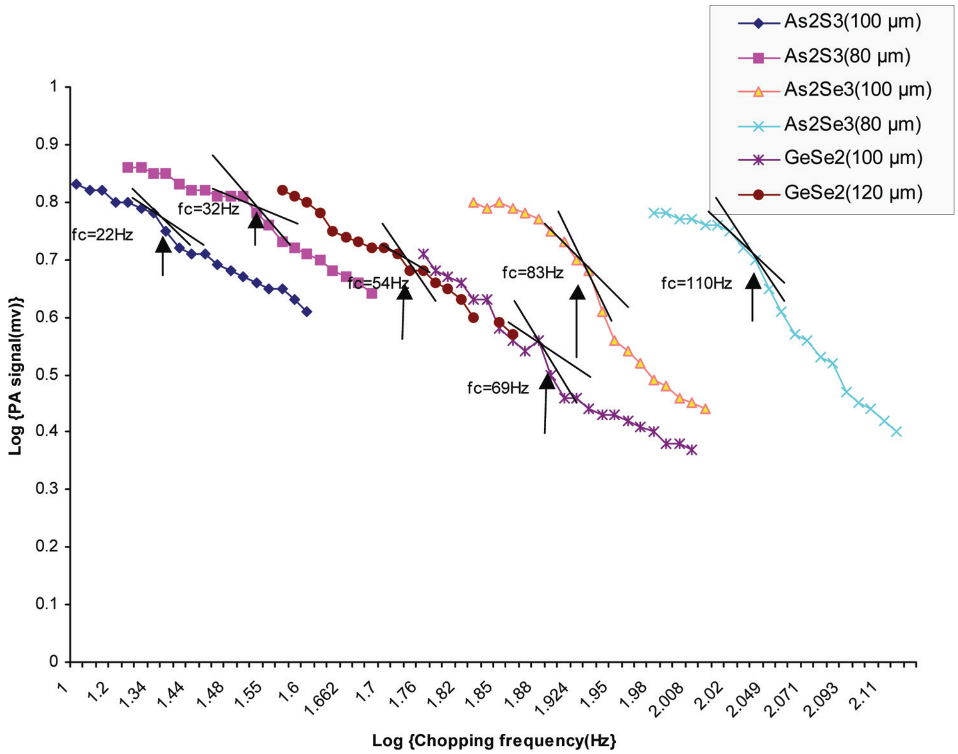

Figure 2. Variation of PA signal with chopping frequency.

Table 1.

Thin films	Thickness t_f (μm)	Thermal conductivity κ (W m^{-1} k^{-1})
As_2S_3	100	0.191
	80	0.185
As_2Se_3	100	1.69
	80	1.5
$GeSe_2$	120	1.1
	100	0.95

The thermal conductivity of these thin films is comparable to those in literatures [8–10]. Here the important point is that the thermal conductivity is not the absolute value but it changes with thickness of the film.

The result shows that the thermal conductivity of thicker films is larger than that of thinner films. This can be explained by the effect of thermal resistances between the film and the surface of the substrate. If we assume that these resistances exist, the obtained thermal conductivity

$$\kappa_f = \frac{\kappa_i}{1 + R_i\kappa_i/t_f}, \tag{1}$$

where κ_i is the intrinsic thermal conductivity of the thin film independent of the thickness of the film and R_i is the total thermal resistance between the layers.

From eq. (1), we can see that the experimentally obtained thermal conductivity κ_f is always lower than κ_i and thinner films show lower κ_f values than thicker film.

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