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NONDESTRUCTIVE DEPTH PROFILING OF MULTILAYER SEMICONDUCTOR FILMS BY A PHOTOTHERMAL DEFLECTION TECHNIQUE

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ABSTRACT

A variation of the photothermal deflection technique is used to study the thermal and optical properties of a multilayer semiconductor film of Indium and silver in a nondestructive fashion. A pump laser beam chopped at specified values of frequencies is focused on the film perpendicular its top surface. A probe beam is made to propagate parallel to the surface at gracing angle. The film acts as the coupling medium between the beams. The probe excites the different layers of the medium optically. Depending on the optical absorption and the thermal diffusion length of each material, the photothermal signal from the layer reaches the surface and influences the propagation of the probe beam. Since the thermal diffusivity is a function of frequency of chopping, the photothermal signal from different layers of the sample can be made to be influence the probe beam at the surface and hence selective study of layers at different depth is possible. The present work reports on the first application of the Photothermal deflection technique to nondestructively depth-profile a semiconductor multilayer film.

1. INTRODUCTION

Several depth profiling methods had been reported during the past few decades. Among these methods the best known examples are based on interferometric, photoacoustic (PA) and recently photodeflection (PD) techniques[1-6]. In the PD technique, a pump beam is used to excite the sample and a probe beam interrogates the details of the response of the system. The absorption of the exciting light beam causes a corresponding change in the index of refraction of the optically heated region in the sample. The absorption also causes an index of refraction gradient to be formed in a thin layer adjacent to the sample surface. By probing the gradient of the varying index of refraction with the probe beam one can relate its deflection to the optical absorption and thermal diffusivity of the sample. The possible ways of probing the sample are passing the probe beam either collinear or transverse to the pump beam. We employed transverse thermal deflection technique for depth profile study than the collinear thermal deflection technique where the probe beam passes through the sample. Depth profile by PDS technique can be achieved by progressively increasing the thermal diffusion time by increasing the period of chopping. The thermal diffusivity μ of the sample is given by[7]

$$\mu = \sqrt{\frac{k}{\pi \rho c f}}$$

where k, ρ, c and f are the thermal conductivity, the density and the specific heat of the sample and f is the light modulation frequency respectively. From the above expression it is clear that higher the chopping frequency shallower is the probing depth. The phase of the thermal deflection of the probe beam contains information about its spatial origin, i.e., the smaller the phase angle shallower the component. If the thermal diffusivities of the corresponding layers are known, the measured phase angles can be used to calculate the thickness of each layer respectively. It is required that the band of each layer should be well resolved and the individual layers are optically transparent at the particular wavelength of absorbance of other layers.

2. MATERIALS

The materials chosen for the present work as multiplayer semiconductor coatings are Indium and Silver. A double layer thin film structure with a non-absorbing top layer and optically and thermally thin bottom layer is formed. This double layer is repeated again to obtain a four-layer structure. Thin film coating is done on a glass substrate of $1 \times 1\ cm^2$ area by thermal evaporation technique.

3. EXPERIMENTAL CONFIGURATION

A He-Ne laser of power 8 mW is used as the excitation source. A weak probe beam (approximately 1 mW power) from another He-Ne laser is passed tangential to the surface of the sample. The position sensor monitors the deflection of the probe beam. The phase and amplitude are measured simultaneously using dual lock-in amplifiers (Stanford Research Systems) having a phase resolution of 0.01^0 . The incident beam is modulated by a mechanical chopper and the phase and amplitude of the signal are measured as a function of chopping frequency. The modulation frequency range in this experiment is from 10 Hz to 500 Hz. The sensitivity of the PD technique has been enhanced by immersing the sample in a transparent liquid having a high coefficient of variation of the index of refraction with temperature taken in a cuvette ($1.5 \times 1.5\ cm^2$). The most commonly used liquid satisfying this condition is CCl_4, for which $dn/dT = 5\times10^{-4}K^{-1}$ (for air, $dn/dT = 5\times10^{-6}K^{-1}$) The experimental setup is automated completely.

4. RESULTS AND CONCLUSION

Figures 2 and 3 show the dependence of the amplitude and phase of the PDS signal with modulation frequency of the beam. The figure-4 represents phase of thermally deflection probe beam against the modulation frequency of pump beam. The steps which appear in the graph are due to delay of the thermal wave in reaching the surface of the sample. This phase lag may be due to mismatch between the thermal diffusivities of the two layers which cause discontinuity in the thermal gradient generated by incident photon energy at the contact surface of the bilayer. In the ideal case, one of the layers coated, for example, silver film, should be optically and thermally thin, which is not true in the real case because of multiple reflection of incident light and the resulting multiple absorption within the layer. The number of steps is found to be equal to the number of layers. The phase lag of the second step appears to be much larger than those of the other layers. The reason is that the thickness of the silver film of the bilayer is reasonably high compared to indium film. Further studies are in progress for evaluation of the thermal diffusivity of each layer individually.

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FIGURES

Transverse Photodeflection

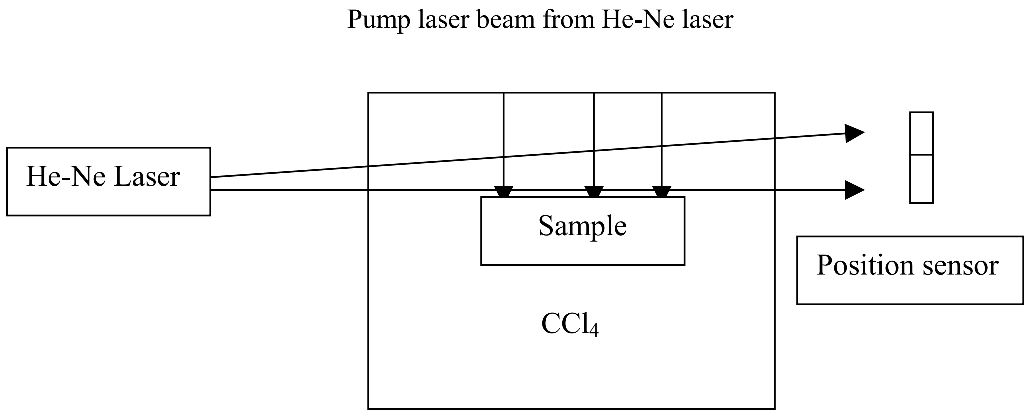

Fig. 1. Experimental set-ups for a transverse PD measurement.

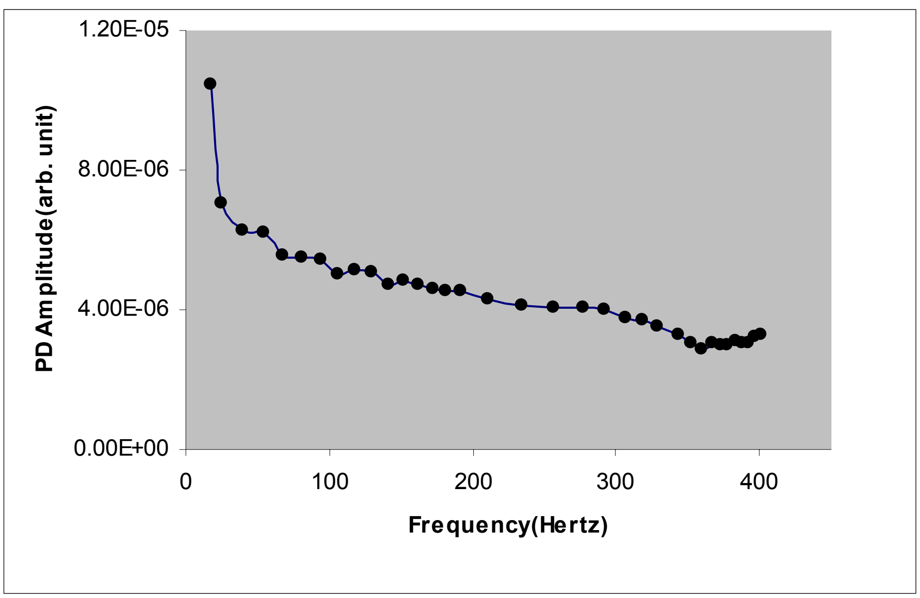

Fig. 2. Transverse PD Signal amplitude vs modulated frequency for carbon black

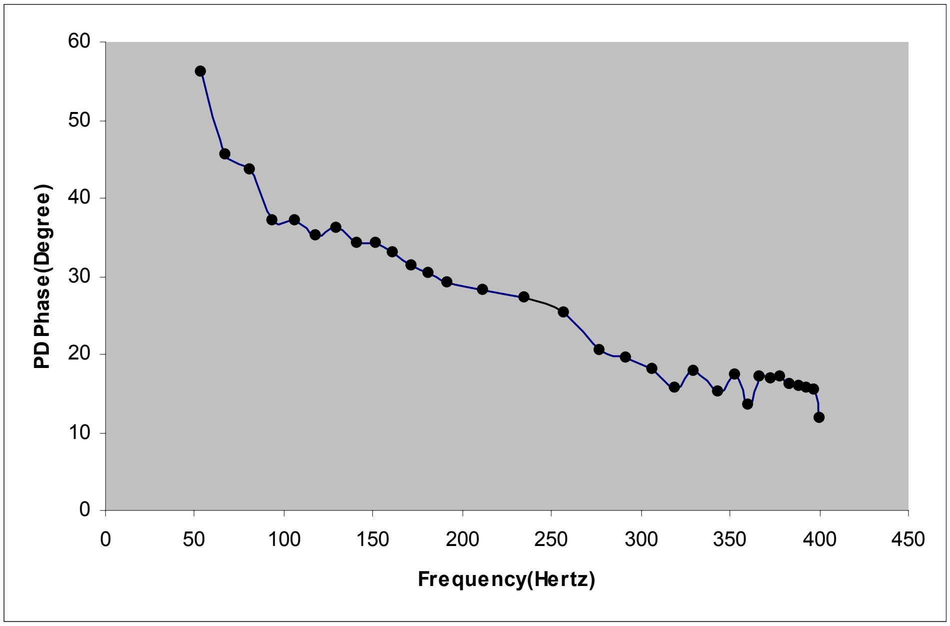

Fig. 3. Transverse PD Signal phase vs modulated frequency for carbon black

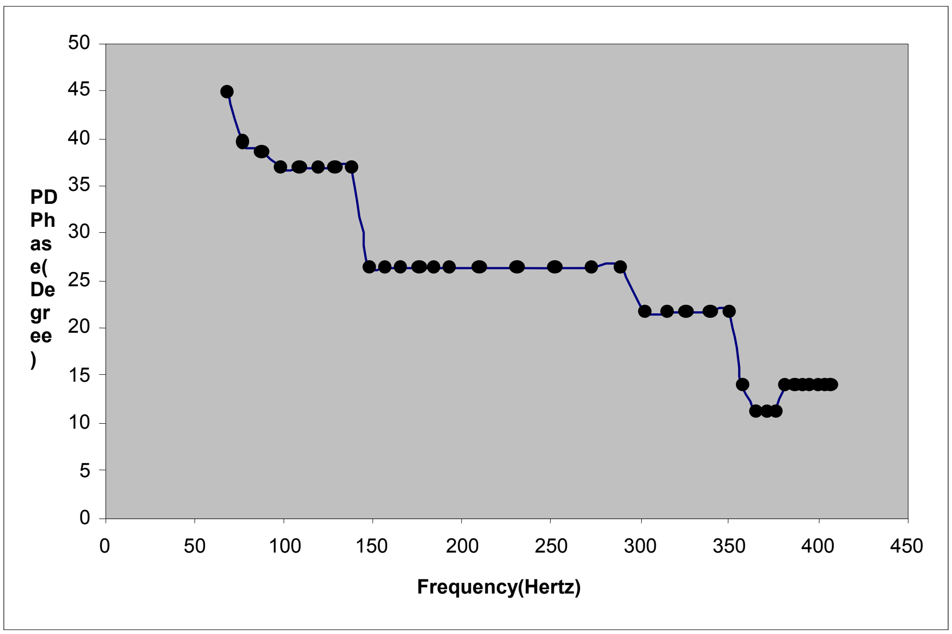

Fig. 4. Transverse PD Signal phase vs modulated frequency for the multilayer sample