Photothermal Spectra of Semiconductors

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Abstract: We measure and calibrate the photothermal spectra of Gallium Arsenide and Cadmium Telluride in the 400-800 nm spectral region using a white light source. The spectra yield the photothermal quantum yields of the materials.

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1. Introduction

We measure the photothermal spectral of two semiconductor materials: Gallium Arsenide (GaAs) and Cadmium Telluride (CdTe) in the visible and near-infrared spectral region. Both materials are widely used in electronics and solar energy industries. The spectrum yields the photothermal quantum yields of the samples, merely their ability to produce heat following the absorption of the light photons. We use a mode-mismatched pump-probe scheme with a focused pump beam and a nearly collimated probe beam. A Xe-lamp provides the pump excitation. We filter the white light using interference filters to generate quasi-monochromatic light. The light is focused onto the sample given rise to a photothermal lens (PTL). A diode-pumped solid-state (DPSS) laser, radiating at 1064 nm, provides the probe light to test the generated lens. The light propagates through the sample and impinges a detector located at the far-field. The PTL distorts the probe light wave-front profile. Changes in the relative transmission of a small aperture yield the PTL signal. The PTL signal is proportional to the PT quantum yield (Ψ_{th}) of the sample. Values of Ψ_{th} equal one demonstrates that 100% of the absorbed energy turns into heat. Photothermal applications demand high Ψ_{th} values. Photovoltaic applications require low Ψ_{th} values.

We define the PTL signal $S(\lambda)$ as the relative transmission change of the probe beam through the aperture. In the situation of high absorbance, $\Psi(\lambda) = K \cdot S(\lambda) / (P(\lambda) \cdot (1 - R(\lambda)))$, where K is a proportionality coefficient independent on the values of the excitation wavelength λ, $P(\lambda)$ is the power for each wavelength, and $R(\lambda)$ is the reflectance of the sample [1]. Values of $\Psi(\lambda)$ of semiconductors are generally unknown.

2. Method

Figure 1a shows a simplified scheme of the photothermal lens spectrophotometer. A Xenon arc-lamp provides the pump beam. A mechanical chopper (Ch) modulates this light at a low frequency (7 Hz). A small glass beam-splitter (B_1) redirects part of the pump beam to a detector used for reference purposes. A set of forty-seven interference filters (IF) yields quasi-monochromatic light in the spectral region 370-840 nm with a spectral resolution of 10 nm and a power density of 0.05 to 0.1 mW/nm. Behind the filters, an aspheric lens focuses the pump light onto the sample. The samples exhibit high absorbance for the pump light, giving rise to a strong PTL effect despite the limited power available. The DPSS laser generates the probe laser. The frequency of this laser is below the quantum gap of the semiconductor resulting in good transparency throughout the sample. A beam-splitter (B_2) directs the probe beam collinearly with the pump beam. Behind the sample, a mirror redirects the beam to a small aperture (A). A semiconductor detector (D_2) measures the probe light transmission through the aperture. A current amplifier (Stanford Research 570) amplifies the signal before sending it for processing by a digital oscilloscope.

The GaAs sample is a doubled polished undoped wafer of 0.625 mm thickness,10-cm diameter, and 100 orientation (University Wafer, Inc.). The CdTe sample is a doubled-polished square piece 7 X 7 mm of 2-mm thickness, and 110 orientation (Sol Ideas Technology Development). The method requires double-polished samples for proper transmission of the probe light. We characterize the transmittance and the reflectance spectra of the samples using the available Xe arc-lamp. We calibrate the absolute value of the transmittance and reflectance by measuring their values using a 200-mW DPSS laser at 532 nm. To perform the calibration of the spectra and provide the value of the PT quantum yield, we perform a photothermal mirror (PTM) Z-scan experiment using a 532 nm laser as an excitation beam and a He-Ne laser at 632 nm as a probe light. Details of the PTM Z-scan method has been recently published [2]. We also use the values of the thermal diffusivity, thermal conductivity, refraction index, thermal elasticity, and the Poisson ratio of both samples available in the open literature [3].

3. Results and Analysis

Figure 1b shows the calibrated PT quantum yield of GaAs. We have performed a PTM Z-scan to calibrate the spectrum. Figure 1c shows the PTM Z-scan of the same GaAs wafer. The solid line in 1c is the theoretical fitting of the experiment, which yields the value $\Psi_{GaAs}(532\ nm)= 0.87$.

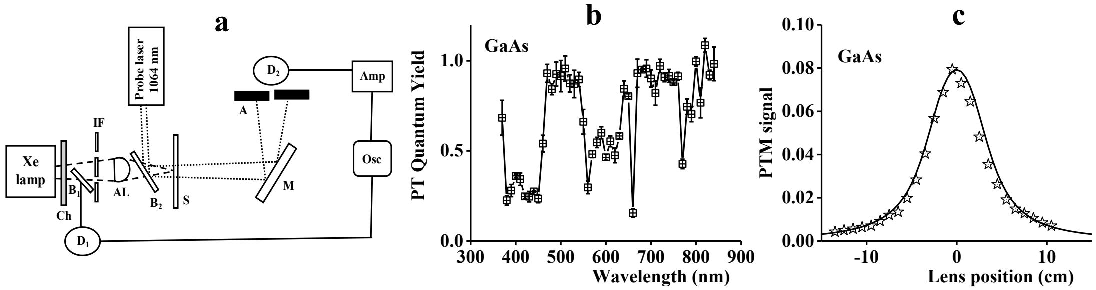

Figure 1. a) Schematic of the PTL spectrophotometer; b) PTL spectrum of GaAs; and c- The PTM calibrated signal from GaAs.

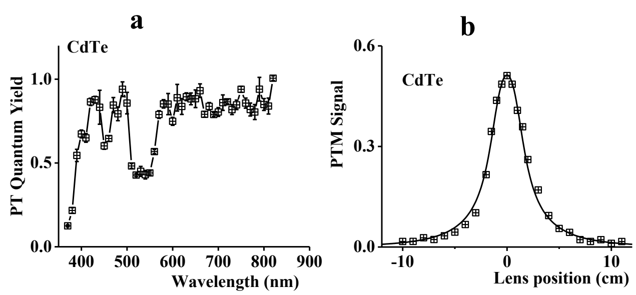

Figure 2. a) PTL spectrum of CdTe, b) The calibrated PTM Z-scan from the CdTe sample signal at 532 nm

Figure 2a shows the PT quantum yield of CdTe, and figure 2b shows its corresponding PTM Z-scan. The solid line in 2b is the theoretical fitting, which yields the value $\Psi_{CdTe}(532\ nm)=0.45$. Both spectra show regions of high Ψ–values which correspond to an efficient generation of heat upon absorption of light. Areas with low Ψ–values show that the energy is used for a non-thermal process (carrier generation, sound, photochemistry, or luminescence).

4. Conclusions

We describe a new spectroscopic method for the analysis of semiconductor materials based on the PTL effect. The technique provides the values of the PT quantum yields of the sample. We discuss the meaning of the PT quantum yield and its importance for the characterization of semiconductor materials. We present the results for well-known semiconductors GaAs and CdTe, but the technique can be applied for any semiconductor.

5. Acknowledgments

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6. References

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