Photothermal Mirror Z-Scan

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Abstract: This work describes a pump-probe photothermal mirror Z-scan experiment aimed at determination of thermal diffusivity, thermoelastic coefficient, and quantum yield of thermal heating of the surface of transparent and non- transparent solid samples including films.

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1. Introduction

We introduce a new pump-probe photothermal mirror (PTM) Z-scan method to measure the thermal diffusivity, thermoelastic coefficient, and quantum yield of thermal heating of the surface of solid samples. The focusing of a beam of light onto the sample generates surfaces distortions due to the thermoelastic deformations induced by the heating of the first layers of the surface [1]. The distorted surface acts as a mirror of thermal origin affecting the diffraction pattern of the reflected beam at the far field. We focus the pump beam using a lens to generate the PTM and use a collimated probe beam of relatively low power to test its presence. The PTM induces a phase shift over the wavefront of the probe beam. The measurement of the relative change of probe light transmission through a small aperture located at the far field provides the PTM signal. By scanning the position of the focusing, we produce different focal spot over the sample's surfaces while keeping the sample's position fixed. This way we generate a single peak Z-scan signature of the PTM signal. The amplitude of the peak is proportional to the phase shift induced on the probe beam phase. The shape of the peak bears information about the pump beam waist dimension and pump Rayleigh range. With a proper calibration by measuring the sample's reflectivity and transmittance, we determine the quantum yield of heating, namely the relative number of absorbed photons energy used for heat generation. Additionally, the phase shift measures also the thermoelastic coefficient of the sample [2-5]. The PTM signal time evolution allows determination of the thermal diffusivity [4-5].

The theoretical model to explain the PTM effects requires the concurrent resolution of the thermal heat diffusion equation and the equation for the thermoelastic deformation generated by the absorption of electromagnetic energy [2-5]. We define the PTM experimental signal as

$$S(z,t)=[T(z,t)-T_o]/T_o \quad , \qquad (1)$$

where z is the lens position ($z=0$ corresponds to the focal length), t is the time, $T(z,t)$ is the probe light transmission through the aperture in the presence of the pump field, and T_o is the probe light transmission in the absence of the pump field. The model shows that the PTM signal strength is proportional to the induced phase shift amplitude defined as

$$\Phi_o = P\,(1-R)\,\Psi\,\alpha_T\,(1+\nu)/(\lambda_p\,\kappa)\ , \qquad (2)$$

where P is the pump power, R is the reflectivity coefficient, Ψ is the thermal quantum yield, α_T is the thermoelastic coefficient, ν is the Poisson module, λ_p is the probe field wavelength, and κ is the thermal conductivity.

2. Method

Figure 1a shows a simplified schematic of the PTM Z-scan set-up. A 200-mW diode pumped solid-state laser (532 nm) provides the pump light. A signal generator modulates this light electronically between 0.1 to 100 Hz. The beamsplitter B redirects part of this light to a detector D_R used for reference purposes. The telescope C_1 collimates the pump beam before entering the focusing lens L (15 cm focal length). This lens focuses the pump beam onto the sample's surfaces. We scan the lens in the direction of the sample to generate the Z-scan signature. A 2-mW He-Ne (632 nm) laser generates the probe beam. A telescope (C_1) collimates the probe light resulting in a parallel beam of

4-mm radius. Mirror M_1 redirects the collimated probe beam toward the sample covering the spot of the focused pump beam. Mirror M_2 collects the reflected probe beam of light and redirects it toward the aperture A. The aperture is at the center of the beam. Behind the aperture, a semiconductor diode records the probe light transmitted through the aperture. A current preamplifier amplifies the signal before sending it to a digital oscilloscope for averaging (not shown in the schematics). The oscilloscope yields *S(z,t)*. A calibrated power sensor measures the power *P* at the sample position. As an example of the technique, we perform PTM Z-scan on a 4-mm thick and 5-mm diameter cylindrical plate of glassy carbon.

3. Results and Analysis

Figures 1b shows the PTM signal of a glassy carbon plate as a function of time in units of the build-up time $t_c=a^2/(4D)$, where $a=40\ \mu m$ is the radius of the beam at the focal point and $D=8\ 10^{-6}\ m^2s^{-1}$ is the thermal diffusivity coefficient. The signal is normalized over its value at $t=0.1\ s$. The white solid line is the theoretical fitting. Figure 1c shows the Z-scan signature of the same sample measured for $P=108\ mW$. The solid line is the theoretical fitting which provides $\Phi_o=-0.095$. The negative value corresponds to a defocusing effect. By measuring $R=0.13$ at $532\ nm$ and confirming a negligible transmission, we estimate $\Psi=0.87$. Using $\kappa= 5.8\ W\ m^{-1o}K^{-1}$ and Eq. 2, we estimate $\alpha_T(1+\nu)=4\ \mu m\ m^{-1}\ ^oK^{-1}$, which is in good agreement with previously reported values [6].

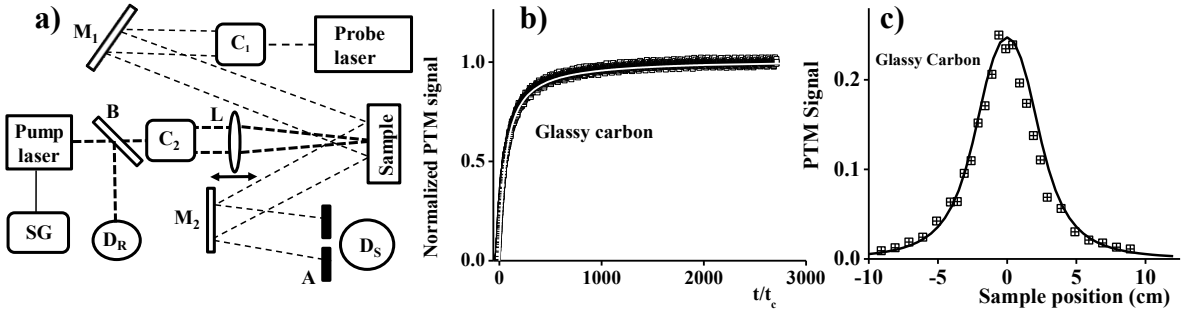

Figure 1. a) PTM Z-scan experimental set-up; b) Normalized PTM signal of glassy carbon measured for $P=108\ mW$ at $532\ nm$ as a function of time in units of t_c; c) PTM Z-scan signature of glassy carbon measured for $t=1\ s$, $P=108\ mW$ at $532\ nm$.

4. Conclusions

This work demonstrates a new method for analysis of the surface of solid samples based on the PTM effect. The technique allows measuring the thermal diffusivity coefficient, the quantum yield of heat generation, and values for the thermoelastic properties of the sample. The method is particularly useful for the study of non-transparent samples where transmission spectroscopy cannot work.

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6. References

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