A modified mode-mismatched thermal lens spectrometry Z-scan model: An exact general approach

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In this work we introduce a modified pump-probe mode-mismatched thermal lens Z-scan theoretical model for measurement of absorption coefficient and thermal diffusivity of semi -transparent liquids. We present an exact solution for the thermal lens signal which consider validity of the experimental parameters in any experimental configuration. In the proposed approach, the pinhole size ρ_0 was considered and optimized, with different distances from sample to detector (L). We illustrate its validity by calculating the thermal lens signal in situations of small and large L values and measuring the absorption coefficient and thermal diffusivity of water performing Z-scan experiment.

Theoretical Model – Previously developed theoretical models, to study TL signals, were based on Fresnel- diffraction approximations, for situations in which the sample is located at a fixed position [1]. Later on, Marcano et al. [2] developed a model for Z-scan experiment based on same approximation, which also included the aberration nature of the TL. This model successfully describes TL signal generated by using a focused excitation beam by measuring transmission of probe light through a small aperture. They claimed an excellent agreement by performing Z-scan experiments between theory and experiment for specific case when the radius of aperture ρ_0 was ignored. However, in more general cases it is necessary to consider the ρ_0 influence on the TL signal. We present the exact analytical theory for Z-scan in far field approximation and discuss theoretical results in mode mis-matched configuration with the exact solution which includes ρ_0 dependence. We perform Z-scan measurement on water and compare results of water absorption coefficient and thermal diffusivity obtained by different TL models. The TL signal including aperture size and L effect is

$$S(z,t) = \Phi_0 \int_{t'}^{1} \frac{2M_1(z,0)M_0(z,\tau)}{(1-exp\{-2\rho_0^2 M_1(z,0)y^2\})M_0(z,0)M_4(z,\tau)} \frac{d\tau}{\tau} [sin\{arctan[\frac{M_2(z,0)-M_2(z,\tau)}{M_1(z,0)+M_1(z,\tau)}] + M_3(z,0) - M_3(z,\tau)\} - exp\{-2\rho_0^2(M_1(z,0) + M_1(z,\tau)y^2)\} \times sin\{arctan[\frac{M_2(z,0)-M_2(z,\tau)}{M_1(z,0)+M_1(z,\tau)}] + \rho_0^2 y^2 (M_2(z,0) - M_2(z,\tau)) + M_3(z,0) - M_3(z,\tau)\}]$$

Eqn. 1

With

$$M_0(z,\tau) = \frac{1}{\sqrt{(1+2m(z)\tau)^2+v(z)^2}}, \quad \text{Eqn. 2}$$

$$M_1(z,\tau) = \frac{(1+2m(z)\tau)}{4((1+2m(z)\tau)^2+v(z)^2)}, \quad \text{Eqn. 3}$$

$$M_2(z,\tau) = \frac{v}{4((1+2m(z)\tau)^2+v(z)^2)}, \quad \text{Eqn. 4}$$

$$M_3(z,\tau) = arctan\{-\frac{v(z)}{1+2m(z)\tau}\}, \quad \text{Eqn. 5}$$

$$M_4(z,\tau) = \sqrt{(M_1(z,0)+M_1(z,\tau))^2 + (M_2(z,0)-M_2(z,\tau))^2} \quad \text{Eqn. 6}$$

m is the degree of the mode mismatching with

$$v(z) = (z - a_p)/z_p + (z_p/L)[1 + (z - a_p)^2/z_p^2] \quad \text{Eqn. 7}$$

here a_p and z_p are waist and Rayleigh parameters of probe beam respectively. The results show there is strong dependence of signal on ρ_0 and L contrary to [2].

Experimental verification – In order to validate the presented modified model we calculate the absorption coefficient and thermal diffusivity of water using the experimental setup shown. A probe beam of 2 mW He-Ne laser at 632 nm and a 532 nm diode-pumped solid state laser (DPSS) with power 480 mW has been used. The presented theory allows to perform fitting on the experimental data using the values of Φ0 and diffusivity as fitting parameters without considering L as a critical unknown parameter. To test the validity of our model, we performed mode-mismatched Z-scan experiment using double distilled and deionized water as a sample. The obtained values for the absorption coefficient and thermal diffusivity match pretty well with literature values.

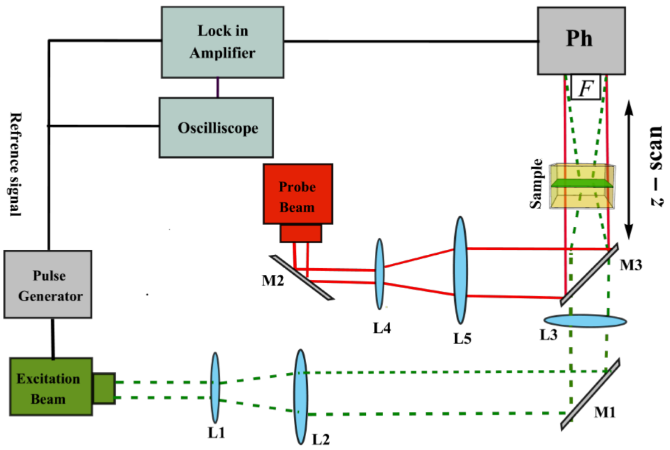

Fig. 1. Experimental configuration of the pump-probe TL setup. Ph: photodetector; L1-L5: lenses; M1-M2: turning mirror, M3: dichroic mirror, F: filter.

References

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[2] A. Marcano, C. Loper, N. Melikechi, Pump–probe mode-mismatched thermal-lens z scan, JOSA B 19 (2002) 119–124.