HIGH-SENSITIVITY ABSORPTION MEASUREMENTS IN LIQUIDS AND SOLIDS

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Abstract

We report on a mode-mismatched pump-probe thermal lens experiment performed to measure low absorption. The use of a collimated probe beam in the presence of a focused excitation beam optimizes the thermal lens experiment. The signal becomes independent on the Rayleigh parameters and waists positions of the beams. We apply this method to study BK7 optical glass and pure water. Linear optical absorption coefficient spectra in the range of 457-528 nm were determined.

Introduction

Measurement of absorption coefficient with high sensitivity is important by several reasons, for instance, for the identification of constituents such as impurity of a given sample. At low absorption, the optical transmission decreases exponentially with the absorption path length following Beer’s law. Based on this law, optical techniques can measure changes in the transmission of about $10^{-3}$, where to increase the sensitivity in the absorption measurement multipass cells have been used. The transmission technique is not the only method for the absorption determination. The thermal lens (TL) spectrometry \cite{1,4} has been developed as alternative way for the characterization of absorption in optical samples. In this work, we applied the mode-mismatched pump-probe TL method, which optimizes the TL experiment \cite{12}, for determination of linear optical absorption spectra in the range of 457-528 nm in water and BK7 glass.

The TL spectrometry is characterized by the incidence of a Gaussian beam in a medium. The energy of the laser beam produces heating in the illuminated region, and as the intensity of the beam is bigger in its center, it generates a temperature radial distribution $\Delta T(r, t)$. The refractive index is given by $n(r) = n_o + (dn/dT)\cdot \Delta T(r)$, whose profile follows the temperature one. Therefore, the Gaussian profile of the incident beam is transferred to the refractive index. So, depending on the $dn/dT$ signal the material behaves like a convergent ($dn/dT > 0$) or divergent ($dn/dT < 0$) lens. The TL signal is defined as the normalized change of the transmission of the probe field through an aperture of radius, $r_o$, much smaller than the radius of the probe beam, centered at the beam axis and located at a distance much larger than the pump Rayleigh parameter. Shen et al. have derived an expression for the TL signal using a diffraction approximation for Gaussian beams, which is given by: \cite{8}

$$I(Z,t) = I_0 \left[ 1 - \theta \tan^{-1} \left( \frac{2m \cdot V}{\left( 1 + 2m \right)^2 + V^2} \right) \right]$$

(1)

where
\[
\theta = -\frac{P_e \cdot \alpha \cdot l}{K \lambda_p} \frac{ds}{dT}
\]

(2)

\[
t_e = \frac{w^2}{4D}
\]

(3)
in which, \( \lambda_p \) is the wavelength of the probe beam, \( D \) and \( K \) are the thermal diffusivity and conductivity, respectively, \( L \) is the detector position, \( P_e \) is the excitation beam power, \( \alpha \) is the absorption coefficient, and \( l \) is the sample thickness. The \( ds/dT \) parameter can be considered constant for the changes in temperature typically observed in a TL experiment (< 0.01 K), and it is equal to \( dn/dT \) in liquid samples, \( m \) and \( V \) are geometrical parameters.

**Experimental Setup**

The experimental setup is shown in Fig. 1. A HeNe cw laser operating at 632.8 nm and \( P_e = 1 \) mW generates the probe beam, which is collimated and directed to the sample before it is enlarged, and subsequently collected onto a silicon photodetector (Thorlabs, DET 310). At the detector plane, the probe beam has a diameter of 4 cm. In front of the detector, an aperture of radius 0.1 cm is placed centered on the axis of the probe beam. The pump beam is provided by an Ar\(^+\) cw laser (Coherent, Innova 90 Plus), which generates different wavelengths between 457 and 528 nm. This beam is focused onto the sample with a 30 cm focal length achromatic lens resulting in a Rayleigh parameter of ~1.7 cm. The collimated probe beam diameter is ~1 mm. Optical filters were used to block the pump beam in the photodetector. The samples are distilled and deionized water, contained in a quartz cell 1 cm thick, and a BK7 optical glass plate 5.7 mm thick. To determine the nonlinear optical phase shift, the TL signal is measured at the position where its value is maximum (sample at position of the excitation beam waist). For negative (positive) photothermal coefficients, the TL signal is negative (positive).

![Experimental Setup Diagram](image)

**Results and Discussions**

Figure 2 shows a typical TL signal from distilled water and BK7 glass plate. The solid lines are results of theoretical fits obtained using Eq. (1), from where the phase shifts were achieved. The following parameters were used: \( D = 1.44 \times 10^{-3} \text{ cm}^2/\text{s}, dn/dT = 99 \times 10^{-6} \text{ K}^{-1}, \) and \( K = 6 \times 10^{-3} \text{ W/cmK} \) for water; and \( D = 5.2 \times 10^{-3} \text{ cm}^2/\text{s}, ds/dT = 6 \times 10^{-6} \text{ K}^{-1} \) and \( K = 11.1 \times 10^{-3} \text{ W/cmK} \) for BK7 glass [10,11]. From these phase shifts the linear absorption coefficients were calculated. The result for water is in good agreement with previous measurements based on integrating cavity methods [7]. The obtained spectra for water and BK7 glass are presented in the Figure 4.
FIG. 2. Transient TL signal for (a) distilled water and (b) BK7 glass. The solid lines are fits with TL equation from the experimental data.

FIG. 4. Absorption spectra for (a) pure water and (b) BK7 glass, in the region of 457 - 514 nm.

Conclusions
A particular configuration of the TL technique, where the pump beam is focused in the presence of a collimated probe beam, has been used for the measurement of low absorption coefficient of transparent materials. Absorption spectra, in the range of 457 to 528 nm, were obtained for distilled water and BK7 glass.

References