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Thermal lens and all optical switching of new organometallic compound doped polyacrylamide gel

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ABSTRACT

In this work thermal lens spectrometry (TLS) is applied to investigate the thermo-optical properties of new organometallic compound containing azomethine group, Dichloro bis [2-(2-hydroxybenzylideneamino)-5-methylphenyl] telluride platinum(II), doped polyacrylamide gel using transistor-transistor logic (TTL) modulated cw 532 nm laser beam as an excitation beam modulated at 10 Hz frequency and probe beam wavelength 635 nm at 14 mW. The technique is applied to determine the thermal diffusivities, ds/dT and the linear thermal expansion coefficient of the sample. All-optical switching effects with low background and high stability are demonstrated.

Introduction

It is well known that dye doped polymer under irradiation of a linear pump beam causes photo induced birefringence owing to photochemical reactions. Dye doped polymer has generated a wide interest in recent years because it offers possibilities for the application in optical storage, optical communication and information processing, especially all-optical modulators [1–8]. All-optical switching using dye-doped polymer is certainly one of the most interesting topics at present [9–12]. However, many problems in the optical switching experiments [13–19] based on polymers still need to be tackled, such as slow response (millisecond order of magnitude), large background, low stability, extinction ratio of the switching signal, etc. Thermal lens spectrometry (TLS) is one of the sensitive photothermal techniques upon temperature gradient which is due to absorption of electromagnetic radiation and nonradiative relaxation of the excited molecules. In the TLS experiment the excitation laser must have Gaussian profile, so when a sample absorbs the beam with Gaussian distributed intensity the temperature distribution has a radial dependence. The temperature gradient causes refractive index gradient which behaves like a converging or diverging lens depending on whether the change rate of refractive index with respect to temperature, is positive or negative [20–22]. The high sensitivity character of this technique makes it very appropriate for measuring the thermal diffusivity of samples which relies on physical changes that happen in the sample.

In this work thermal lens spectrometry is applied to evaluate the thermo-optic coefficient of Dichloro bis [2-(2-hydroxybenzylideneamino)-5-methylphenyl] telluride platinum(II): polyacrylamide gel. In TL experimental set up a transistor-transistor logic (TTL) modulated cw laser of wavelength 532 nm and cw laser at 635 nm wavelength were used as the excitation source and the probe beam, respectively. A simple all-optical switch is demonstrated in the dye: polyacrylamide gel. The all-optical switching effect has been studied at 14 mW power and 0.55 mM concentration of the sample.

Preparation of materials

The sample of new organometallic compound: polyacrylamide gel was prepared from Dichloro bis [2-(2-hydroxybenzylideneamino)-5-methylphenyl] telluride platinum(II) and polyacrylamide (average Mw = 10,000 g/mol, Sigma–Aldrich) by dissolving (1 g, 2.2 mmol/L) the dye in 50 mL distilled water, and (0.1 g, 1.4 mmol/L) polyacrylamide dissolved in 50 mL distilled water, then the dye solution and the polyacrylamide solution were mixed. The mixture was stirred at room temperature for 50 min to inter all dye molecules within polymer chains, then the solution was filtered through a 0.2 μm syringe filter. After that, the solution of dye: polyacrylamide was mixed, heated (up to 85 °C) and stirred for 1 h, then the mixture was cooled to room temperature to obtain a dye: polyacrylamide gel. The chemical structure of Dichloro bis [2-(2-hydroxybenzylideneamino)-5-methylphenyl] telluride platinum(II) is shown in Fig. 1.

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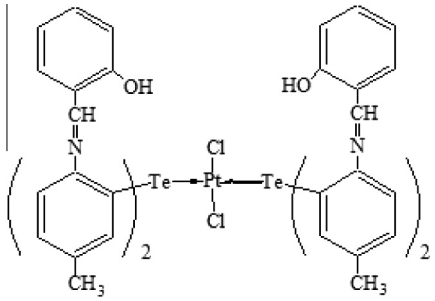

Fig. 1. Dichloro bis [2-(2-hydroxybenzylideneamino)-5-methylphenyl] telluride platinum(II).

Thermal lens

The thermal lens (TL) experimental setup is shown in Fig. 2, the sample is illuminated by two TEM_{00} Gaussian laser beams, one of which is used for exciting the sample to produce a local temperature increase, using a transistor–transistor logic (TTL) modulated laser beam (532 nm at 35 mW) as an excitation beam modulated at 10 Hz frequency and focused by a +50 cm focal, and the other to probe the thermal effect. The probe beam is focused by +20 cm focal length lens and is aligned at an angle smaller than 1.4° with respect to the excitation beam. The sample was laced at $\sqrt{3}\,Z_c$ from the probe beam waist.

When the probe beam passes through the created lens, its optical path length undergoes a temporal change that can be observed by measuring the beam center intensity in the far field. The propagation of the probe beam laser through the TL results in either a defocusing ($dn/dT < 0$) or a focusing ($dn/dT > 0$) of the beam center. The theoretical treatment of the TL effect considers the aberration of the thermal lens as an optical path length change to the probe laser beam, which can be expressed as an additional phase shift on the probe beam wave front after its passing through the sample [23].

Finally, using Fresnell diffraction theory, the probe beam intensity at the detector plane can be written as an analytical expression for absolute determination of the thermo-optical properties of the sample, as [24–27]:

$$I(t) = I(0)\left[1 - \frac{\theta}{2}\tan^{-1}\left[\frac{2mV}{\left[(1+2m)^2+V^2\right]\frac{t_c}{2t}+1+2m+V^2}\right]\right]^2, \quad (1)$$

In Eq. (1) $I(t)$ is the temporal dependence of the probe laser beam at the detector $I(0)$, is the initial value of $I(t)$ when t is zero, θ is the thermally induced phase shift of the probe beam after its passing through the sample,

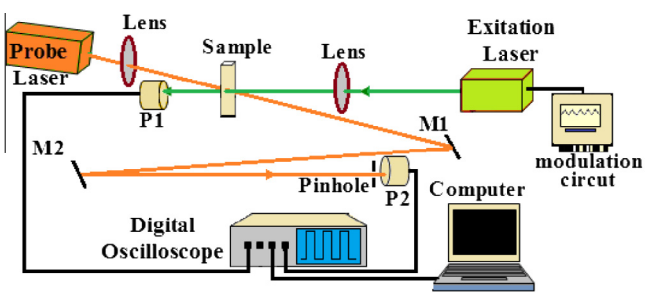

Fig. 2. Thermal lens technique. M1and M2 are silver mirrors and P1 and P2 are a photodiode connected to a digital storage oscilloscope.

$$V = \frac{Z_l}{Z_c}, \quad m = \left(\frac{w_p}{w_e}\right)^2, \quad (2)$$

where ω_p and ω_e are the probe beam and excitation beam spot sizes at the sample, respectively Z_c is the confocal distance of the probe beam, Z_l is the distance from the probe beam waist to the sample.

$$\theta = -\frac{P_e A_e L}{K\lambda}\varphi\left(\frac{ds}{dT}\right)$$

where p_e is the excitation beam power (35 mW), A_e is the optical absorption coefficient of the sample at the excitation beam wavelength (cm^{-1}), λ is the laser probe beam wavelength 635 nm at 14 mW beam power, L is the sample thickness, K is the thermal conductivity ($K = 0.598$ W/m K) and (ds/dT) is the temperature coefficient of the optical path length change at the probe beam wavelength.

The characteristic time constant of the thermal lens is t_c. It depends on the excitation beam spot size at the sample ω_e and thermal diffusivity D, and can be expressed as:

$$D = \frac{w_e^2}{4t_c}, \quad (3)$$

The parameter, θ and t_c can be determined by fitting the experimental data to Eq. (1).

Results and discussion

Basic experimental technique for a thermal blooming measurement is to employ a laser beam of appropriate frequency focused using a long focal length lens. This creates an artificial beam waist, which is a function of the focal length f, the unfocussed beam size and the excitation wavelength. Heat generated in the region of absorption increases the local temperature, thereby modifying the refractive index and inducing an optical lens, which could be diverging or converging depending on the sign of $\partial n = \partial T$ the temperature coefficient of refractive index of the medium. The TL develops over a period of time governed by the rise time of the exciting beam and also characteristic of the thermal time constant of the medium. During this time, if one allows another probe beam to pass through the irradiated region and observes the spot at far field, obviously the spot will increases in size, called thermal blooming [28–29]. An example is shown in Fig. 3. It is well known that this size change in the probe spot enables us to calculate $\partial n = \partial T$ and consequently various photothermal parameters of the sample.

Fig. 4 shows a typical TL transient signal for the dye compound: polyacrylamide gel sample at room temperature. We fitted the experimental data with Eq. (1) yielding $\theta = (0.3682 \pm 0.0046)$ and $t_c = (18.1 \pm 1.31)$ ms. Using Eq. (2). for t_c with $\omega_e = (21.63 \pm 0.09) \times 10^{-3}$ cm, it was possible to obtain the thermal diffusivity $D = (6.462 \pm 0.03) \times 10^{-5}$ cm^2/s. Using our measured value $A_e = 0.267$ cm^{-1}, t_c from the fit and keeping in mind that $\theta = -(P_e A_e L/K\lambda)\varphi(ds/dT)$ (Eq. (2)), we obtained $ds/dT = (1.165 \pm 0.015) \times 10^{-5}$ K^{-1} where φ is the fraction of absorbed energy converted into heat per photon. In the case of non-luminescent samples, such as the samples studied in this work, all absorbed energy is converted into heat, so $\varphi = 1$.

The parameter ds/dT determined by TL measurements can be written as [30,31],

$$\frac{ds}{dT} = (n-1)(1+\nu)\alpha_T + \frac{dn}{dT} + \frac{1}{4}n^3 Y\alpha_T(q_{11}+q_{12}), \quad (4)$$

where α_T is the linear thermal expansion coefficient, ν is the Poisson ratio, Y is the Young modulus, q_{11} and q_{12} are the stress optic coefficients, parallel and perpendicular to the direction of the laser beam propagation. Neglecting the last term of the above equation,

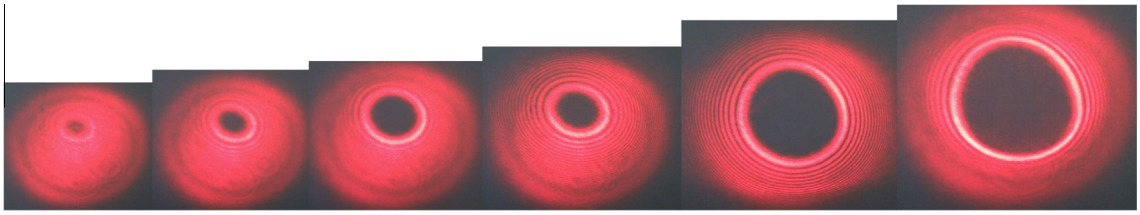

Fig. 3. Photograph showing the thermal blooming of the probe beam.

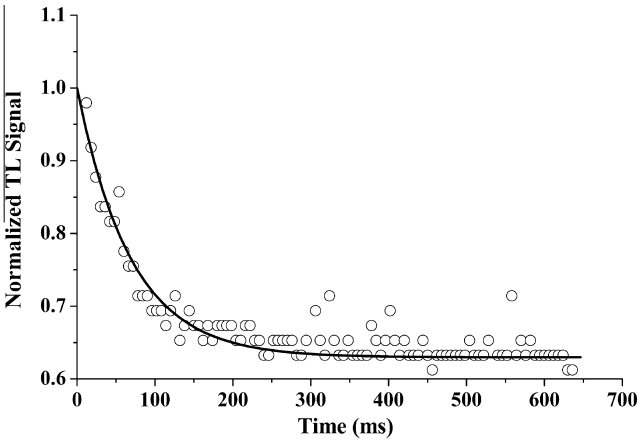

Fig. 4. Typical transient TL signal for dye: polyacrylamide gel. The solid line corresponds to the data fitting to Eq. (1).

and using $n = 1.546$, $dn/dT = -2.2691 \times 10^{-5}\,K^{-1}$, and $v = 0.45$ [32], we can estimate the value of α_T of Dichloro bis [2-(2-hydroxybenzylideneamino)-5-methylphenyl] telluride platinum(II): polyacrylamide gel as $\alpha_T = 1.847 \times 10^5\,K^{-1}$.

Fig. 5. shows an oscilloscope trace of transient optical switching (below) together with the input TTL modulated pump signal (above) the all optical switching effect of the sample at room temperature with beam power at 14 mW. It is clear that when the beam is turned on, the intensity of the signal beam detected increases with a rising time about several milli seconds. When the beam is off, the transmitted intensity of signal beam decreases with a falling time about 10 ms. As well known that without the control beam, Dichloro bis [2-(2-hydroxybenzylideneamino)-5-methylphenyl] telluride platinum(II): polyacrylamide gel molecules are randomly oriented. The sample is optically isotropic and cannot exhibit any birefringence.

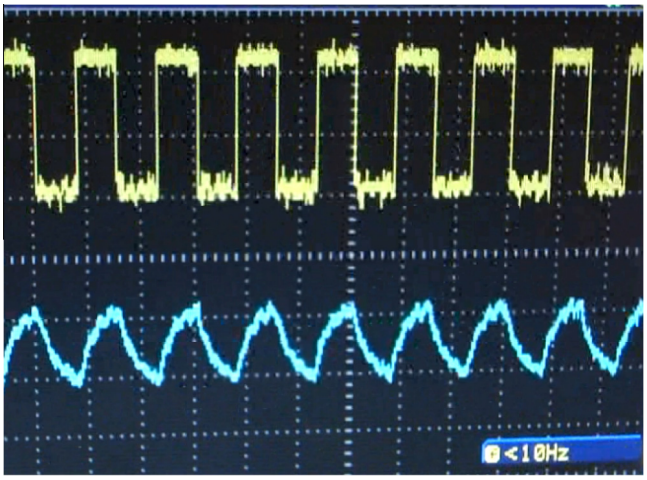

Fig. 5. Inverted optical switching: pump beam (upper trace), probe beam (lower trace).

Conclusions

In this paper we discuss the use of the TL technique for investigating the thermal properties and thermal diffusivity of Dichloro bis [2-(2-hydroxybenzylideneamino)-5-methylphenyl] telluride platinum(II): polyacrylamide gel. It is also discussed how the experimentally determined TL parameters can be used for determination of the linear thermal expansion coefficient of the sample. Optical switching based on defocusing effect is demonstrated. It can be seen that the dye with polyacrylamide gel has the strong all optical switching effect.

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