Thermal diffusivity measurements in vegetable oils with thermal lens technique

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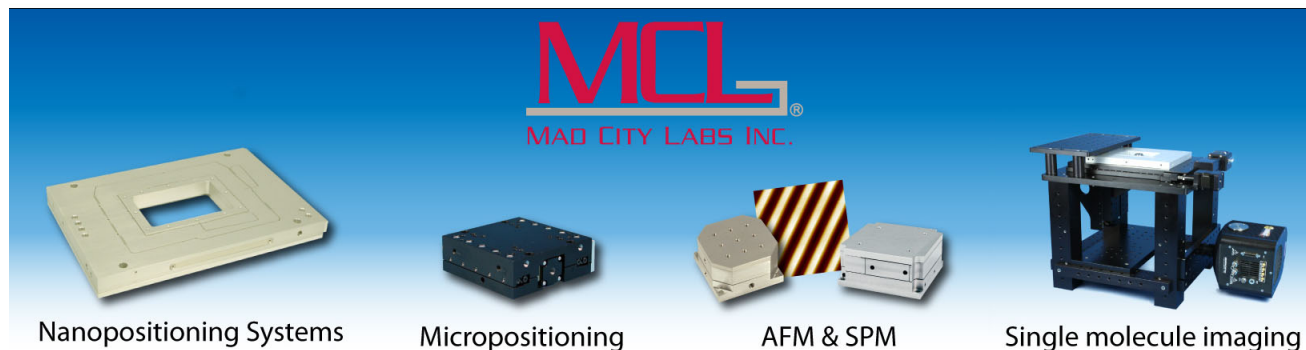Rev. Sci. Instrum. **73**, 3337 (2002); 10.1063/1.1497495

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Thermal diffusivity measurements in vegetable oils with thermal lens technique

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Using a thermal lensing experimental setup the thermal properties of several vegetable oils were obtained. The samples were oils from Amazonian species and olive (the popular identifications are piqui, copaiba, buriti, and babaçu). The two lasers mismatched mode experimental configuration was used, with a He–Ne laser as the probe and an Ar^+ laser as the excitation one. The time resolved spectra were measured using an automatic system, and fitting the aberrant theoretical model to the data, the characteristic relaxation time were obtained, and knowing this value, the thermal property of each oil was solved. © *2003 American Institute of Physics.* [DOI: 10.1063/1.1517726]

I. INTRODUCTION

The thermal lens effect was originally investigated for laser characterization,[1] now it is a very useful and sensitive technique to investigate physical properties in a wide variety of materials. It is capable to measure optical[2,3] and thermal[4–6] properties of transparent samples with an enhanced accuracy, for solid samples,[2,3] liquids, as well as other complex systems.[5,6] In this article, an experimental setup of this technique is used to investigate the thermal properties of several samples of vegetable oils, four Amazonian species, and olive. All of these materials have medical, nutritional, and cosmetic uses in the northern region of Brazil, and their economical relevance is a strong motivation for the research of their physical characterization.

A thermal lens (TL) is produced illuminating a transparent sample with a laser beam with a TEM_{00} Gaussian profile: this is the excitation beam. It generates a thermal distribution that induces a proportional change in the refractive index. Such a temperature gradient in the sample gives different optical path lengths, in each point, for the light of a probe laser beam, which passes through the heated space in the material. The intensity at the center of the probe beam is electronically detected far away from the sample, this is the so-called thermal lens signal (TLS), and its time evolution is analyzed to obtain the physical parameters of the material.

II. EXPERIMENTAL SETUP

We use an Ar^1 laser (514.5 nm) as an excitation beam, focused on the sample with 51 μm of waist radius (20 mW). The probe beam was a 1 mW He–Ne laser (632.8 nm). It had a radius on the sample of 180 μm. A personal computer (PC) controlled a shooter which protected a mechanical diaphram,

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both of them were used for limiting the exposure of the sample to the light; when they were opened, the sample and a photodiode trigger were illuminated, and the last one sent a signal to initialize the data acquisition. The maximum intensity of the probe beam was centered on the photodiode detector and its time variation, in the form of a voltage, was registered by a Hewlett-Packard 7090A recorder and then sent to the PC, as a function of time, through a general purpose interface bus. See Fig. 1 for a schematic representation of the experimental setup. Several cubes of thin glass walls were filled with each kind of oil (dimensions of the glass layer: 2 cm×2 cm×50 μm), the internal width of the container, along the laser beam, was 1 mm and the samples were placed at the waist of the excitation laser.

III. THEORY

We use the aberrant model theory, in the mismatched mode,[7,8] where the sample is at the waist of an excitation laser with a Gaussian spot. The time variation of the TLS is
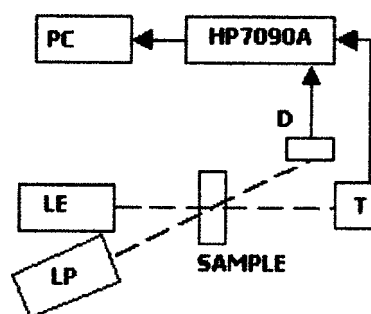

FIG. 1. Schematic representation the experimental setup. LE: laser used for excitation; LP: probe laser; *D*: signal detector; *T*: trigger detector; HP7090A: data acquisition device; PC: personal computer.
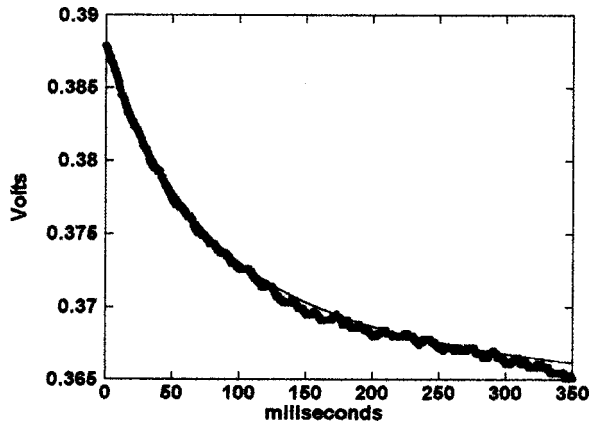
FIG. 2. Time evolution of the TL signal for olive. Symbols represent the experimental data and the solid line, beneath the points, the best fit to Eq. (1).

$$I(t) = I_0 \left[1 - \frac{\theta}{2} \arctan \right.$$

$$\left. \times \left(\frac{2mV}{[(1+2m)^2 + V^2] \times \left(\frac{\tau}{2t}\right) + 1 + 2m + V^2} \right) \right]^2,$$

(1)

where

$$m = \left(\frac{\omega_p}{\omega_e}\right)^2, \quad V = \frac{Z_1}{Z_C}, \quad \text{and} \quad \theta = \frac{A_e P_e}{\lambda_p k} \frac{ds}{dT}. \quad (2)$$

In the earlier equations ω_e (ω_p) is the spot size of the excitation (probe) laser beam at the sample; θ is the difference between the thermally induced phase shift on the probe beam at $r-0$ and $r = \sqrt{2}\omega_e$; I_0 is the value of the signal at $t=0$ (or $\theta=0$); $\alpha(\kappa)$ is the thermal conductivity (diffusivity) of the sample; Z_1 is the distance between the sample and the waist of the probe beam; and Z_c is the confocal distance of the last one ($Z_1 = 5.20$ cm and $Z_c = 1.84$ cm in our experiments); P_e is the incident power and A_e is the optical absorption coefficient at the excitation beam wavelength, λ_e; ds/dT is the temperature coefficient of the optical path length for the
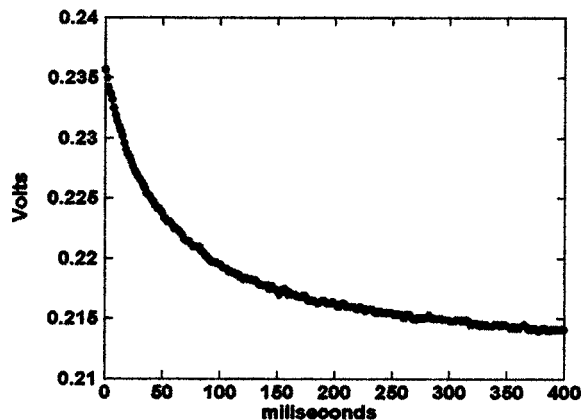

FIG. 3. Time evolution of the TL signal for piqui. Symbols represent the experimental data and the solid lines their best fit to Eq. (1).

TABLE I. Thermal diffusivities for the five oils. Errors are the standard deviation of several measurements of each sample and they are consistent with the asymptotic standard errors of the Levenberg–Marquardt algorithm used in the fitting process. We use the gnuplot software and the PAW subroutines of the CERN Libraries.

Oil	Thermal diffusivity (10^{-4} cm^2/s)	Error (%)
Mauritia flexuosa (buriti)	9.5	1.5
Copaifera officinalis (copaiba)	16.7	6.3
Caryocar brasiliense (piqui)	3.8	3.2
Orbignia Martiana (babaçu)	6.7	2.1
Olive	5.4	2.6

probe beam. λ_p is the probe beam wavelength. The so-called characteristic time of TL, τ, is related to α as $\alpha = \omega_e^2/4\tau$. With these definitions, $I(t)$ could be a rising or a decreasing function of time, depending on the sign of ds/dT. In both cases, it has a monotonic behavior.

Equation (1) describes the time resolved transient that creates the TL. The conditions assumed in its derivation, including the homogeneity of the sample, are: (i) infinite medium along the radial direction, i.e., sample radius much larger than the excitation and probe beam radii. This ensures that border effects are negligible; (ii) sample with low optical absorption coefficient, A_e, the intensity of the excitation beam is uniform along the sample axis (perpendicular direction to the sample facet); (iii) negligible heat flux to the surroundings of the sample facets. For solid and liquid samples in air, this condition is generally well satisfied provided the sample thickness is larger than ω_e and ω_p. Conditions (ii) and (iii) ensures the temperature to be dependent only on the radial coordinate, not on the axial one, thus simplifying the theoretical analysis performed to derive Eq. (1).

IV. RESULTS AND DISCUSSION

We measured the TLS from five different oils, and the time evolution of the TL signal from olive and piqui, is shown in Figs. 2 and 3 [symbols represent the experimental points and lines are the result of their best fit to Eq. (1)]. The rest of the plots for buriti, copaiba, and babazu are similar to Figs. 2 and 3. As one can see, the signal decreases with time, indicating that the thermal lens is divergent, thus defocusing the probe beam on the detector. This behavior relies on the fact that the temperature coefficient of the optical path length, ds/dT, is negative for oil and this is also the case for most transparent liquids and plastics. Table I summarizes the thermal diffusivity values obtained from the fitting to the five sets of data.

V. CONCLUSIONS

Several vegetable oils were studied and a thermal lens experiment was used to measure their thermal diffusivities. This photothermal technique has the capability of analyze this materials and the thermal properties measurement gives an adequate parameter for the characterization of such organic fluids. A special interest of this work is focused on the Amazonian species, whose physical characterization is just beginning.

ACKNOWLEDGMENTS

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