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OPTICAL PROBING OF THERMAL WAVES. APPLICATION TO SPECTROSCOPY AND IMAGING.

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When an absorbing sample is uniformly irradiated by a modulated beam of light, its surface exhibits a periodic temperature variation, which can be written $T = T_o \cos \omega t$. At a distance x from the heated plane of the sample, the temperature in the non-absorbing fluid is :

$$T = T_o \exp(-x/\mu_f) \cos(\omega t - x/\mu_f) \quad (1)$$

where μ_f is the thermal diffusion length of the fluid ($\mu_f = \sqrt{2k_f/\rho_f C_f \omega}$; C_f, specific heat ; ρ_f, density of the fluid) (Rosencwaig, 1977).

Let us point out that T_o is a function of the optical (absorption, reflection) properties of the sample and of the thermal properties (k, ρ, C) of the sample and of the transparent surrounding fluid. The associated temperature gradient induces a deflection ϕ of an helium neon laser beam propagating parallel to the surface of length L (Boccara, Fournier, Badoz, 1980).

$$\phi = \frac{L}{n} \cdot \frac{dn}{dT} \cdot \frac{dT}{dx} = -\frac{L}{n} \cdot \frac{dn}{dT} \frac{\sqrt{2}T_o}{\mu_f} \exp(-\frac{x}{\mu_f}) \cos(\omega t - \frac{x}{\mu_f} + \frac{\pi}{4}) \quad (2)$$

This formula is restricted to a very simple case where the surface is uniformly heated. More detailed calculations for a non uniform heat distribution are given elsewhere (Jackson, Amer, Boccara and Fournier 1981).

The deflection signal may be used to measure T_o and obtain informations similar to those reached by using the classical P.A. detection.

Figure 1 shows this experimental set-up. The sample is heated by a modulated source and the thermal gradient is probed by an He-Ne laser. The sample is either immersed in a liquid or in contact with the surrounding air. When possible, the use of a liquid leads to an increase of the signal by two orders of magnitude, because of its larger dn/dT value and of the reduction of the thermal diffusion length μ_f. The minimum deflection of the probe beam, measured with a position sensor, is about 10^{-8} to 10^{-9} radian depending upon the modulation frequency and corresponds to surface fluctuations of 10^{-7} - 10^{-8} degree for an immersed sample (probing length ∿ 1 cm). This sensitivity is at least two orders of magnitude larger than conventional photoacoustic detection.

THERMAL MEASUREMENTS

It is obvious (Formula 2) that thermal parameters of the solid (through T_o) and (or) of the fluid (through μ_f) can be reached by the deflection measurement. Figure 2 shows the amplitude and the phase of the deflection in air close to periodically heated plane sample.

So the thermal diffusion length of gas and liquids can be easily obtained by these methods.

Recently, in order to avoid the influence of the buckling on photoacoustic signal, the deflection measurements have been used to determine the phase and

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the amplitude of the surface temperature which lead to the knowledge of thermal diffusivity and effusivity (Le Poutre, Charpentier, Boccara and D. Fournier 1981).

PHOTOTHERMAL IMAGING.

Usually the set-up (Fig. 1) is used with a laser light source (He-Ne or Argon) and the scanning is obtained by a combination of optics and sample displacements. With our detection one can reach either the substructure signals usually observe in photothermal imaging (such as photoacoustic imaging) (Fig. 3), or information related to probe localization such as the geometrical shape of the surface (precision $\sim 0.1\ \mu$). The latter being achieved by recording the phase of the signal which varies linearly (formula 2) with the distance between the sample surface and the probe beam (Fig. 4).

Finally, the probe being sensitive to three dimensional effects, in some cases large enhancements of signal associated with 'diffraction' of thermal waves may be observed (Aamodt and Murphy 1981, Jackson et al 1981).

SPECTROSCOPY.

With the photothermal deflection sensitivity, new fields have been opened to spectroscopy of "exotic samples". Let us point out that by coupling this detection with a Fourier Transform interferometer we have now achieved sensitivities two to three orders of magnitude larger than conventional photoacoustic spectroscopy. Fig. 5 shows the absorption of a 0.7 μ thick amorphous silicon sample. The noise equivalent signal corresponds to an absorption of 10^{-5} in the coating which is far better than photoelectric measurements. Moreover using the same set-up we have also been able to measure dichroism spectra.

Finally we would like to point out that the photothermal deflection is particularly well adapted for "in situ" measurements at solid-liquid interface. Indeed we have recently been able to monitor absorbing compounds which may appear or disappear during an electrochemical cycle (Roger, Fournier and Boccara).

REFERENCES

1. A.C. BOCCARA, D. FOURNIER and J. BADOZ 1980 Applied Physics Letters 36 (2), 130-132.
Thermooptical spectroscopy : detection by the "mirage effect".

2. D. FOURNIER, A.C. BOCCARA and J. BADOZ 1981
Second topical meeting on photoacoustic spectroscopy, Berkeley.
Photothermal deflection Fourier transform spectroscopy : A tool for high sensitivity absorption and dichroism measurements.

3. W. JACKSON, N. AMER, A.C. BOCCARA and D. FOURNIER 1981
Applied Optics 20 (8) 1333-1344.
Photothermal reflection spectroscopy and detection.

4. F. LEPOUTRE, P. CHARPENTIER, A.C. BOCCARA and D. FOURNIER 1981
Second topical meeting on photoacoustic spectroscopy, Berkeley
Photoacoustic measurements of thermal diffusivity. Description of the "Drum effect".

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5. J.C. MURPHY and L.C. AAMODT 1981
   Second topical meeting on photoacoustic spectroscopy, Berkeley,
   Signal enhancement in photothermal produced by three dimensional heat flow.

6. J.P. ROGER, D. FOURNIER and A.C. BOCCARA 1981
   To be published.

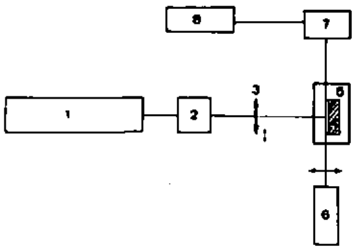

Fig. 1 – Experimental set-up for creating and probing thermal waves. 1. Light source. – 2. Chopper. – 3. Scanning optics (imaging) or still optics. – 4. Sample – 5. Liquid cell. – 6. He-Ne laser – 7. Position detector – 8. Lockin amplifier.

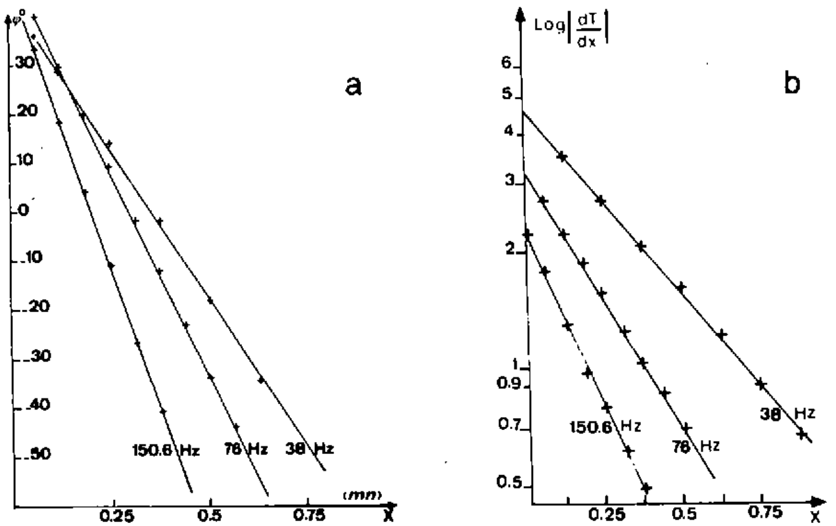

Fig. 2 – Deflection phase (a) and amplitude (b) as a function of the distance from the sample. One can deduce μ_g = 0.25, 0.34 and 0.47 mm at 150, 76 and 38 Hz respectively.

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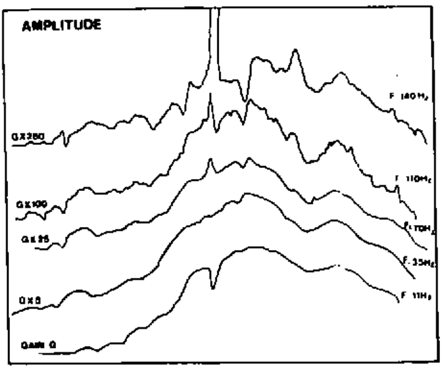

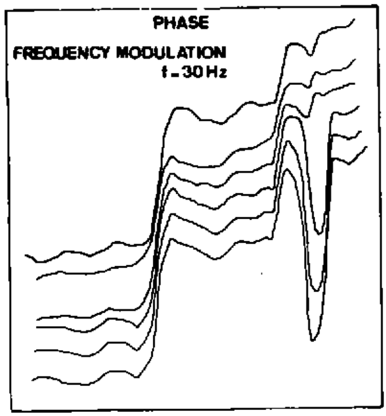

Fig. 3 - Photothermal imaging. Observation of a hole situated 0.3 mm below the surface at various frequencies. (Higher frequencies enhance 3-dimensional effects).

Fig. 4 - Profile analysis of a piece of bakelite (steps of 20 and 10 μ) through the phase measurement of the photothermal deflection signal.

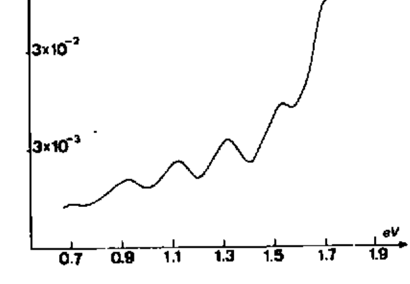

Fig. 5 - Weak absorption measurement on thin films using the photothermal deflection Fourier Transform Spectroscopy. The sample was immersed in CCl_4.