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Detection of phase transitions in liquid crystals using the mirage effect

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We describe here a novel technique which makes use of the photothermal mirage effect to study phase transition in liquid crystals. Results of the measurements done with two nematic liquid crystals are given to illustrate this technique. We observe an enhancement in the signal amplitude during phase change which is due to the large magnitude of the refractive index gradient developing at the transition temperature.

Thermo-optic effects have recently been used to study phase transition in liquid crystals. Amongst such studies, most work has been concentrated on the photo-acoustic effect [1–7]. However, Seo *et al.* [8] used a photo-thermal beam deflection technique to study phase transition, using a pump-probe configuration, and recently Rajasree *et al.* [9] found the use of the mirage effect for the detection of phase transition in solids.

The mirage technique, which was first introduced in the early 1980s by Boccara *et al.* [10], exploits the phenomenon of the optical beam deflection due to a refractive index gradient (RIG). A hot body heats up the surrounding medium so as to generate an RIG directed away from the surface. A light beam (probe beam) propagating normal to the RIG and parallel to the hot surface is deflected from the original path. This is the mirage effect. The amount of deflection is a function of the magnitude of the RIG in the vicinity of the sample surface, and this in turn will depend on the various thermal parameters of the sample, as well as on the distance between the sample surface and the detector, together with the relevant geometrical factors. The magnitude of the beam deflection can be measured using a position sensitive detector (PSD).

The present paper deals with the determination of phase transition temperatures for two nematic liquid crystals using the mirage technique.

The experimental set-up used was similar to that of Rajasree *et al.* [9], with suitable modification for the study of liquid crystals. We now describe the experimental set-up briefly, with reference to the schematic diagram shown in figure 1. A chopped laser beam with a gaussian cross section (FWHM = 0·84 mm) from a stabilized 5 mW He–Ne laser is made to pass the heated sample, grazing the surface at a distance of 0·42 mm. The sample is enclosed in a chamber with appropriate windows to avoid air convection, which may cause erratic fluctuations of the probe beam. The sample is placed in a small pit (1 mm depth and 2 mm diameter) made in an aluminium block (3 cm × 5 cm × 1 cm) which is heated by an electrical heating element attached to a temperature controller. The temperature is measured using a thermocouple kept in a

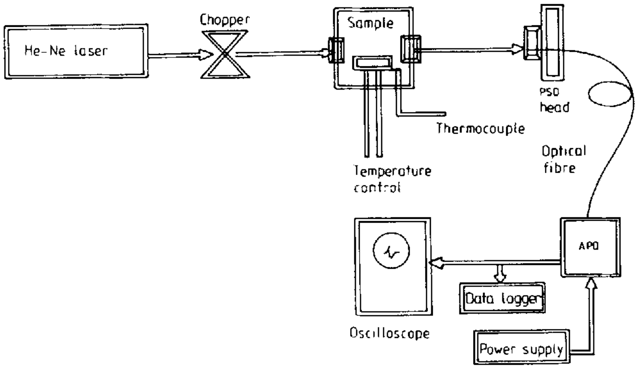

Figure 1. Schematic diagram of the experimental set-up.

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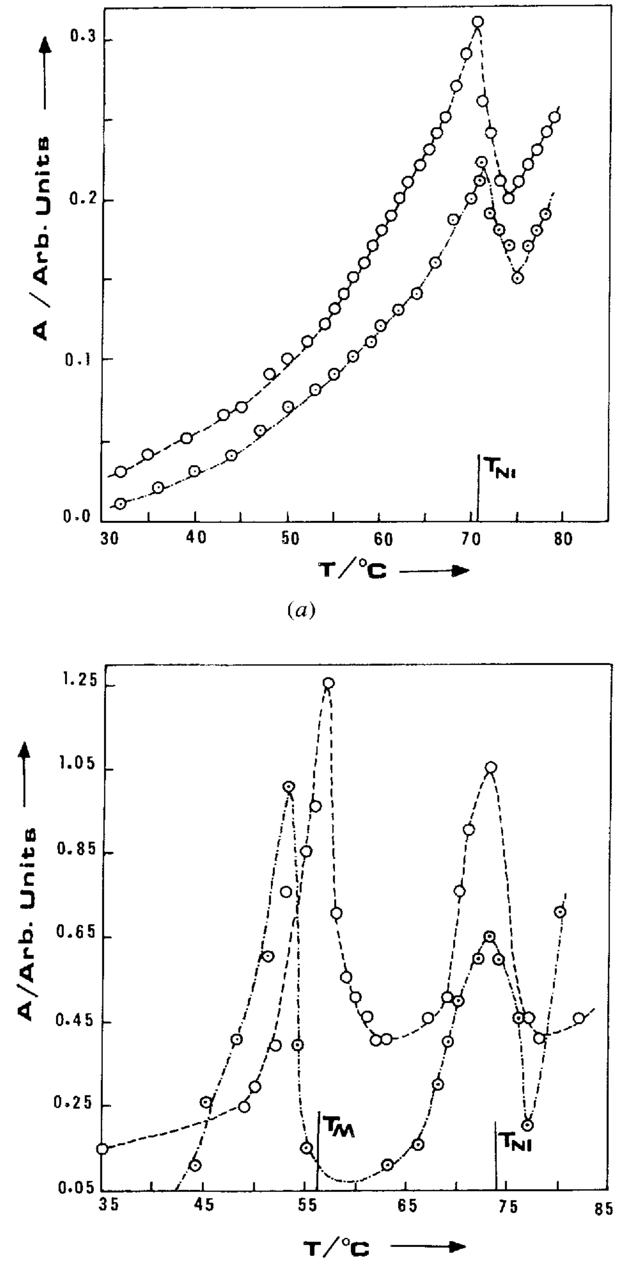
mercury filled cavity on the aluminium block. The PSD consists of a step-index multimode optical fibre with a core diameter of 80 μm (cladding 120 μm) with the polished tip coupled to an avalanche photodiode (Thorn EMI Si APD type S30 500) at the other end. A specially designed highly stable, ripple-free, variable voltage (125–250 V DC) power supply is used to bias this detector so that it operates in the required unsaturated region of the operating characteristics of the APD. (The power supply uses electronic filtering, which provides a high ripple rejection ratio of 94 dB.) The output of the APD is monitored across an appropriate load resistance using a digital AC voltmeter.

The fibre tip is mounted on an *XYZ* translator. Initially, at room temperature, the chopped probe beam is adjusted to fall on the polished tip of the fibre to get a maximum signal (v_0) from the APD detector corresponding to the centre of the beam. As the sample surface is heated (at a rate of about 0·5°C min^{-1}), the probe beam is deflected and the PSD output (v_1) is reduced. The difference ($v_0 - v_1$) is taken as the deflection signal. As the rate of heating is small, the lag in the thermocouple reading is not appreciable for thin samples. A data logger is used to print the signal levels at intervals of 0·5 s.

The above experimental set-up was used for the detection of phase transition for two nematic liquid crystals E8 and M21 (Merck Ltd, U.K.). As the thermal properties of the sample undergo drastic variation at the phase transition temperature, phase transition is bound to affect the deflection signal in a measurable way due to the consequential changes produced in RIG. Figures 2 (*a*) and (*b*) display signal amplitude as a function of temperature for the two liquid crystals E8 and M21, respectively. Near the transition temperature an enhancement in the signal is observed. This anomalous behaviour in the signal obviously arises due to the rapid changes in thermal parameters such as the specific heat and thermal conductivity of the material during phase transition.

The two curves in each of the figures 2 (*a*) and (*b*) correspond to the data when the sample is heated and cooled. As expected, at the nematic–isotropic transition temperature, T_{NI}, the maximum in amplitude is observed precisely at the same temperature for both heating and cooling. On the other hand, supercooling occurs in the nematic phase below the melting point T_{M} and solidification always occurs at a lower temperature. It is obvious from figure 2 (*b*) that the nematic liquid crystal has changed to a solid phase at ~ 5°C below T_{M}. The phase transition temperatures determined using the present technique agree well with those reported earlier for these liquid crystals [11, 12].

We have described the use of the mirage effect to detect phase transition in liquid crystals. Instead of measurements of signal fluctuations at the transition temperature [9], we observe enhancement in the signal amplitude during phase change. This has the advantage that it avoids the use of a pump beam [8] which requires a complex set-up.



(*b*)

Figure 2. (*a*) The plot of the signal amplitude (*A*) versus temperature (*T*) for E8. (*b*) The plot of the signal amplitude (*A*) versus temperature (*T*) for M21. Symbols denote heating (–○–) and cooling (· –○– ·).

Thus the photothermal mirage effect may provide a reliable tool to determine phase transitions in liquid crystals. However, more work needs to be done before this technique can be used to characterize polymesomorphic liquid crystal phase transitions, especially those involving cholesteric and various smectic mesophases. Experiments in this direction are underway.

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