Space Charge Field Generation and Thermal Effect in a Dye-Doped Twisted Nematic Liquid Crystal Cell

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INTRODUCTION

Nematic liquid crystals exhibit long-range orientational order of the axes of the molecules, the average direction being described by the nematic director **n**. These materials are known for their large nonlinear optical properties (Tabiryan et al., 1986; Palffy-Muhoray, 1990; Khoo, 1994), possess very broadband (0.4 mm–12 mm) birefringence and transparency, and have a large susceptibility to ac, dc and optical fields. These properties combine to make nematic liquid crystals ideal materials for image sensing, display and processing devices (Khoo & Wu, 1993; Khoo, 1994).

Optical reorientation in nematics is one nonlinear property that has been studied in detail (Janossy, 1998). In analogy to reorientation by ac or static fields, an impinging optical field will realign the birefringent director axis through dipolar interaction (Khoo & Wu, 1993; Khoo, 1994). In dye-doped nematic films, the dye dopant produces photocharges, which migrate and diffuse within the film and set up various dc space charge fields that exert a torque on the liquid crystal director axis, resulting in reorientation and changes in the refractive index. In particular, the most nonlinear optical effect observed to date has been reported in methyl red-doped nematic films, which show that these photo-induced space charge fields can be so large that no applied dc field is needed to create observable director axis reorientation effects (Khoo et al., 1999).

The dissolution of dye molecules in the nematic liquid crystal within the solubility limit induces significant absorption in the visible range. A straightforward consequence of light absorption is heating, which leads to various thermo-optical effects (Ono & Harato, 1999; Ono & Kikuhara, 2000). In this paper we discuss the combined effects of the induced space charge field and heating due to absorption in a twisted nematic cell, using the pump-probe configuration.

METHODOLOGY

The liquid crystal used is nematic E7 doped with methyl red. The twisted nematic cell is prepared by sandwiching the lightly-doped (~1% by weight) liquid crystal between two rubbed polyimide-coated glasses. The director axis of the nematic liquid crystal lies on the plane of the substrates, which are placed such that the director axis of the film rotates by 90° from the entry to the exit windows, as shown in Fig. 1.

The experimental setup is shown in Fig. 2. A vertically polarized Argon-ion laser beam at 514 nm is used as the pump signal. A low power He-Ne laser beam, also vertically polarized, is used to probe the effect of the induced space charge field and increasing temperature due to absorption. At low power, the polarization of both laser beams follow the director axis and thus these are similarly rotated, making them pass through the

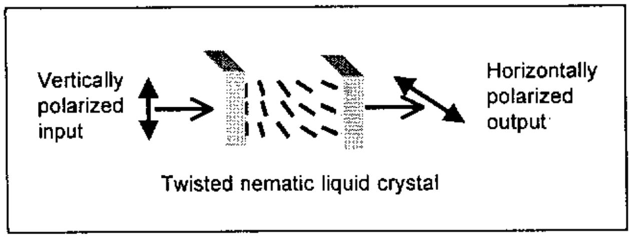

Fig. 1. Geometry of the twisted nematic cell, showing polarization states of the input and output laser beams.

analyzer, which is oriented horizontally. A filter is placed immediately before the sensor such that between the analyzer and the sensor, only the He-Ne beam is detected.

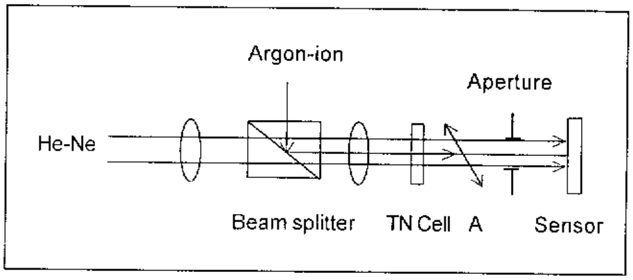

Fig. 2. Experimental setup for optical limiting effect. The diameter of the beam spot on the nematic film is 4 mm, sample thickness is 50 microns.

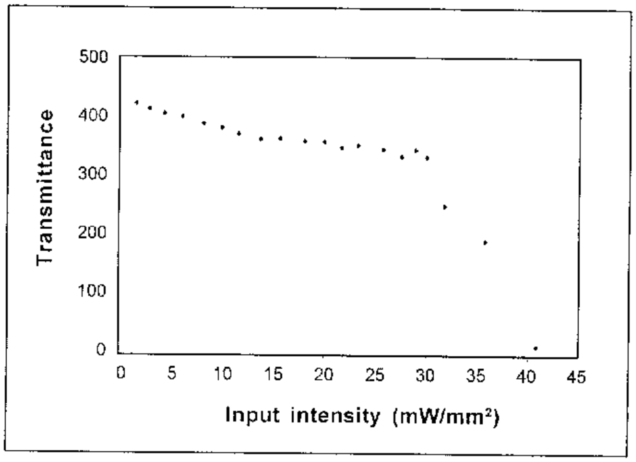

Fig. 3. Input pump beam intensity vs. transmitted probe beam intensity

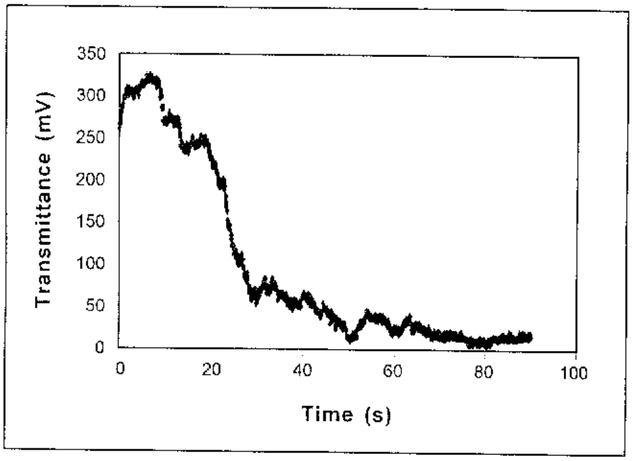

Fig. 4. Time response of the optical switching effect. Input intensity = 41 mW/mm²

RESULTS AND DISCUSSION

The results are shown in Figs. 3 and 4. Fig. 3 plots the transmitted He-Ne laser intensity as a function of the input Argon beam intensity. Fig. 4 shows the time response of the combined effects. At high laser power, a space charge field is induced inside the TN cell, in the direction normal to the plane of the cell window. This causes the director axis to tilt towards a direction normal to the window and as a consequence, the analyzer at the exit end causes the output He-Ne laser power to decrease with increasing incident Argon-ion laser power (Fig. 3).

Also, during continuous illumination, the absorption caused by the dye molecules in the TN cell causes the index to change from $n_{//}$ (1.745) to n_{iso} (1.590) as the cell temperature increases towards the nematic → isotropic temperature T_{N-I}. For nematic E7 this transition temperature is 60.5 °C. At very high laser power (>30 mW/mm²), the twisted nematic sample begins to turn isotropic, characterized by a liquid hole forming in the region illuminated by the high-power beam. The "knee" in Fig. 3 characterizes the onset of this transition. The hole will grow in size as the increase in power continues. The liquid crystal having attained the isotropic state, the incident laser polarization (which is vertical) is unchanged and at the exit it will be perpendicular to the analyzer (which is at 90° with respect to the vertical) and thus the transmitted laser power is minimized. Upon removal of the high-intensity pump beam, this liquid hole returns to the nematic phase and the transmitted intensity gradually increases from zero to its initial value.

The combined effects of reorientation due to the induced space charge field and the thermal effect, observed in the polarizer-analyzer configuration used, result in reduced transmission as input power is increased. The dye-doped twisted nematic cell therefore can be characterized as a light-controlled optical switch. In this case the control is the pump beam, which causes the TN cell to gradually diminish the transmitted intensity of the probe beam and, upon attaining the threshold value, "switches off" the cell, i.e., the transmitted intensity drops to zero. The removal of the control causes the transmitted intensity to gradually return to the initial value (the cell returns to the nematic state); in effect the cell is "switched on."

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