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Electro-optic modulation using an organic single crystal film in a Fabry–Perot cavity

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Electro-optic modulation has been demonstrated using single crystal film of an organic electro-optic material, [*N*-(4-nitrophenyl)-*L*-prolinol] (NPP), placed in a Fabry–Perot cavity. The transverse geometry was used for electro-optic modulation. The cavity used had a finesse of about 50. The modulation depth achieved was about 0.7% for a low ac field of 0.5 V/μm applied along the charge-transfer (polar) axis on the film. The results are promising for applications of such films in high speed optical signal processing. © *1998 American Institute of Physics.*
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The Fabry–Perot interferometer is a high resolution spectroscopy tool that has many applications. Using inorganic electro-optic materials in Fabry–Perot interferometry, various potential applications have been demonstrated.[1,2] Organic electro-optic materials have many attributes that are suitable for a variety of potential applications in electro-optics. In particular, organic single crystal electro-optic materials have very large electro-optic coefficients and high figures of merit for specific applications. Using the modified shear method,[3] large-area ($\sim 1\ \mathrm{cm}^2$) single crystal films of electro-optic materials have been obtained. These thin films have allowed detailed nonlinear optical and electro-optical measurements. In this letter, possible applications in devices such as in a Fabry–Perot cavity will be discussed. Fabry–Perot cavities involving a polymeric electro-optic thin film as a spacer were previously discussed.[4] Since the single crystal films have significantly larger electro-optic coefficients more efficient devices should become possible.

The schematic of the Fabry–Perot cavity used in this work is shown in Fig. 1. The single crystal film of NPP was grown on a quartz substrate the backside of which was coated with gold which acted as a mirror. Gold electrodes were also deposited on the NPP film to apply the electric field along the charge transfer axis that lay parallel to the film plane. Thus, a transverse configuration was used for the electro-optic modulation and the gap between the electrodes was about 1 mm. The other mirror of the cavity was attached to a piezoelectric drive for tuning the cavity length. The transmittance of a Fabry–Perot cavity assuming negligible absorption can be expressed as

$$T = \frac{T_0}{1 + F\ \sin^2\ \delta}, \tag{1}$$

where F is the finesse of the cavity. The total phase retardation has two terms, $\delta = \delta_0 - (n^3 r \pi l E)/\lambda$, where δ_0 is due to the linear refractive index and the second term is induced by the electro-optic effect. The modulation of transmitted light due to the electro-optic effect, $\Delta T/T_0$, can be expressed as

$$\frac{\Delta T}{T_0} = \frac{F\ \sin 2\delta}{(1 + F\ \sin^2\ \delta)^2}\, \frac{n^3 r \pi l}{\lambda}\, E. \tag{2}$$

Here, r is the electro-optic coefficient, n is the refractive index, l is the thickness of the film, E is the electric field, and λ is the wavelength of the laser beam (1.064 μm):

$$\frac{1}{T_0}\frac{dT}{d\delta} = \frac{F\ \sin 2\delta}{(1 + F\ \sin^2\ \delta)^2}. \tag{3}$$

The setup for the measurement of transmittance and electrically induced modulation is shown in Fig. 2. An ac voltage [500 V across 1 mm] was applied on the sample and a lock-in amplifier was used to measure the transmittance as

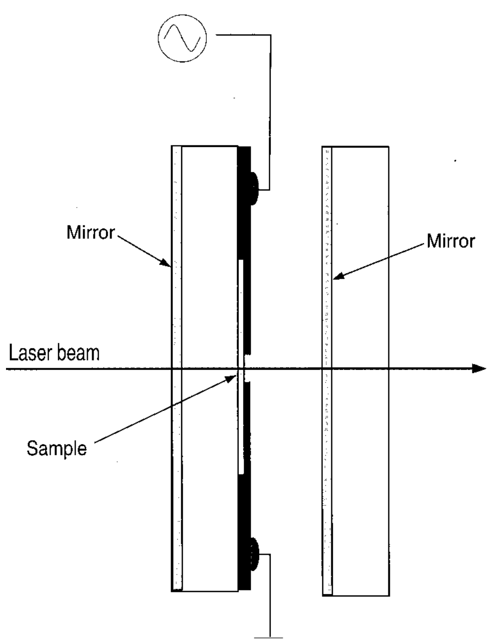

FIG. 1. Schematic of the Fabry-Perot cavity containing single crystal film of NPP.

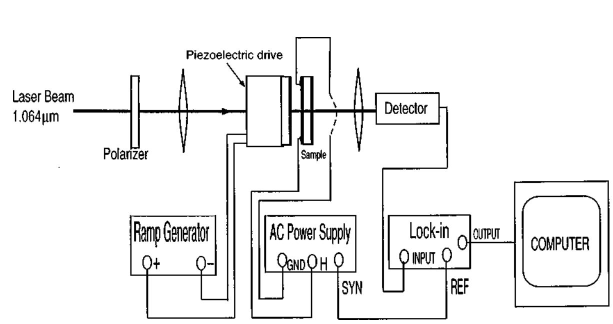

FIG. 2. Experimental setup for measurement of electro-optic modulation.

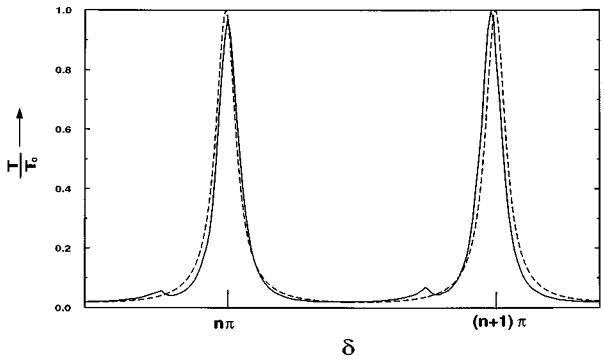

FIG. 3. Normalized transmittance through the Fabry–Perot cavity: measured (solid line) and calculated for $F=50$ (dashed line).

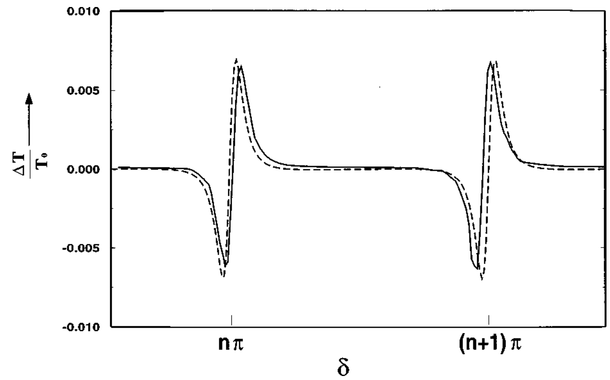

FIG. 4. Experimental $\Delta T/T$ (solid line) and calculated $\Delta T/T$ with $r_{12}=65$ pm/V (dashed line).

one of the mirrors was moved by the piezoelectric drive. The transmittance through the Fabry-perot cavity is shown in Fig. 3(a) and the calculated transmittance of the Fabry–Perot cavity with $F=50$ is shown in Fig. 3(b) for comparison. It was shown that the measured transmittance through the cavity agrees well with the calculated values indicating that the finesse of the cavity was about 50. For the electro-optic modulation, electric field was applied along the charge-transfer axis (y axis). The polarization of the laser beam was in the x direction. The electric field-induced change in the refractive index is given by, $\Delta n=-(1/2)n_x^3 r_{12}E$. Figure 4(a) is the modulation $\Delta T/T_0$ measured by lock-in detection at the fundamental modulation frequency (f). Figure 4(b) shows the calculated values using Eq. (2) and utilizing the known electro-optic coefficient, $r_{12}=65$ pm/V.[5] Here we need to mention that the transmittance modulation at the second harmonic of the modulation frequency ($2f$) has been observed. However, that contribution was due to the mechanical movement within the cavity (capacitive force) and this mechanical effect had no contribution to the results obtained at the fundamental modulation frequency (f). The measurement was repeated over a frequency range of 1.0–4.0 kHz for ac fields and essentially the same results were obtained. Considering the film dimensions and the gap between the electrodes, we expect the ac frequency used was far less than any acoustic phonon resonance due to the inverse piezoelectric effect, and thus the measured effect was predominantly electronic.[6] As the results show, the modulation of transmittance was as high as 0.7% at a low applied field of 0.5 V/μm. The thickness of the film used in this measurement was about 1 μm. Utilizing thicker ($\sim$20 μm) single crystal films the modulation depth can be increased many times. Considering other possible materials such as DAST which has an electro-optic coefficient about 6 times that of NPP, much larger modulation can be introduced at a low voltage. Clearly, Fabry–Perot geometry is very well suited for such applications using organic single crystal film.

In summary, electro-optic modulation using an organic (NPP) single crystal film in a Fabry–Perot cavity has been demonstrated. The results suggest many potential applications of such device structures containing organic single crystal films.

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