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REFRACTION OF LIGHT BY GRADED BIREFRINGENT MEDIA

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ABSTRACT

To date, proposals to use the Kerr effect to map divergent electric fields have not considered refraction of light in the graded potential. Spatial variation of the strength or direction of the field will produce non-uniform refractive indices, and significant refraction of light in regions of high divergence may distort the final image and introduce an error in the field measurement. Experimental evidence for this effect is presented and its implications to optical field mapping are discussed.

INTRODUCTION

Electro-optical measurements using the Kerr effect have been used extensively for electric field mapping in insulating fluids [1–4]. In a few examples [5, 6, 7], this technique has been applied to divergent electric fields: Such studies have examined the preconditions for electrical discharges in fluids, for example. However, previous investigations of divergent fields have not explicitly considered refraction in the graded potential. Since the birefringence of a Kerr electro-optical material depends on the electric field, spatial variation of the strength or direction of the field will produce graded refractive indices. Significant refraction of light in regions of high divergence may distort the final image and complicate interpretation of experimental data. The demonstration described below gives direct evidence for the above named effect.

BACKGROUND

In the geometric limit, light follows a path S that minimizes

$$\psi = \int_S n(\mathbf{r})|\mathrm{d}\mathbf{r}|,$$

where n is the refractive index. Since the refractive index may depend on position, the optical path generally describes a curve. Following Evans and Rosenquist [8], ψ is minimized provided $\delta\psi$ is stationary with respect to variation of the path. These authors further show that geometric ray follows the follows a path that satisfies the differential equation

$$n\nabla n = \mathbf{r}'',$$

where the prime denotes differentiation with respect to a stepping parameter, which is choosen such that $|\mathbf{r}'| = n$.

EXPERIMENT

A cylindrical field geometry was examined; analysis of this case is simplified somewhat since the electric field is everywhere orthogonal to the rotational axis. Monochromatic light, 514.7 nm, from an argon ion laser was linearly polarized perpendicular to the rotational axis. Light from the laser was directed onto a resolution test chart and, ultimately, onto the photocathode of an image-converter camera. The intervening optics provided an image of the test chart at the position of a narrow slit in front of the camera and at the photocathode. The camera was operated in the streak mode and was synchronized with the time-of-application of a high-voltage pulse to a small test cell that was filled with nitrobenzene. A thin wire was centered in the cell and a negative-going high-voltage pulse was applied to the wire, see Figure 1.

The high-voltage pulse was measured using a resistive voltage divider; and the voltage waveform as well as the camera timing pulse were recorded by a high-speed digitizer. The test cell was mounted on a translational stage and the wire could be accurately positioned relative to the laser beam.

RESULTS AND DISCUSSION

The photographic data shown in Figure 2 give direct evidence for "steering" of the light through the divergent field region: clearly the position and, upon close examination, the magnification of the final image depend on the applied voltage.

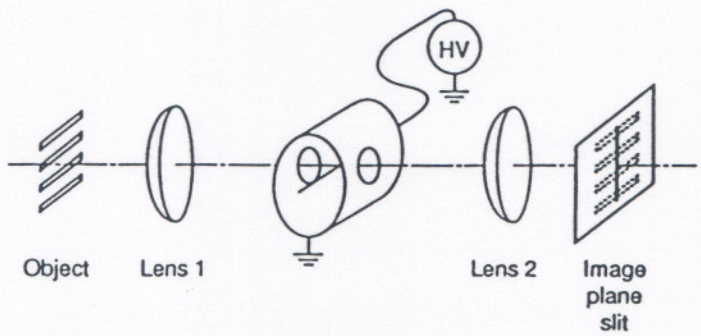

Figure 1: Schematic of the optical system. The high voltage electrode, a wire 200 μm in diameter, was positioned to lie in the focal plane of the relay lens pair formed by lenses 1 and 2. The object, a standard resolution test chart, was imaged onto a narrow slit and a high-voltage pulse was applied to the wire. The image was recorded by a streak camera.

These results give some indication of the level of complexity required for analysis of photographic data obtained from highly divergent fields. To good approximation [1], the fields encountered in a normal Kerr cell reduce to a simple relationship for phase difference $\Delta\phi$ between linear polarizations parallel and perpendicular to the field within the cell E,

$$\Delta\phi = 2\pi LBE^2,$$

here B is the Kerr coefficient and L is the path length in the field. This same relationship does not hold rigorously in the case of divergent fields. Indeed, the paths followed by orthogonal linear polarizations through the field are not the same. Thacher [1] provides a thorough discussion of the optic effects that may be encountered due to the fringe fields in a normal well designed Kerr cell; however, to our knowledge, more severe experimental conditions, i.e., the fields near a sharp point in a point-plane electrode geometry, have not been examined in detail.

ACKNOWLEDGEMENTS

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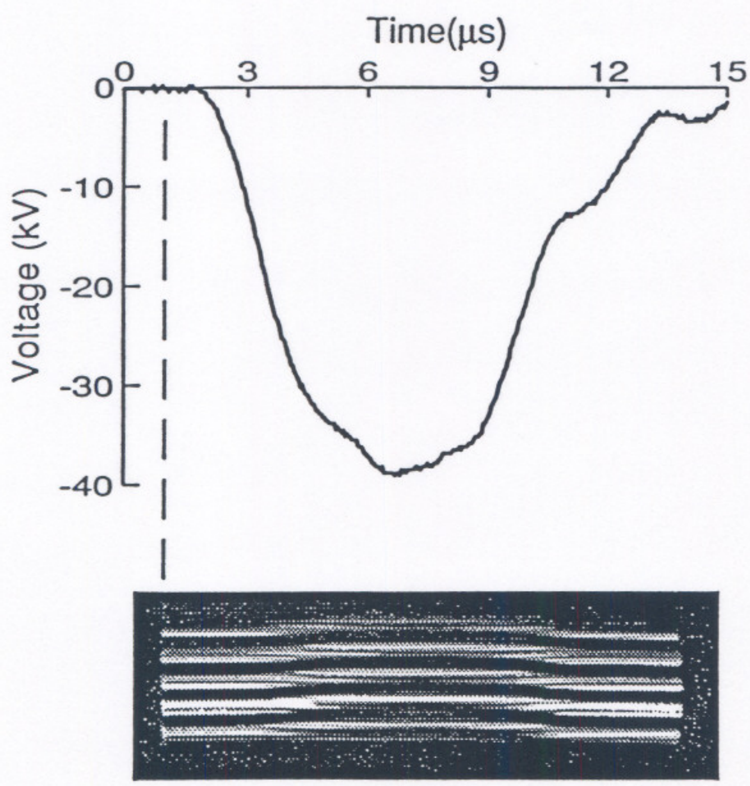

Figure 2: Streak photograph of the "steered" image. The voltage waveform is shown in the upper panel and the corresponding streak photograph below. The start of the streak is indicated by the vertical broken line and the horizontal time scale is the same for both.

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