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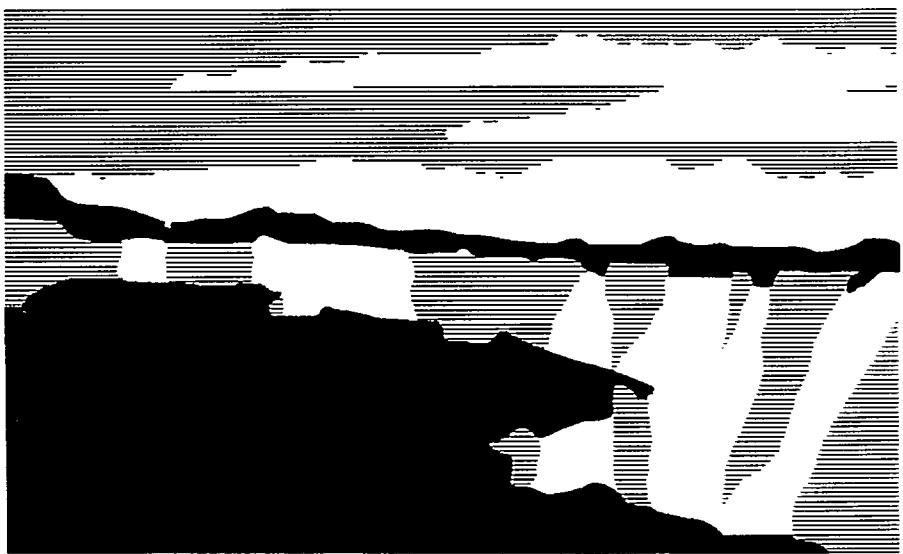
Title: Integration of Electro-Optic Lenses and Scanners on
Ferroelectr LiTa₀₃

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INTEGRATED ELECTRO-OPTIC LENS / SCANNER

INTEGRATION OF ELECTRO-OPTIC LENSES AND SCANNERS ON FERROELECTRIC LiTaO_3

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An integrated electro-optic lens/scanner device was fabricated on a ferroelectric LiTaO_3 wafer. This was done using lithographically defined domain-inverted regions extending through the crystal thickness. A lens power of $0.233 \text{ cm}^{-1}\text{kV}^{-1}$ and a scanner deflection of $12.68 \text{ mrad}^{-1} \text{ kV}^{-1}$ was observed. We also demonstrate an electro-optic lens stack collimator which collimates an input beam focused to a $5\mu\text{m}$ waist diameter at -2.3kV .

Keywords: Integrated Optics, Ferroelectrics, Electro-optics, Scanners, lenses.

INTRODUCTION

With the increasing application of optics in communications, data storage, display, printing, and defense, there is a fundamental drive towards smaller, faster, cost-effective and energy-efficient devices to manipulate light. Such manipulation includes reflection, refraction, scanning, focusing, and frequency shifting, to name a few.

The Electro-Optic effect, which provides an external electric field tunable refractive index change in a material, is ideal for many of these functions due to its high bandwidth of operation (inherently approaching GHz, but in practice limited mainly by the voltage driver), compactness, possibility of integration on a single chip of a nonlinear optical material, and low power consumption.

The fabrication of electro-optic scanners,^{[1],[2]} lenses,^{[3],[4]} and quasi-phase-matched frequency doublers^{[5],[6]} have all been demonstrated on ferroelectric crystals. Recently, we reported a stand-alone integrated device with variable focus electro-optic lenses and electro-optic scanners fabricated on a single wafer chip of ferroelectric LiTaO₃.^[7] Here we report additional frequency response studies on this device. We also present results on a collimating electro-optic lens stack fabricated on a LiTaO₃ wafer.

INTEGRATED SCANNER / LENS DEVICE

The lenses and scanners were made by selective inversion of ferroelectric 180°domains into corresponding shapes on a single crystal Z-cut LiTaO₃ wafer.^[6] Figure 2 shows the lens and scanner

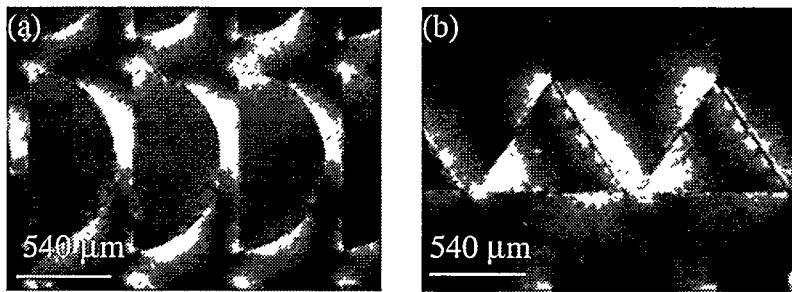


FIGURE 1. Ferroelectric domains shaped as (a) cylindrical lenses (b) prisms in Z-cut LiTaO₃ crystals as observed under cross polarizers. Polarization P_s is normal to the image plane.

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prism shaped domain regions created by this technique. This was achieved through a combination of lithographically defined electrodes to apply electric fields in selective regions in combination with chemical

patterning of the wafer to aid the selectivity in domain reversal. The process has been described in detail elsewhere.^[6]

The device therefore had two sections integrated in the same wafer chip. The first section had a series of 10 hemispherical electro-optic lenses as shown in Fig. 1(a) which were $R=540 \mu\text{m}$ in radius and spaced $84 \mu\text{m}$ apart. The second section has a series of 7 electro-optic prisms as shown in Fig 1(b), $940 \mu\text{m}$ base, $720 \mu\text{m}$ height and separated by $\sim 40 \mu\text{m}$ s. The wafer was $d=225 \mu\text{m}$ thick. The final device had two sets of electrodes to operate the lenses and scanner sections independently. Application of an electric field, E_3 , results in a refractive index change $\Delta n = n_e^3 r_{33} E_3$ across a domain wall. Here n_e is the extraordinary refractive index and r_{33} the electrooptic coefficient. Application of an electric field to the electro-optic lenses such that the electric field inside the lenses was antiparallel to the spontaneous polarization P_s resulted in focusing of light travelling through the wafer thickness. This is shown in Fig. 2 by the Fast Fourier Transform simulation of the device done using beam propagation method. Also shown in Fig. 2 is the deflection of the output light by the scanner. A voltage to the scanner part deflects the light at the output from its straight line path, say to the left. A voltage of opposite polarity deflects light in the other direction to the right.

Using a beam profiling CCD camera (Coherent LaserCam) placed at the output of the device, the lens and scanner sections were independently tested. We experimentally measured focal lengths as a function of applied voltage. When no voltage was applied to the

lenses, the output beam simply diverges. At 1kV, we measured the focal length $f= 4.34$ cms. Since the focal length $f=1/\phi$, we measured

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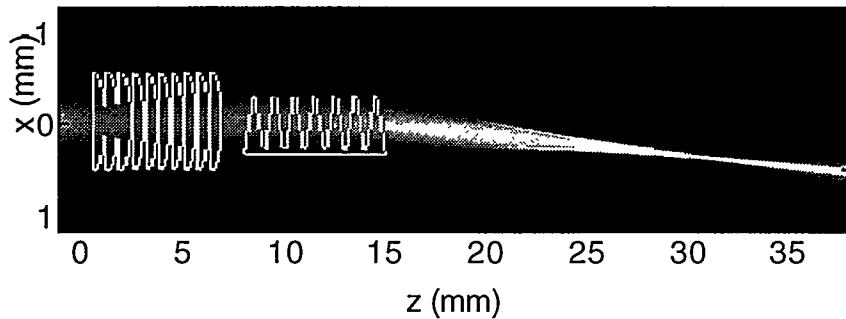


FIGURE 2. A FFT simulation using the Beam propagation method of the performance of the lens/scanner device at an electric field of 8 kV/mm for both lens and scanner sections. The wavelength used was 632.8 nm

a lens power dependence of $\phi/V=0.23 \text{ cm}^{-1} \text{ kV}^{-1}$ where $V=E_3 d$ is the applied voltage. Theoretically, the total lens power $\phi=N_i \Delta n/R = N_i n_e^3 r_{33} E_3 / R$ where N_i is the number of lenses, and the weak lens approximation holds. Using a value of $r_{33}=27 \text{ pm/V}$, $n_e=2.18$, and $d=225 \mu\text{m}$, we predict the theoretical expected power as $0.23 \text{ cm}^{-1} \text{ kV}^{-1}$ which is in excellent agreement with our experimental measurement.

The electro-optic scanner was characterized independently by measuring the deflection angle from a straight line travel on application of a voltage. The experimentally measured deflection was $12.68 \pm 0.22 \text{ mrad/kV}$. Theoretically, we predict the deflection to be $\theta=\Delta n L/W$, where L is the total length of the scanner and W , the width of the scanner. Using a total length $L=7 \times 940 \mu\text{m}$ and $W=720 \mu\text{m}$, we predict a deflection angle of 12.65 mrad/kV which is again in excellent agreement with the measured value.

The frequency response of the scanner was tested using a driver which put out ± 375 V at 225 kHz. There was no observable degradation of the scanning performance at this frequency. Scan

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frequencies of greater than 10MHz at a few tens of volts appears to show no degradation as well, though it is harder to quantify for such low voltages. The upper limit for the frequency performance of the scanner has not yet been established.

COLLIMATING ELECTRO-OPTIC LENS STACK

Figure 3 shows a stack of cylindrical electro-optic lenses formed in a wafer of LiTaO_3 . This stand-alone collimating lens stack was designed to collimate light with a beam waist of 2-10 μm diameter at less than 2.5 kV. The wafer thickness is 210 μm .

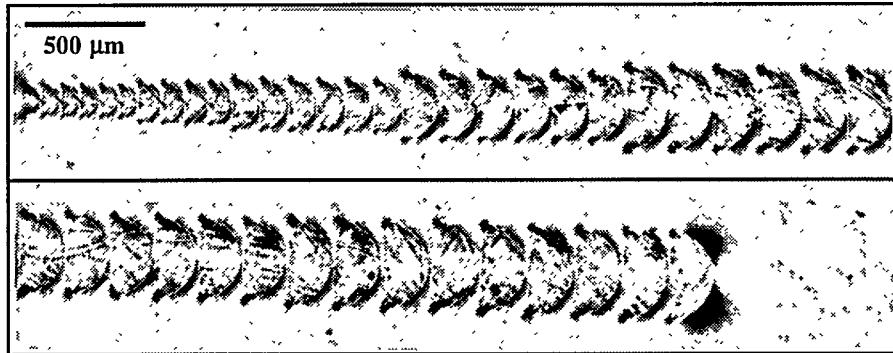


FIGURE 3. Optical image of 180° domains shaped as cylindrical electro-optic lens stack in Z-cut LiTaO_3 . The bottom half is a continuation of the top half of the figure. Polarization is normal to the plane of image.