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SELF-ACTIVATED LIQUID CRYSTAL CELLS USING PHOTOVOLTAIC SUBSTRATES (POSTPRINT)

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14. ABSTRACT
We show that photovoltaic fields are capable of efficiently reorienting liquid crystals, leading to new concepts of optically addressable light modulators. Using an arrangement consisting of a liquid-crystal layer between $LiNbO_3$:Fe photovoltaic substrates, we observed spatial filtering due to self-phase modulation in a planaroriented cell and nonlinear transmission between crossed polarizers in a twist-oriented cell. These processes do not require an external electric field. The substrates are arranged such that light propagates along the +c axis in each substrate, allowing a secondary process of power transfer to occur through contradirectional photorefractive two-beam coupling.

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Self-activated liquid-crystal cells with photovoltaic substrates

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We show that photovoltaic fields are capable of efficiently reorienting liquid crystals, leading to new concepts of optically addressable light modulators. Using an arrangement consisting of a liquid-crystal layer between $LiNbO_3$:Fe photovoltaic substrates, we observed spatial filtering due to self-phase modulation in a planar-oriented cell and nonlinear transmission between crossed polarizers in a twist-oriented cell. These processes do not require an external electric field. The substrates are arranged such that light propagates along the +*c* axis in each substrate, allowing a secondary process of power transfer to occur through contradirectional photorefractive two-beam coupling. © 2006 Optical Society of America

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$LiNbO_3$:Fe is capable of producing a bulk electric field[1,2] on the order of 140 kV/cm. Upon illumination, an asymmetrical potential associated with this material causes the photoionized electrons to move in a preferential direction, generating a photoinduced current and subsequent electric field in the region of light known as the photovoltaic (PV) field. We propose a hybridized liquid-crystal (LC) arrangement utilizing the PV field to activate a LC. The arrangement consists of a LC layer between two $LiNbO_3$:Fe substrates. When illuminated, the PV field in each substrate creates a field between the two substrates sufficient to reorient the LC molecules; therefore an external electric field is not necessary. The cell can be constructed with planarly aligned LC molecules, to create a spatial filter due to transverse phase modulation of the beam,[3–5] or with a twisted nematic alignment, to create a PV light valve when the cell is placed between crossed polarizers. In the latter case the rotation in polarization experienced by the incident beam is disrupted by the PV field-induced reorientation of the LC, reducing the transmitted power when the cell is placed between crossed polarizers.

In addition to being PV, $LiNbO_3$:Fe is also a photorefractive material. This makes contradirectional two-beam coupling (TBC) possible when two mutually coherent counterpropagating beams couple through the recording of a reflection grating.[6–8] Power transfer occurs in a single direction determined by the signs of the charge carriers and the effective electro-optic coefficient for a given crystal orientation.[9] In the self-pumped TBC configuration a transfer of power occurs between the pump beam and a Fresnel-reflection-generated signal beam from the rear surface of the crystal.[10–12] The crystal *c* axis is oriented such that the signal beam is amplified at the expense of the pump beam. To take advantage of the photorefractive effect, the $LiNbO_3$:Fe substrates are arranged such that light propagates along the *c* axis, allowing TBC to take place in each substrate while the PV field simultaneously activates the LC.

The substrates used for this study were 25.4 mm $\times 25.4$ mm $\times 1.0$ mm $LiNbO_3$:0.05 mol % Fe_2O_3 crystals, where the thickness along the *c* axis was 1.0 mm. The *c* surfaces of each crystal were optically polished and spin coated with a rubbing layer consisting of a mixture of 0.125 wt. % Elvamide in methanol and were rubbed for planar alignment. Elvamide is a methanol soluble nylon multipolymer resin (DuPont). Each cell was constructed by using 20 μm spacers and was filled with TL205 (Merck), a highly resistive low-ionic LC, reducing the effects of

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screening charges that may result from a more ionic LC. At 589 nm and 20°C, Merck reports an ordinary index of 1.527 and a Δn of 0.217 for TL205.[13] To describe the behavior of the photorefractive substrates, data were also taken in the absence of the LC. For these experiments the cell was filled with an index-matching fluid of $n=1.7$, simulating any reduction in etalon effects resulting from the presence of the LC. The spatial filters were constructed with the $LiNbO_3$:Fe substrates rubbed antiparallel, while the substrates for the PV light valves were rubbed orthogonally to one another to produce a twist in the LC alignment. This longitudinal twist induces a rotation in the polarization of incoming light, which is disrupted by the reorientation of the LC when the system is subject to optical radiation.

The experimental arrangement is shown in Fig. 1. The pump beam, at a power of 1 mW originating from a continuous-wave 532 nm intracavity frequency doubled YVO_4:Nd laser (Coherent Verdi-5), was focused within the LC layer at an optimum position corresponding to the shortest response time. A 100 mm focal length plano–convex lens at $\approx f/30$ was used, yielding a $1/e$ diameter of $\approx 20\ \mu m$ at the focal plane. The pump beam, polarized parallel to the rubbing direction of the LC cells, propagated along the positive c axes of each substrate. The c-axis absorption coefficients were approximately $1.53\ cm^{-1}$ for each substrate. A photodiode and an oscilloscope were used to monitor the transmitted laser power for a 5.5° full cone angle. A polarizer oriented orthogonally to the polarization of the incident laser beam was placed after the sample for measurements involving crossed polarizers.

Results for self-phase modulation in a hybridized planar cell are shown in Fig. 2(a). The vertical dotted lines divide the plot into three regions. In the absence of the LC, a steady decrease in transmitted power is seen as a result of TBC in the photorefractive substrates. However, with the addition of the LC a much faster reduction in transmitted power is initially observed, as seen in region 1 of Fig. 2(a). This is attributed to a lensing effect that occurs as a result of the Gaussian profile of the incident beam intensity. A buildup of charges on the surfaces of the $LiNbO_3$:Fe substrates occurs as the PV field builds up in each substrate. The buildup of charges and the subsequent field across the LC layer is initially strongest in the center of the Gaussian beam, where the beam is most intense, so there is a greater influence on the

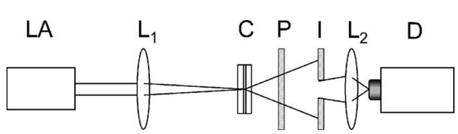

Fig. 1. Experimental arrangement used for testing the PV field-induced reorientation of hybridized cells. The pump beam, originating from a 532 nm laser (LA), was focused onto the hybridized cell (C) using a 100 mm focal length plano–convex lens (L_1). The transmitted power with a cone angle determined by the iris (I) was focused onto the detector (D) by using a collection lens (L_2). A polarizer (P) oriented orthogonally to that of the incident laser polarization was used for experiments involving crossed polarizers.

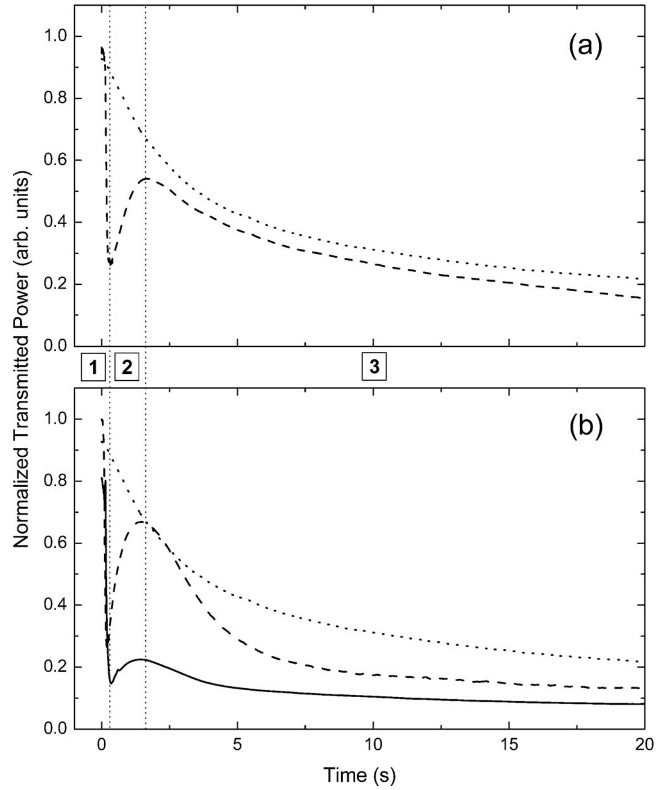

Fig. 2. Transmitted power for (a) the hybridized spatial filter and (b) the PV light valve. The transmitted power in the absence (dotted curve) and presence (dashed curve) of the LC is given for both cells. Results for the PV light valve when placed between crossed polarizers are also shown (solid curve).

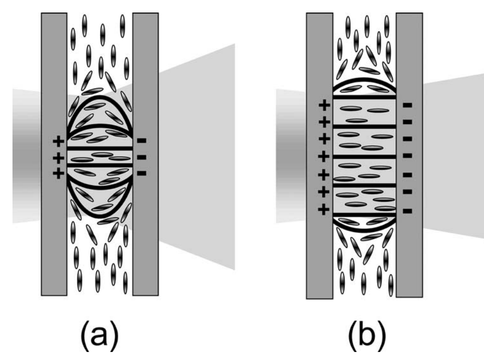

Fig. 3. The shaded region represents the portion of the cell illuminated by a laser beam propagating from left to right. (a) In the transient regime, the Gaussian profile of the incident light initially results in a graded index of refraction. (b) As a steady state is reached, surface charges gradually build up on the substrates in the less intense edges of the incident Gaussian beam, strengthening the field in this region.

LC orientation here than at the edges of the beam. This is depicted in Fig. 3(a), where the shaded region represents the portion of the cell illuminated by the laser beam. Because the LC molecules are reoriented to varying degrees across the inhomogeneous region of illumination, the incident light experiences a graded index of refraction, and the LC acts as a lens to strongly diverge the incident light. This is perceived as a decrease in the transmitted power reaching the detector. However, the surface charges gradually build up in the less intense edges of the beam, inducing a more complete reorientation of the LC molecules throughout the illuminated region. As depicted in Fig. 3(b), this results in a loss of the graded index of refraction, thereby disrupting the lensing effect and reducing the divergence of the transmitted beam. This accounts for the subsequent increase in transmitted power reaching the detector observed in region 2 of Fig. 2. The reduction in transmitted power observed in region 3 is a result of the TBC occurring in the $LiNbO_3$:Fe substrates. Cells constructed with glass substrates showed no response, ruling out any contribution from the LC nonlinear effect.

Results for the PV light valve are seen in Fig. 2(b). In the absence of the LC, a steady decrease in transmitted power is seen as a result of TBC in the photorefractive substrates. In the presence of the LC, a lensing effect diverges the incident light, resulting in the sudden decrease in transmitted power seen in region 1 of Fig. 2(b). However, in this configuration the reorientation of the LC also disrupts the longitudinal twist, and the incident beam does not experience a rotation in polarization as it propagates through the cell. The presence of an output polarizer oriented orthogonally to the polarization of the incident light allows for birefringent switching, causing the cell to function as a light valve. Absorption by the polarizer was measured and taken into account. Because of the Gaussian nature of the incident beam, the longitudinal twist is more strongly disrupted in the center of the beam where the PV field is the strongest. While the buildup of surface charges on the $LiNbO_3$:Fe substrates in the edges of the incident beam results in a loss of the lensing effect, it also further prevents the rotation of polarization in the edges of the beam. In the absence of the output polarizer, only the lensing effect is seen, and the transmitted power reaching the detector increases in region 2. However, in the presence of crossed polarizers, the buildup of surface charges allows more of the transmitted beam to be polarized orthogonally to that of the output polarizer, accounting for the less significant increase in transmitted power reaching the detector in region 2 of Fig. 2(b). Although the crossed polarizers would completely block the transmitted light in principle, this outcome is prevented as natural leakage of the surface charges prevents a complete disruption in the twist of the LC alignment, particularly at the edges of the beam. Additional light leakage occurs when photorefractive noise, which is generated within the lithium niobate windows,[14] results in random polarization states of the output beam. The reduction in power observed in region 3 of Fig. 2(b) is again a result of the ongoing TBC occurring in the substrates.

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