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Research Article

Voltage-Controllable Guided Propagation in Nematic Liquid Crystals

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Voltage-controllable guided channels are formed in a planar nematic liquid crystals cell. The director of liquid crystals can be aligned by applying external voltage, which results in a difference of the refractive index between two adjacent channels; therefore, the incidence beam can be coupled from one channel to another. First, we discussed the propagation of the beam and the self-focusing in a single channel; then we discussed the propagation of the beam and the coupling effect in the two channels. The results showed that the propagation of the beam can be selected in each channel by applying voltages in the two individual electrode channels.

1. Introduction

Optical waveguide elements play an important role in the applications of optical communication, optical signal processing, integrated optical circuits, and optical networking [1, 2]. Many devices have been designed for the split, combine, couple, and phase modulation of the optical signal systems [1, 3]. Controlling the path of the propagating beam is the primary aim of the optical switching system, and the optical signals can be transferred to different guided channels. Somekh *et al.* proposed the concept of optical waveguide arrays [3], and the potential for optical switching applications has attracted much attention. Haus et al. theoretically predicted that the optical signal switch can be achieved by the external control of the waveguide arrays [4, 5]. Christodoulides et al. predicted the existence of solitary waves in arrays, and such unique properties have developed all-optical signal processing [6]. Gia Russo et al. investigated guided light and found the directional characteristics in the layered crystalline media [7, 8]. Channin et al. studied the waveguide characteristics and discussed the voltage-addressable optical properties in a liquid-crystal medium [9, 10]. Aligned nematic liquid crystals are a good choice for large changes in optical properties, which can be easily driven by applying external voltage. Tsai et al. investigated a multiguided directional coupler based on planar-aligned nematic liquid crystals and discussed the dependence of the coupling effect on the external voltage, the polarization of the incident beam, and the temperature [11, 12].

This work discusses guided light in a single channel and two channels, where the propagation of the beam can be selected in each channel by applying different voltage in the individual electrode channels. In addition, self-focusing and the coupling effect are discussed.

2. Preparation of Sample and Experimental Setup

The nematic liquid crystal (NLC) in this experiment is E7 (ne = 1.7462 and no = 1.5216 at 20°C for λ = 589 nm; nematic phase ranges = −10 to 60.5°C, from Merck). An empty cell is constructed with two indium-tin-oxide (ITO) coated glass plates. One of the two plates is etched with a two-stripe ITO pattern as the upper electrode, and the other plate is used as the grounding electrode. The spacing between the etched region and the nonetched region is 15 μm. These two plates are coated with polyimide film and rubbed parallel to the ITO electrode stripes (z-axis). The glass slides are separated by two

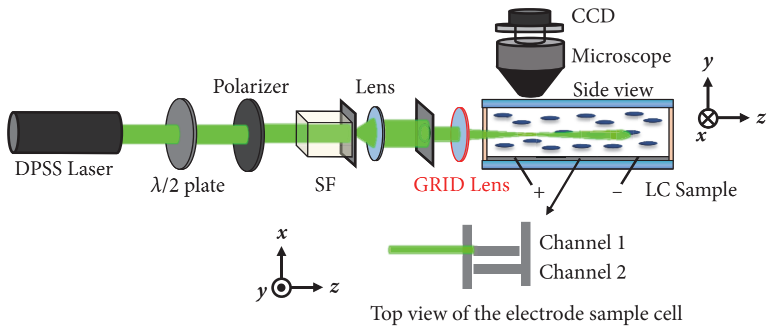

FIGURE 1: Experimental setup of voltage-controllable guided propagation in a nematic liquid crystals coupler.

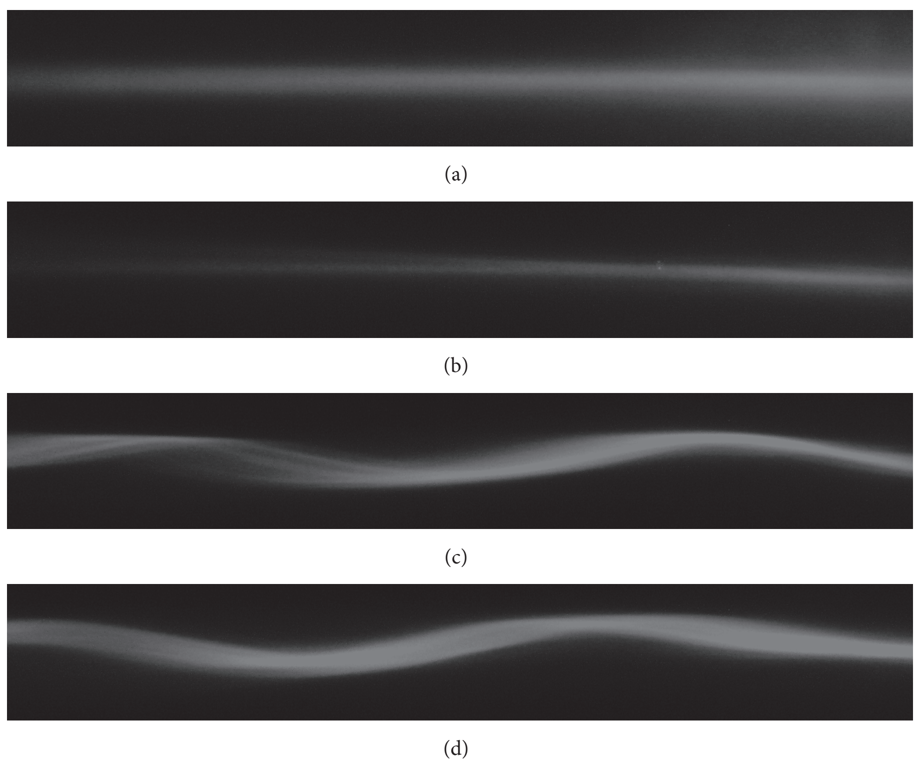

FIGURE 2: The guided light in a single channel by applying external voltages of (a) 0 V, (b) 1.5 V, (c) 2.2 V, and (d) 3.0 V.

25 μm thick plastic spacers, and the NLCs are injected into the empty cell to form a directional coupler.

Figure 1 presents voltage-controllable guided propagation in a nematic liquid crystals coupler. A linearly polarized (along the x-axis) beam of the 532 nm diode-pump solid-state laser (DPSS) impinges normally onto the side of the sample cell, which is focused on the cross-sectional region of the NLCs medium within the striped electrode of channel 1 using a gradium singlet lens (GRID lens). The focal point is around 3.0 mm from the surface of the side glass, and the focus spot has a diameter of about 3.2 μm. A half-wave plate ($\lambda/2$ WP, for 532 nm) and a polarizer are inserted between the DPSS laser and the spatial filter (SF) in order to change the direction of polarization and the intensity of the incident beam. By applying an external voltage on the sample cell, the NLC molecules are reoriented, which results in the distribution of the refractive index in the medium, and the optical channels are formed under a single or two electrode stripes.

Guided propagation, self-focusing, and the coupling effect are discussed in three different situations: guided light propagation (I) in a single channel, (II) in two channels by applying equal external voltages in each of the two electrode stripes, and (III) in two channels by applying the different external voltages in each of the two electrode stripes.

3. Results and Discussions

Figure 2 presents a guided light in a single channel by applying various external voltages. A laser beam, which is linearly polarized in the x-direction, is introduced into the channel from the left and propagates along the z-axis. With the applied voltage of $V_{app} = 0$ V, the guided light diverges after propagating distance $z = 25$ μm, as shown in Figure 2(a).

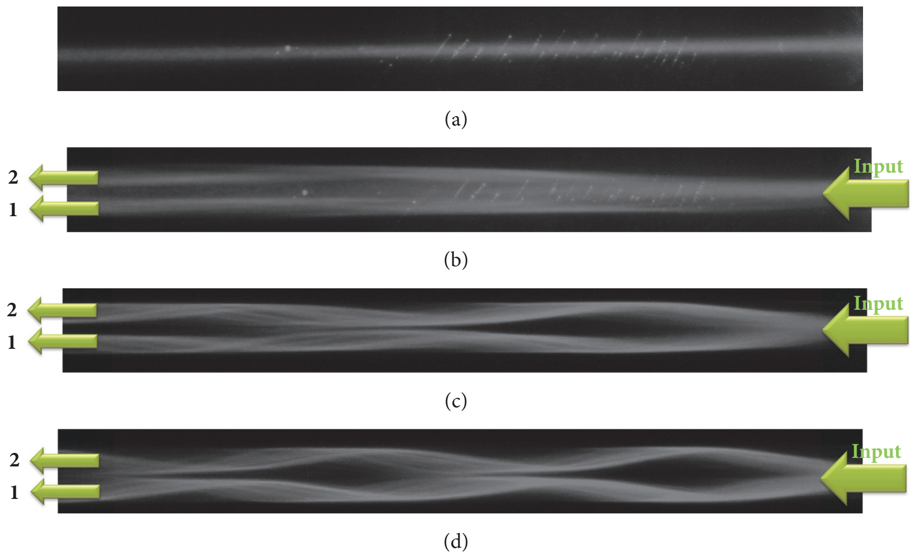

FIGURE 3: The guided light propagation by applying the same external voltages of (a) 0 V, (b) 1.5 V, (c) 2.2 V, and (d) 2.5 V in the two channels.

Initially, the liquid crystal molecules are horizontally aligned to the z-axis, while the x-direction polarized beam encounters the ordinary uniform refractive index distribution in the medium. With the increased applied voltage of V_{app} = 1.5 V, the guided light propagates in the channel, as shown in Figure 2(b). The liquid crystal molecules tend to align in the x-axis, while the x-direction polarized beam sees the extraordinary and ordinary refractive index of the liquid crystals in the guided channel and outside the channel, respectively, thus forming a waveguide-like structure. With the applied voltages of V_{app} = 2.2 V and 3.0 V, the self-focusing of the propagated beam is observed, as shown in Figures 2(c) and 2(d). The liquid crystal molecules around the channel can be reoriented due to the edge effect of the electric field, which forms an approximately gradient distribution of the refractive index around the channel in the medium.

Figure 3 presents the guided light propagation by applying the same external voltages of V_{app} = 0 V, 1.5 V, 2.2 V, and 2.5 V in the two channels. Initially, the incident beam is introduced into channel 1 with V_{app} = 0 V, as shown in Figure 3(a). With the applied voltage of V_{app} = 1.5 V, a part of the guided light gradually trends to channel 2, while part of the guided light still propagates in channel 1, as shown in Figure 3(b). Waveguide-like structures are formed, which results in total reflection in both channel 1 and channel 2. With V_{app} = 2.2 V and 2.5 V, each of the two beams travels back and forth in the vicinity of its channel, as shown in Figures 3(c) and 3(d). An approximate gradient distribution of the refractive index around the two channels is formed, which results in self-focusing in each channel.

Figure 4 presents the guided light propagation by applying fixed voltage V_{app} (1) = 2.2 V in channel 1 and applying voltage V_{app} (2) = 0 V, 1.5 V, 2.2 V, and 2.8 V in channel 2, which correspond to Figures 4(a)–4(d), respectively. Initially, the incident beam is introduced into channel 1, and self-focusing is observed, as shown in Figure 4(a). At V_{app} (2) = 1.5 V (i.e., V_{app} (1) is larger than V_{app} (2)), a small part of the guided light gradually couples to channel 2, as shown in Figure 4(b). In the condition of V_{app} (2) = 2.2 V (i.e., V_{app} (1) is equal to V_{app} (2)), the coupling effect is clearly observed, and the propagation behavior seems to be the same in both channel 1 and channel 2, as shown in Figure 4(c). At V_{app} (2) = 2.8 V (i.e., V_{app} (1) is smaller than V_{app} (2)), a large part of the guided light gradually couples to channel 2, as shown in Figure 4(d). The results show that the propagation of the incident beam can be easily tuned in channel 1 or in channel 2 due to the distribution of the refractive index when applying external voltage.

4. Conclusions

In summary, voltage-controllable guided channels are formed in a planar nematic liquid crystals cell. Nematic liquid crystal molecules can be easily reoriented by applying external voltage, which results in the difference of the refractive index between two neighboring channels. Therefore, the incidence beam can be coupled from one channel to another.

First, we discussed the propagation properties of the beam in a single channel. The self-focusing of the light can be observed at V_{app} = 2.2 V and 3.0 V. Then we discussed the guided light propagation by applying the voltages in the two channels; the beam coupled from one channel to another can be observed. The results show that the propagation of the incident beam can be easily tuned in each of the two channels, due to the distribution formation of the refractive index by applying external voltage.

Data Availability

The authors confirm that the data supporting the findings of this study are available within the article.

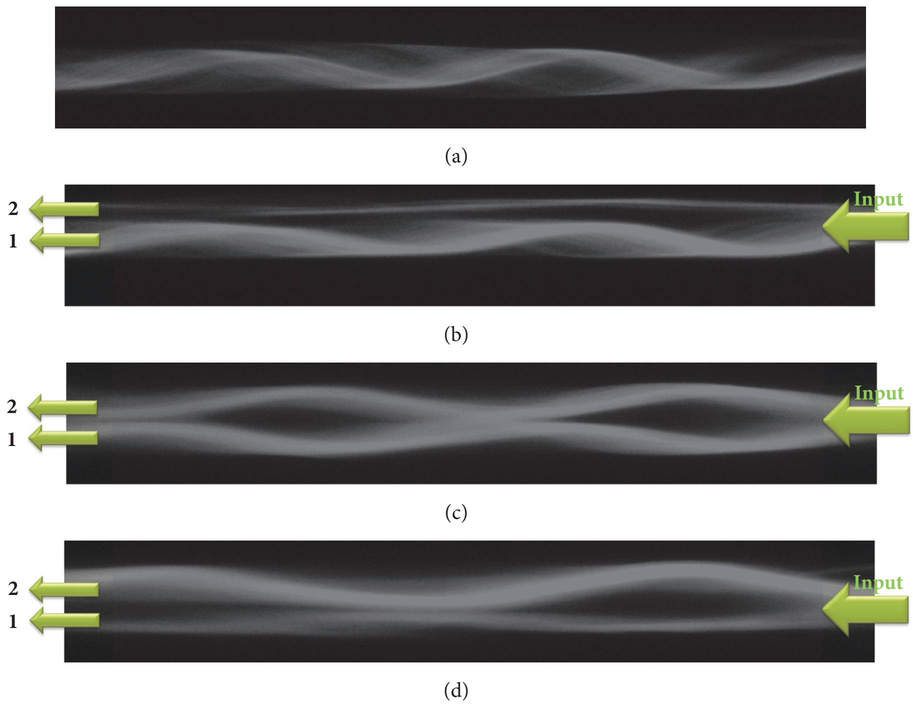

Figure 4: The guided light propagation by applying the fixed voltage of V_{app} (1) = 2.2 V in channel 1 and applying voltages of V_{app} (2) = 0 V, 1.5 V, 2.2 V, and 2.8 V in channel 2, which correspond to (a)–(d), respectively.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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