Photolithography of thick photoresist coating in anisotropically etched V-grooves for electrically controlled liquid crystal photonic bandgap fiber devices

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Published in:
Proceedings, OFC

Publication date:
2009

Document Version
Publisher's PDF, also known as Version of record

Compact Electrically Tunable Waveplate Based on Liquid Crystal Photonic Bandgap Fibers

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Abstract: A compact tunable waveplate based on negative dielectric liquid crystal photonic bandgap fibers is presented. The birefringence can be tuned electrically to work as a quarter-wave or a half-wave plate in the wavelength range 1520nm-1580nm.

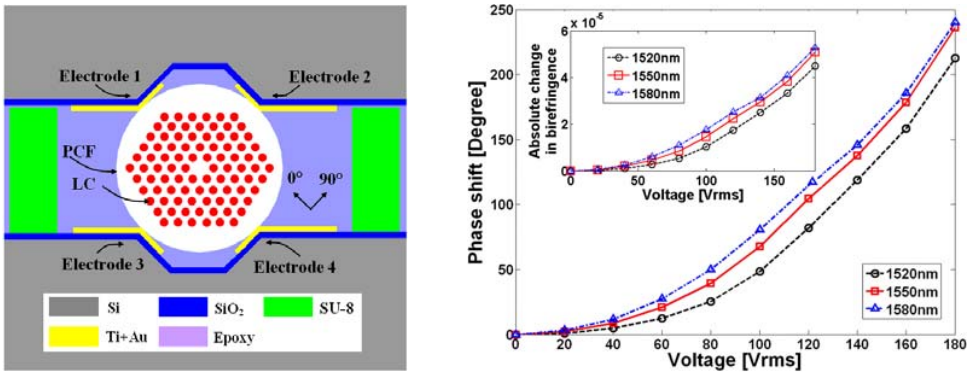
OCIS codes: (230.3720) Liquid-crystal devices; (060.5295) Photonic crystal fibers

1. Introduction

Liquid Crystal (LC) infiltrated Photonic Crystal Fibers (PCFs) have attracted significant interest in the past decade due to their unique optical properties and high sensitivity to thermal and electric field [1-7]. Since LCs normally have larger electro-optic effect than other high-index liquids, electrically driven Liquid Crystal filled Photonic BandGap (LCPBG) fiber devices for switching [3], or as long-period grating [7] with millisecond response time have been developed. Also, a continuously tunable birefringence controller with phase shift of 60° by using a dual-frequency LCPBG fiber has been proposed [4]. Here, to our knowledge, we demonstrate the first compact electrically tunable waveplate realized in a negative dielectric LCPBG fiber device. The birefringence is tuned electrically to give both a quarter-wave and a half-wave plate in the wavelength range 1520nm-1580nm.

2. Experimental results

The cross section of the device is shown in Fig. 1(a). A LCPBG fiber is mounted between two v-grooves fabricated in a silicon substrate by standard UV lithography and KOH wet etching techniques. 200nm gold electrodes are deposited on the side walls of the grooves, forming a set of electrodes, which fix the fiber at four orthogonal corners relative to the core. The electrode patterning of this device is achieved by using electrodeposition of Eagle 2100 ED photoresist on top of the gold layer with subsequent UV lithography, development, gold and titanium etch, and photoresist stripping. The electrodes are electrically isolated from the silicon substrate by a thermal oxide layer with the thickness of 2µm, and a 10nm titanium layer is used as an adhesion layer between the gold layer and the oxide. SU-8 supporting structures are built up to keep a certain space between the bottom and top chips, and to make sure they are parallel enough (e.g. the space between electrode 1 and 3, or electrode 2 and 4 is D/1.414=88.4µm, where D=125µm is the outer diameter of the fiber) during the assembly which is sealed with epoxy afterwards.



(a) (b)

Fig. 1(a). The cross section of the LCPBG fiber device. Fig. 1(b). Electrically induced phase shift of this LCPBG device for different voltages in the wavelength range 1520nm-1580nm. The inset shows the electrically induced absolute change in birefringence of this LCPBG device as a function of voltage.

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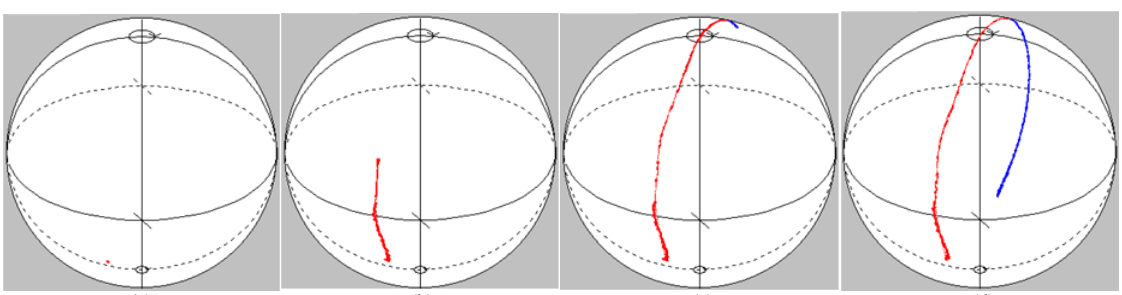
The fiber used in the experiments is a Large Mode Area PCF (LMA-13, Crystal Fibre A/S), with a solid core surrounded by 5 rings of air holes arranged in a triangular lattice. The hole diameter, inter hole distance and outer fiber diameter are 4.3μm, 8.5μm and 125μm, respectively. A negative dielectric LC MLC-6608 (Merck, Germany) with a dielectric anisotropy $\Delta\varepsilon$=-4.2 is infiltrated for 20 mm of the length of the fiber by using capillary forces.

When an electric field is applied to the LCPBG fiber, the LC reorients depending on the applied voltage. The two orthogonally polarized guiding modes experience different refractive indices compared to the case in which the field is off and this introduces a phase shift between them. To demonstrate the electrically induced phase shift and correspondingly induced birefringence, a polarized and tunable laser source operating from 1520nm to 1620nm is connected to this LCPBG device through a polarization analyzer. A polarization controller is used to find a polarization state with a transmission spectrum between the maximum and minimum states. The polarization analyzer launches the light in the LCPBG device and resolves the output light into the Stokes parameters, which is then plotted on the surface of the Poincaré sphere. Any change inducing a phase shift between the orthogonal polarizations in the fiber device results in a rotation on the sphere. The device is driven by a 1 kHz sine wave in bipolar mode. The total insertion loss of this device in the whole test system is 3.2dB, and the activation loss under 180Vrms is less than 1dB. During the experiments, the working temperature of this device is stabilized at 25°C.

Figure 2(a)-(d) show the phase shift on the Poincaré sphere when a driving voltage of 0Vrms, 100Vrms, 150Vrms and 180Vrms is applied to this LCPBG device by launching 1550nm polarized laser light. The red line represents the polarization states in the near part of the sphere and the blue line represents the polarization states on the opposite side of the sphere. Figure 1(b) plots the electrically induced phase shift and the inset of Fig. 1(b) plots the corresponding birefringence change of this LCPBG device as a function of voltage in the wavelength range 1520nm-1580nm. A phase shift of 212.7° is obtained by applying 180Vrms, which gives a birefringence change of 4.17×10^{-5} at 1520nm by the relation given in [4]. More phase shift and birefringence are observed when an input signal with a longer wavelength is launched, e.g. a phase shift of 236.2° and 240.1°, and a change in birefringence of 4.79×10^{-5} and 5.09×10^{-5} are obtained for 1550nm and 1580nm, respectively. Concerning the birefringence control, a higher degree of tunable birefringence can be achieved if a PCF with a smaller structure is used.

In conclusion, we have fabricated and experimentally demonstrated a compact electrically tunable all-in-fiber waveplate working in the wavelength range 1520nm-1580nm based on a PCF infiltrated with a negative dielectric anisotropy LC. The four orthogonal groove electrodes can be connected in different electrode configurations corresponding to a rotatable direction of electric field, and therefore, give the potential for realizing an optical axis rotatable waveplate with electrically tunable birefringence.



(a) (b) (c) (d)

Fig. 2. Phase shift on the Poincaré sphere when a driving voltage of (a) 0Vrms, (b) 100Vrms, (c) 150Vrms, (d) 180Vrms is applied to this LCPBG device by launching 1550nm polarized laser light.

3. References

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