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Published in:
The 21st Annual Meeting of the IEEE Lasers & Electro-Optics Society

Link to article, DOI:
10.1109/LEOS.2008.4688477

Publication date:
2008

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

Citation (APA):
Wei, L., Eskildsen, L., Weirich, J., Scolari, L., Alkeskjold, T. T., & Bjarklev, A. O. (2008). Tunable All-in-Fiber Waveplates Based on Negative Dielectric Liquid Crystal Photonic Bandgap Fibers. In The 21st Annual Meeting of the IEEE Lasers & Electro-Optics Society (pp. MEI). IEEE Press. DOI: 10.1109/LEOS.2008.4688477

Tunable All-in-Fiber Waveplates Based on Negative Dielectric Liquid Crystal Photonic Bandgap Fibers

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***Abstract*-Tunable all-in-fiber waveplates based on negative dielectric liquid crystal photonic bandgap fibers are presented. The birefringence can be tuned electrically and thermally to work as a quarter-wave or a half-wave plate in the range 1520nm-1580nm.**

I. INTRODUCTION

Photonic Crystal Fibers (PCFs) are microstructured waveguides with a large number of air holes running along the length of the fiber and usually located in the cladding region [1]. An initial index-guiding PCF can be converted to a bandgap-guiding PCF by infiltrating the air holes with Liquid Crystals (LCs), which allow for optical [2], thermal [3, 4], and electrical [4-7] tuning. A continuously tunable birefringence controller with phase shift of 60° by using a dual-frequency Liquid Crystal filled Photonic BandGap (LCPBG) fibers has been proposed [7]. The behaviour of LCs with negative dielectric anisotropy, whose molecules tend to reorient perpendicular to the direction of the electric field, has also been investigated recently [8]. Here, we experimentally demonstrate continuously tunable waveplates by using negative dielectric anisotropy LC in the wavelength range 1520nm-1580nm. The birefringence of these devices can be tuned thermally and electrically for realizing both quarter and half waveplates.

II. EXPERIMENTAL RESULTS

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 $\Delta\varepsilon = -4.2$, having a 90° splay alignment as shown in the bottom inset of Fig. 1, is infiltrated for 20 mm of the length of the fiber by using capillary forces.

From the previous work [8], we know the lower order bandgap starting at 1507nm is shifted towards shorter wavelengths by increasing temperature. During the shift, the bandgap still covers the 1550nm region. Therefore, in this paper we investigate the polarization sensitivity and corresponding activation loss for 1550nm firstly. Broadband light from a supercontinuum source (SuperK, Koheras A/S) is collimated using a fiber-coupled lens and polarized using a broadband Glan-Thompson polarizer. The polarized output is

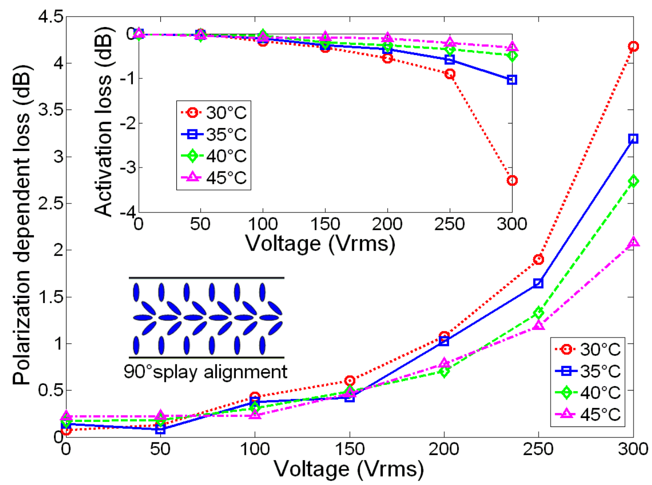

Fig.1 Polarization dependent loss of LMA-13 filled with MLC-6608 at 1550nm for different temperatures. The top inset shows the activation loss at 1550nm. The bottom inset shows the 90° splay alignment of MLC-6608.

passed through three achromatic wave plates (quarter, half, quarter) to have full broadband polarization control of the light source in the wavelength range of 1200nm to 1650nm. The polarized beam is coupled into the LMA-13, and then butt-coupled to the LC filled PCF. The transmission spectrum is measured by an optical spectrum analyzer, and normalized to that of the unfilled fiber. The device is driven in bipolar mode by a 1 kHz sine wave. When an electric field is applied, the minimum transmission can be found by adjusting the three wave plates, while the maximum transmission can be obtained by only rotating the half-waveplate 45° from the position which gives the minimum transmission. Fig. 1 and the top inset of Fig. 1 plot the measured polarization dependent loss (PDL) and activation loss (AL) at 1550nm for different temperatures, respectively. At 1550nm the PDL is 4.2dB at 300Vrms and 30°C. The AL is lower than 3.5dB under the same conditions, and less than 1.0dB at higher temperatures. When the temperature increases, PDL and AL are getting smaller. This is because the dielectric anisotropy $\Delta\varepsilon$ decreases as the temperature increases, and the molecules of LC are more difficult to drive or more driving voltage is needed to obtain the same degree of reorientation. For realizing tunable waveplates and birefringence controllers, low PDL and AL are required. 180Vrms is therefore considered as the maximum driving voltage. For different temperatures, when the device is

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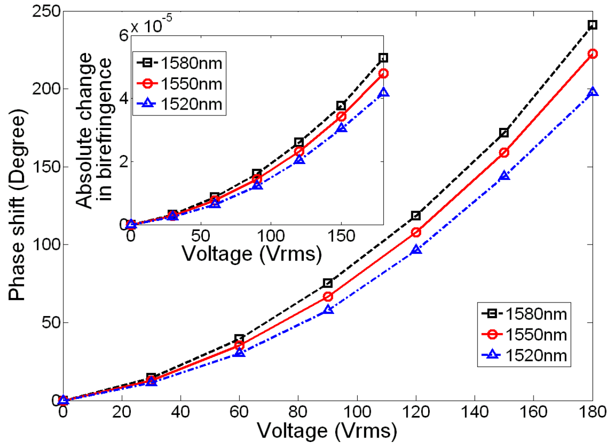

Fig.2 Electrically induced phase shift of LMA-13 filled with MLC-6608 for different voltages at 30°C. The inset shows the electrically induced absolute change in birefringence of LMA-13 filled with MLC-6608 for different voltages at 30°C.

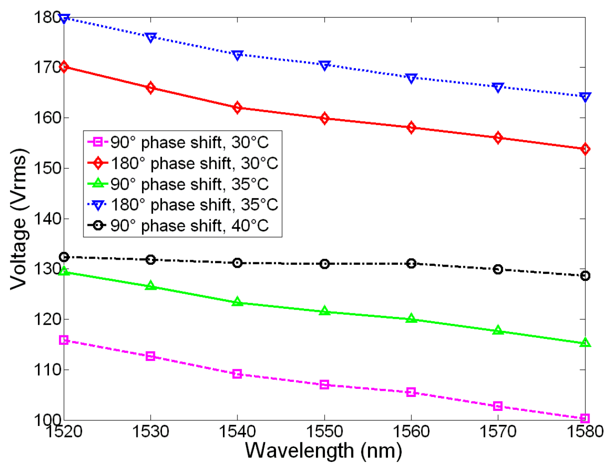

Fig.3 Driving voltage as a function of wavelength for realizing quarter and half waveplates at different temperatures.

driven by 180Vrms, the maximum AL is 0.45dB, while the maximum PDL is only 0.67dB taking the small variation caused by placing and rotating three free space waveplates into account.

When an electric field is applied to the LCPBG fiber, the LC reorients depending on the applied voltage. The two orthogonally polarized guided modes experience different refractive indices compared to the case in which the field is off and this introduces a phase shift between them. This gives an opportunity to develop electrically controlled wave plates and polarization controllers. To demonstrate the electrically induced phase shift and corresponding induced birefringence, a polarized and tunable laser source operating from 1520nm to 1620nm is connected to the LCPBG fiber 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 fiber 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. Fig. 2 plots the electrically induced phase shift and corresponding birefringence change of an LMA-13 filled with 20mm MLC-6608 as a function of voltage for different wavelengths at 30°C. A phase shift of 197.8° can be obtained by applying 180Vrms, which gives a birefringence of 4.17×10^{-5} at 1520nm as shown in the inset of Fig. 2. More phase shift and birefringence is observed when an input signal with a longer wavelength is launched, e.g. a phase shift of 222.5° and 241.1°, and a change in birefringence of 4.79×10^{-5} and 5.29×10^{-5} are obtained for 1550nm and 1580nm, respectively. The same measurement has also been taken for 35°C and 40°C. Fig. 3 plots the driving voltage as a function of wavelength for the device as a quarter-wave plate with 90° phase shift and a half-wave plate with 180° phase shift at different temperatures. When working at longer wavelengths, lower voltage is needed to achieve the same phase shift as working at shorter wavelengths. This is because the long-wavelength edge is more sensitive to the electric field than the short-wavelength edge of the same bandgap, which is caused by different sensitivity of PBG modes to the electrically induced LC alignment. Maximum driving voltage variation of 16.3Vrms is observed, when the device performs as a quarter-wave and a half-wave plate both at 30°C and 35°C. However, only 3.7Vrms variation is needed to achieve a stable performance for using it as a quarter-wave plate at 40°C.

III. CONCLUSION

In conclusion, we have experimentally demonstrated the tunable all-in-fiber waveplates based on a PCF infiltrated with a negative dielectric anisotropy LC. The device works in the wavelength range 1520nm-1580nm, and the birefringence is tuned electrically and thermally to give both a quarter-wave and a half-wave plate operation with less than 0.67dB polarization dependent loss and 0.45dB activation loss in the temperature range 30°C-40°C.

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