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Wei, Lei; Alkeskjold, Thomas Tanggaard; Bjarklev, Anders Overgaard

Published in:
Conference proceedings, ECOC.

Publication date:
2009

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

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Citation (APA):
Wei, L., Alkeskjold, T. T., & Bjarklev, A. O. (2009). Compact electrically controlled broadband liquid crystal photonic bandgap fiber polarizer. In *Conference proceedings, ECOC.* (pp. 1-2). IEEE.

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Compact Electrically Controlled Broadband Liquid Crystal Photonic Bandgap Fiber Polarizer

Lei Wei[(1)], Thomas Tanggaard Alkeskjold[(2)], Anders Bjarklev[(1)]

[(1)] DTU Fotonik, Technical University of Denmark, DK-2800 Lyngby, Denmark, lewe@fotonik.dtu.dk
[(2)] Crystal Fibre A/S, Blokken 84, DK-3460 Birkerød, Denmark

Abstract *An electrically controlled liquid crystal photonic-bandgap fiber polarizer is experimentally demonstrated. A maximum 21.3dB electrically tunable polarization extinction ratio is achieved with 45° rotatable transmission axis as well as switched on and off in 1300nm-1600nm.*

Introduction

Infiltrating liquid crystals (LCs) into the air holes of a solid core photonic crystal fiber (PCF) changes the guiding principle from modified total internal reflection to bandgap guiding[1-7]. The unique property of LCs, compared with other high-index liquids, is their large electro-optic effect, which allows for electrically driven liquid crystal photonic bandgap (LCPBG) fiber devices for switching[2] with millisecond response time, or as tunable wave plates[6]. A compact LCPBG fiber based broadband polarizer working at the 1550nm region has also been developed[5]. However, the insertion loss was 10.5dB due to the misalignment of the single mode fibers (SMFs) and PCF during the device assembly. 3dB and 3.5dB variations of activation loss and polarization extinction ratio for different electrode connections are also observed at a driving voltage of 39Vrms, respectively, which also limit the applications of this all-in-fiber device.

In this paper, we experimentally improve the performance of this device. Only 2.7dB insertion loss for the whole device is obtained, and relatively lower activation loss and higher polarization extinction ratio are achieved compared to the results in[5]. The polarization extinction ratio is continuously tunable with 45° electrically rotatable transmission axis as well as switched on and off. The improved performance enables this compact device more easily applied in optical communication systems.

Device and experiments

The fiber used in the experiments is a large mode area PCF (LMA-10, Crystal Fibre A/S, Denmark), with a solid core surrounded by air holes arranged in a triangular lattice. The hole diameter, inter-hole distance and outer fiber diameter are 3.09µm, 7.23µm and 125µm, respectively. The liquid crystal is E7 (Merck, Germany). The cross section of the LCPBG device is illustrated in Fig. 1. The LC E7 is infiltrated for 10 mm of the length of the fiber by using capillary forces, and then mounted between two v-grooves fabricated on a silicon substrate. Two SMF pigtails are also fixed in the grooves at each end of the LCPBG fiber for coupling in and out of the device. The Au electrodes are deposited on the side walls of the grooves, forming two orthogonal sets of electrodes. The electrode patterning is achieved by using thick photoresist coating and two-step exposure[8]. In order to ensure a high fiber coupling quality, SU-8 fiber fixing structures are built up on the electrodes. The assembly is sealed with epoxy, and the top and bottom sides of the device are electrically grounded.

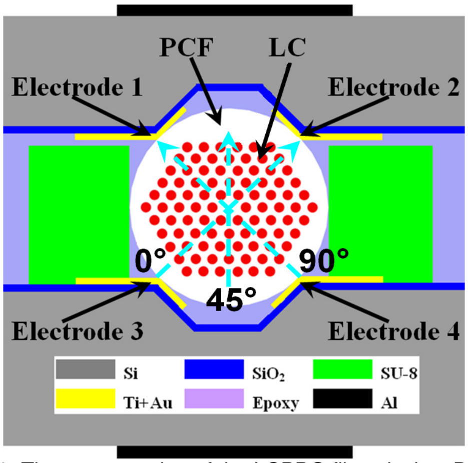

Fig. 1: The cross section of the LCPBG fiber device. Dotted lines show the direction of electric field effectively applied to the LCPBG fiber.

The performance of this device is tested using a broadband polarizer and three achromatic wave plates (quarter, half, quarter, 1200nm-1650nm) coupled to the light from a supercontinuum source (SuperK, Koheras A/S, Denmark) to have a full broadband polarization control. The transmission spectrum is measured by an optical spectrum analyzer (0.1nm resolution), and normalized to the spectrum without inserting the device. Using the four electrodes it is possible to control the direction of the electric field in the transversal direction and thereby the transversal orientation of the LC molecules, in this way obtaining one more degree of freedom in controlling the device. The device is driven in bipolar mode by using two 1 kHz sine wave signals Vs, -Vs. The device electrodes are connected in different electrode configurations (ECs) corresponding to three directions of the electric field (0°, 45°, and 90°) as the dotted lines shown in Fig. 1:

EC1 (0°): electrode 1=-Vs, electrode 4=Vs.

EC2 (45°): electrode 1=electrode 2=-0.707Vs, electrode3=electrode 4=0.707Vs.

EC3 (90°): electrode 2=-Vs, electrode 3=Vs.

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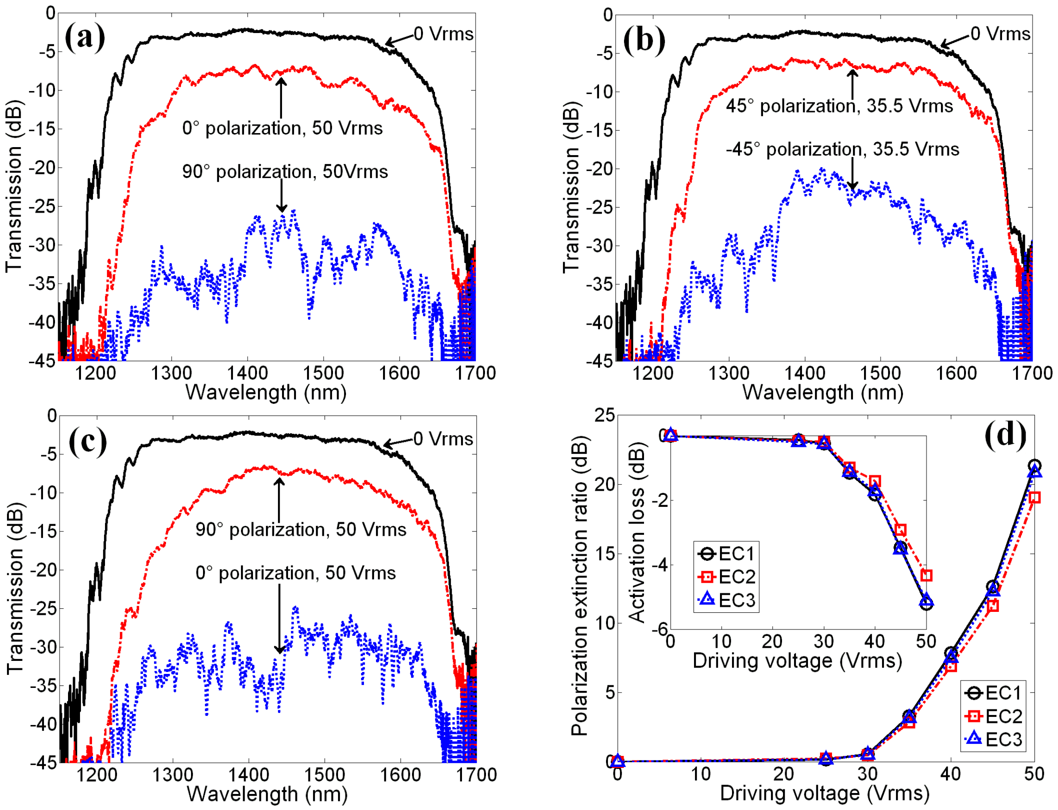

Fig. 2: Normalized transmission spectra of the polarizer at 0Vrms together with the polarization dependent transmission spectra for different electrode configurations (a) EC1, (b) EC2, (c) EC3 at the effective driving voltage of 50Vrms. (d) Polarization extinction ratio and corresponding activation loss shown in the inset at 1450nm as a function of effective driving voltage for different electrode configurations.

Fig. 2(a), (b) and (c) plot the normalized transmission spectra of the polarizer at 0Vrms together with the polarization dependent transmission spectra for EC1, EC2 and EC3 at the effective driving voltage of 50Vrms. Due to the reduction of hole size, the spectral position of the bandgap at 0Vrms is blue-shifted compared to the results in[5]. When the electric field is applied, the transmission axis of the polarizer is aligned orthogonally to the direction of the electric field related to the reorientation of the LC molecules along this direction which causes polarization dependent scattering, because of reverse tilt domain defects of the LC[2], and the bandgap becomes highly polarized. The total insertion loss of the device is only 2.7dB at 1450nm in the middle of the bandgap due to the small variation in the fiber outer diameter, and this value can be further reduced to around 1.5dB. The 3dB bandwidth of the polarizer centered at the 1450nm is 300nm, 310nm and 290nm for EC1, EC2 and EC3, respectively. Since the effective mode index of the cladding states belonging to the short wavelength bandgap edge mode is pushed up and into the bandgap, the short-wavelength edge is red-shifted. Fig. 2(d) shows the polarization extinction ratio and corresponding activation loss at 1450nm as a function of effective driving voltage for different ECs. The polarization extinction ratio is continuously tuned when the driving voltage is above the Fredericks threshold at 30Vrms in this case, where the LC molecules start to reorient. A larger activation loss has to be addressed in application systems when a higher polarization extinction ratio is required. With the driving voltage of 50Vrms, EC1 and EC3 have almost the same polarization extinction ratio of around 21dB, but 19.1dB for EC2. Also, the activation loss is equal for EC1 and EC3, but 0.8dB lower for EC2. These differences are probably caused by the variations of electric field distribution within the PCF between EC1, EC3 and EC2, since the air holes with LC are arranged triangularly in the transversal plane and the electric field distribution depends on the angular rotation of PCF with respect to the direction of electric field where the LC region is covered.

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