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# Electrically Tunable Bandpass Filter Based on Liquid Crystal Photonic Bandgap Fibers

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**Abstract:** An electrically tunable bandpass filter based on two photonic crystal fibers filled with different liquid crystals is demonstrated. Both the short-wavelength and long-wavelength edge are tuned individually or simultaneously with the response time in milliseconds.

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

## 1. Introduction

Photonic crystal fibers (PCFs) have attracted significant interest in the past decade due to their unique optical properties and high degree of design freedom [1]. Infiltrating the air holes with liquid crystals (LCs) can convert an initial index-guiding solid-core PCF to a bandgap-guiding PCF. Optical properties of liquid crystal filled photonic bandgap (LCPBG) fibers can be tuned thermally [2], electrically [3-6] and optically [7]. All-in-fiber devices based on LCPBG fibers have been demonstrated for switching [3,8], filtering [2,4], or controlling the polarization [4,5]. The fabricated devices have also been applied in filtering the amplified spontaneous emission (ASE) noise in optical communication systems [9] and realizing true-time delay in microwave photonic systems [10].

Optical bandpass filters are extensively used as key components in fiber-optic communications, fiber-optic sensing, and Optical Coherence Tomography (OCT). The tunability of the bandwidth represents a degree of freedom well desired in these applications. An all-in-fiber tunable bandpass filter has been investigated by applying a thermal gradient to a PCF filled with a high index fluid [11]. Here, we experimentally demonstrate an electrically tunable bandpass filter based on two solid-core PCFs infiltrated with different LCs in a double silicon v-groove assembly. The tunability of bandwidth is achieved by individually or simultaneously controlling the driving voltage of each LCPBG fiber with the response time in the millisecond range.

## 2. Device and experiments

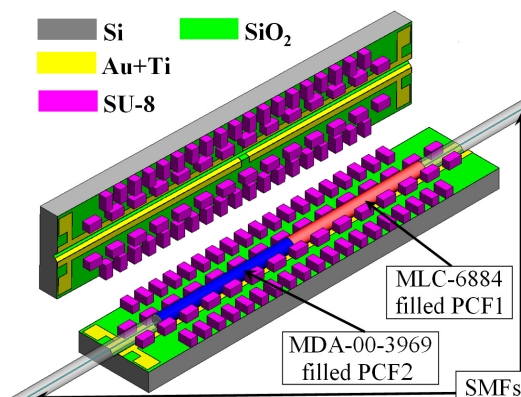


Fig. 1. Chip assembly of the LCPBG fiber device.

When two solid-core PCFs with different dimensions are infiltrated with different LCs, the resulting transmission spectrum is the overlap of two different spectra of each LCPBG fiber. When the driving voltage of each LCPBG fiber is changed, the bandgap related to that LC shifts and the overlap is narrowed or enlarged depending on the direction of the bandgap shift.

The fibers used in the experiments are large mode area PCFs (NKT Photonics A/S, Denmark), with a solid core surrounded by 5 rings of air holes arranged in a triangular lattice. By using capillary forces, LC MLC-6884 (Merck, Germany,  $n_o=1.48$ ,  $n_e=1.57$  at 589nm) is infiltrated for 10mm in PCF1 with the hole diameter and inter-hole distance of 5.51 $\mu$ m and 9.57 $\mu$ m, LC MDA-00-3969 (Merck, Germany,  $n_o=1.50$ ,  $n_e=1.72$  at 589nm) is infiltrated for 10mm in PCF2 with the hole diameter and inter-hole distance of 6.02 $\mu$ m and 9.69 $\mu$ m. The two end-facets are butt-coupled, as

shown in Fig. 1, and then mounted in a v-groove fabricated on silicon substrate by UV lithography and KOH wet etching. Two single mode fiber (SMF) pigtails are fixed in the groove at each end of the LCPBG fibers for coupling in and out of the device. The Au electrodes are deposited on the side walls of the groove, forming one pair of electrodes. In order to ensure a high fiber coupling efficiency, SU-8 fiber fixing structures are built up on the electrodes [12]. The height of each SU-8 structure is  $80\mu\text{m}$  and the distance between two neighbouring structures is  $126\mu\text{m}$ , taking the small variation of the fiber outer diameter into account. A top lid containing a v-groove with two separated pairs of electrodes is placed on top of the fibers and fixes the fibers in the grooves. The assembly is sealed with epoxy. The device is driven by 1 kHz sine wave.

A supercontinuum source (NKT Photonics A/S, Denmark) is used and the transmission spectrum is measured with an optical spectrum analyzer and normalized to the transmission spectrum without inserting the device. Figure 2(a) shows the transmission spectra of individual LCPBG fiber. The temperature is fixed at  $25^\circ\text{C}$ . No voltage is applied on MDA-00-3969 filled PCF2, while 90Vrms is applied to MLC-6884 filled PCF1. The yellow region is the overlap of two spectra in the wavelength range of 1520-1680nm. When the driving voltage increases, the long-wavelength edge of MLC-6884 filled PCF1 is shifted towards shorter wavelengths while the short-wavelength edge of MDA-00-3969 filled PCF2 in the overlapped region is shifted to longer wavelengths. Therefore, both the short-wavelength and long-wavelength edge of the formed filter can be tuned individually or simultaneously, which allows the fabrication of bandpass filters with a continuously tunable bandwidth.

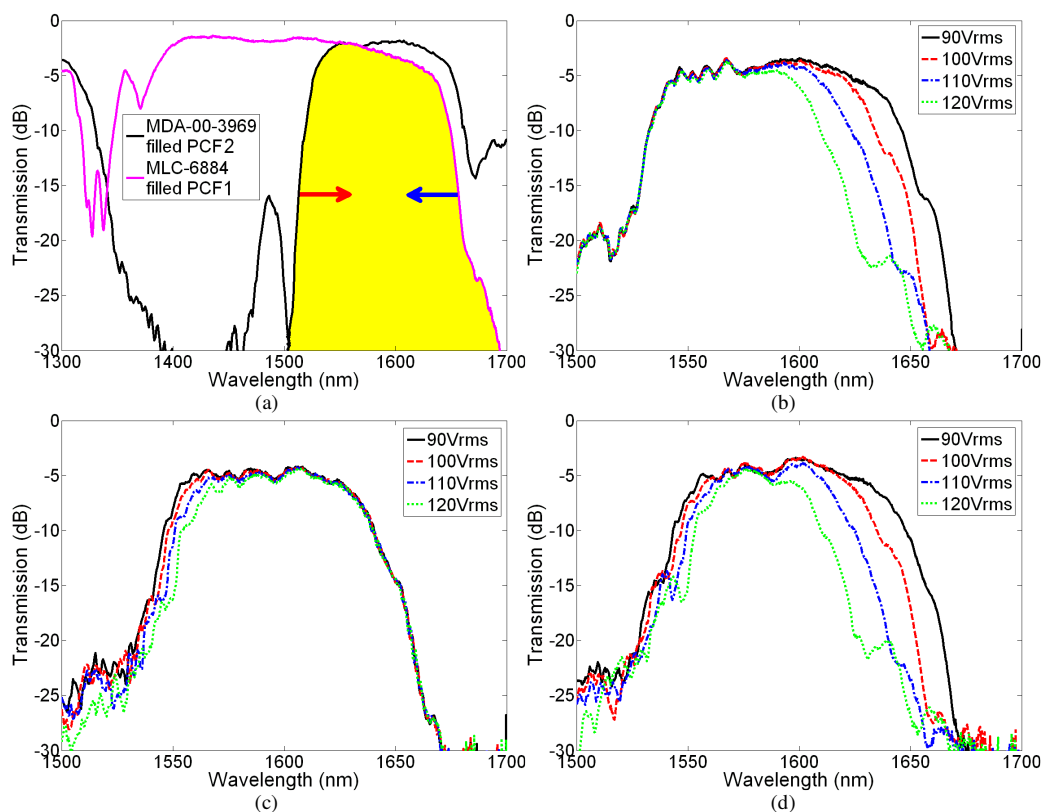


Fig. 2. (a) Transmission spectra of individual LCPBG fiber. The yellow region is the overlap of two spectra. (b) Transmission spectra of the device when the driving voltage of MLC-6884 filled PCF1 changes and no voltage is applied to MDA-00-3969 filled PCF2. (c) Transmission spectra of the device when the driving voltage of MDA-00-3969 filled PCF2 changes and 90Vrms is applied to MLC-6884 filled PCF1. (d) Transmission spectra of the device when the driving voltages of two LCPBG fibers are changed simultaneously.

Figure 2(b) shows the transmission spectra of the device when the driving voltage of MLC-6884 filled PCF1 changes and no voltage is applied to MDA-00-3969 filled PCF2. The long-wavelength edge of this filter is shifted towards shorter wavelengths by increasing the voltage, while the short-wavelength edge is kept. During the tuning process, the tunability of 3dB-bandwidth is 36nm, when the driving voltage varies from 90Vrms to 120Vrms. The total insertion loss of this device is 4.7dB at the central wavelength of 1595nm of the filter, which is mainly contributed by the coupling loss from different interfaces in the device (air:MLC-6884, MLC-6884:MDA-00-3969, MDA-00-3969:air), the scattering loss of LCs and a slight misalignment of SMFs and PCFs due to the small variations in the fiber outer diameter. Figure 2(c) shows the transmission spectra of the device when the driving

voltage of MDA-00-3969 filled PCF2 changes and 90Vrms is applied to MLC-6884 filled PCF1. The short-wavelength edge is shifted towards longer wavelengths by increasing the voltage, while the long-wavelength edge is kept. The tunability of 3dB-bandwidth is 12nm, when the driving voltage varies from 90Vrms to 120Vrms. When the driving voltages of two LCPBG fibers are changed simultaneously, both the short- and long-wavelength edge can be shifted. The 3dB-bandwidth changes from 95nm to 48nm, when the driving voltage varies from 90Vrms to 120Vrms.

The response time of this device is also investigated. When the driving voltage is on, there is a low transmission on the edges of the filter, while high transmission is found when the driving voltage is off. Therefore, switching is performed by amplitude modulating the 1 kHz sine driving voltage by a 50% duty-cycle 5 Hz square envelope. A photodiode is used to detect the intensity of the light at the output of the device and an oscilloscope displays the photodiode voltage. The rise and decay time  $t_{ON}$  and  $t_{OFF}$  are measured from 90% to 10% and from 10% to 90% amplitude modulation, respectively. The chosen wavelength for MDA-00-3969 filled PCF2 is 1548nm and for MLC-6884 filled PCF1 is 1620nm, which is done in order to have the maximum sensitivity to the shift caused by an applied electric field. Figure 3 shows the response time as a function of the driving voltage.  $t_{OFF}$  for MDA-00-3969 filled PCF2 converges towards 18.6ms and for MLC-6884 filled PCF1 converges towards 15.1ms, which are weakly dependent on the driving voltage.  $t_{ON}$  for MDA-00-3969 filled PCF2 is from 4.3ms to 2.5ms and for MLC-6884 filled PCF1 is from 2.9ms to 1.8ms, which are determined by a balance between the dielectric torque and the viscous torque working against any reorientation.

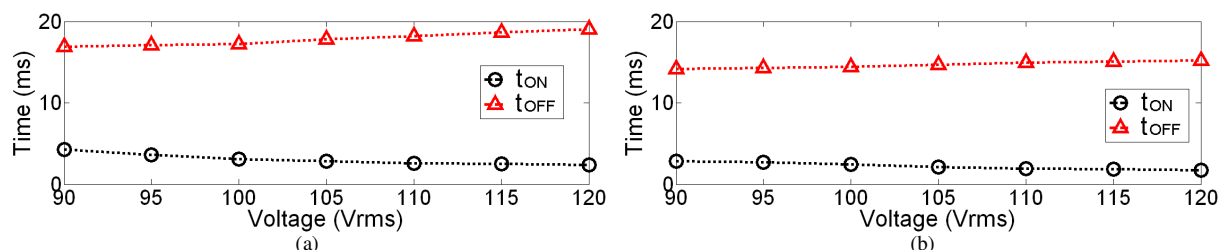


Fig. 3. Measured response time as a function of driving voltage (a) MDA-00-3969 filled PCF2, (b) MLC-6884 filled PCF1.

### 3. Conclusions

We have demonstrated a continuously tunable bandpass filter based on two solid-core PCFs infiltrated with different LCs in a double silicon v-groove assembly. Compared to single LC filling, this device offers more flexible bandwidth tunability. Considering the large number of available electrical tunable LCs and the high degree of freedom in PCF design, this compact LCPBG fiber device based on multiple LCs is a promising candidate for a variety of applications, where the bandwidth tunability would allow for further optimization.

### 4. References

- [1] P. St. J. Russell, "Photonic crystal fibers," *Science* **299**, 358-362 (2003).
- [2] T. T. Larsen, A. Bjarklev, D. S. Hermann, and J. Broeng, "Optical devices based on liquid crystal photonic bandgap fibres," *Opt. Express* **11**, 2589-2596 (2003).
- [3] M. W. Haakestad, T. T. Alkeskjold, M. D. Nielsen, L. Scolari, J. Riishede, H. E. Engan and A. Bjarklev, "Electrically tunable photonic bandgap guidance in a liquid crystal filled photonic crystal fiber," *IEEE Photon. Technol. Lett.* **17**, 819-821 (2005).
- [4] L. Scolari, T. T. Alkeskjold, J. Riishede, A. Bjarklev, D. S. Hermann, A. Anawati, M. D. Nielsen, and P. Bassi, "Continuously tunable devices based on electrical control of dual-frequency liquid crystal filled photonic bandgap fibers," *Opt. Express* **13**, 7483-7496 (2005).
- [5] D. C. Zografopoulos, E. E. Kriezis and T. D. Tsiboukis, "Tunable highly birefringent bandgap-guiding liquid crystal microstructured fibers," *J. Lightwave Tech.* **24**, 3427-3432 (2006).
- [6] T. R. Wolinski, S. Ertman, P. Lesiak, A. W. Domanski, A. Czapl, R. Dabrowski, E. Nowinowski-Kruszelnicki and J. Wojcik, "Photonic liquid crystal fibers – a new challenge for fiber optics and liquid crystals photonics," *Opto-Electron. Rev.* **14**, 329-334 (2006).
- [7] T. T. Alkeskjold, J. Lægsgaard, D. S. Hermann, A. Anawati, J. Broeng, J. Li, S. -T. Wu, and A. Bjarklev, "All-optical modulation in dye doped nematic liquid crystal photonic bandgap fibers," *Opt. Express* **12**, 5857-5871 (2004).
- [8] T. T. Alkeskjold and A. Bjarklev, "Electrically controlled broadband liquid crystal photonic bandgap fiber polarimeter," *Opt. Lett.* **32**, 1707-1709 (2007).
- [9] M. N. Petersen, L. Scolari, T. Tokle, T. T. Alkeskjold, S. Gauza, S. -T. Wu, and A. Bjarklev, "Noise filtering in a multi-channel system using a tunable liquid crystal photonic bandgap fiber," *Opt. Express* **16**, 20067-20072 (2008).
- [10] L. Wei, W. Xue, Y. Chen, T. T. Alkeskjold, and A. Bjarklev, "Optically fed microwave true-time delay based on a compact liquid-crystal photonic-bandgap-fiber device," *Opt. Lett.* **34**, 2757-2759 (2009).
- [11] P. Steinvurzel, B. J. Eggleton, C.M. de Sterke and M. J. Steel, "Continuously tunable bandpass filtering using high-index inclusion microstructured optical fibre" *Elect. Lett.* **41**, 463-464 (2005).
- [12] L. Wei, T. T. Alkeskjold, and A. Bjarklev, "Compact design of an electrically tunable and rotatable polarizer based on a liquid crystal photonic bandgap fiber," *IEEE Photon. Technol. Lett.*, accepted for publication.