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# A Polarization Maintaining Filter based on a Liquid-Crystal-Photonic-Bandgap-Fiber

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## Abstract

A polarization maintaining filter based on a liquid-crystal-photonic-bandgap-fiber is demonstrated. Its polarization extinction ratio is 14 dB at 1550 nm. Its tunability is 150 nm.

## Introduction

Photonic crystal fibers (PCFs) present the unique characteristic of having microholes running along their length. Liquid materials can be infiltrated into these fibers, allowing control and manipulation of their optical properties. Solid core PCFs allow light to be guided by modified total internal reflection, similarly to standard optical fibers [1]. If the microholes of these fibers are filled with a liquid having a refractive index higher than the constituent material of the fiber, anti-resonances of the high-index rods give rise to discrete photonic bandgaps where the light is confined to the core [2]. In particular, among liquid materials, liquid crystals (LCs) are attractive because they exhibit very high thermo-optic and electro-optic effects, leading to the possibility of realizing tunable components [3]. All-in-fiber tunable devices such as spectral filters, switches, polarization controllers and polarimeters have been fabricated by using this technique and their tunability achieved thermally, electrically or optically [3,4,5]. Birefringence tunability has also been demonstrated in highly birefringent PCF filled with LCs [6]. A further degree of freedom in the design of such devices is also given by the possibility of tapering the fiber or inflating the holes, such that the bandwidth of the transmission bands can be narrowed and the shape tailored [7]. This leads to the possibility of fabricating all-in-fiber bandpass, notch, high-pass or low pass filters with a tunable operating wavelength and a tunable bandwidth, representing an alternative choice to bulk optics filters because alignment issues are overcome in this case. They are fiber compatible and may find applications in dynamic optical networks and adjusted to the specific network in order to optimize its performances.

Here a polarization maintaining (PM) filter based on a 30 cm PCF filled with 1.2 cm LC is demonstrated. A polarization extinction ratio (PER) of 14 dB at 1550 nm is measured. The PM filter is thermally tunable and a 150 nm shift of the bandgaps is achieved by tuning the filter from 30°C to 70°C. Such

a filter can be used, for example, in mode-locked fiber lasers to perform spectral shaping and intra- and extra-cavity dispersion management. A high PER of all the elements used in fiber lasers is crucial for the laser stability.

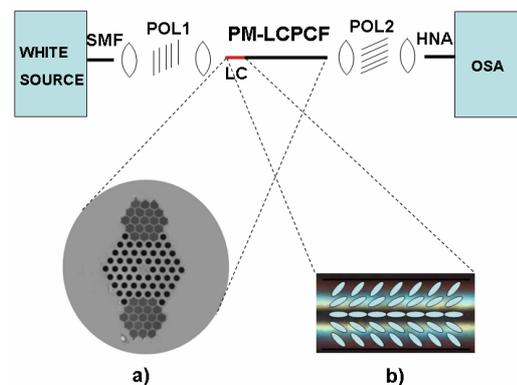


Figure 1 : Schematic of the setup. a) Micrograph of the fiber used in the experiment (LMA-PM-15) b) Alignment of the LC infiltrated in the fiber.

## Setup and discussion

The fiber used in this experiment is a large mode-area PM fiber with a core size of 15  $\mu\text{m}$  (LMA-PM-15) from Crystal Fibre A/S, Denmark. A cross-section of the fiber is shown in the inset a) of Fig.1. The hole size  $d$  is 4.7  $\mu\text{m}$  and the inter-hole distance  $\Lambda$  is 9.8  $\mu\text{m}$ . Boron rods are inserted on opposite sides of the core at the preform stage in order to obtain stress-induced birefringence that facilitates the polarization maintaining properties of the fiber. LMA-PM-15 has a birefringence  $\geq 8 \times 10^{-5}$  in the range 900-1700 nm and a PER of  $\geq 20$  dB at 1550 nm. A LC named MDA-00-3969 from Merck, Germany, is infiltrated in the PCF for 1.2 cm by using capillary forces. MDA-00-3969 is a dual-frequency nematic LC, with an ordinary and extraordinary index of 1.4978 and 1.7192 (measured at 589.3 nm), respectively. Microscope investigations of this LC infiltrated in a 5  $\mu\text{m}$  silica capillary show that the alignment is splayed, with a 45° angle to the boundaries, as illustrated in the inset b) of Fig.1. The LCPCF device is positioned between two polarizers.

Lenses with a magnification of 20X and a NA of 0.5 are used to couple white light from a halogen lamp into the LCPCF, as illustrated in the setup of Fig.1. The light is collected by an optical spectrum analyzer through a high numerical aperture optical fiber.

The PER measurement is done using the crossed-polarizer method. The first polarizer is aligned along the slow or the fast axis of the fiber. The second polarizer is added and the two polarizers are iteratively rotated to minimize the transmission in the bandgaps. The resulting spectrum is measured (red curve in Fig.2). Now the second polarizer is rotated 90°, such that it will be co-aligned with polarizer 1. The transmission spectrum is measured again (black curve in Fig. 2). The polarization extinction ratio is the ratio between the power measured in these two cases – the polarizers in-line and the polarizers crossed – in dB units. In order to verify that polarizer 1 is in fact aligned along one of the two PM axes, polarizer 1 is rotated 90° and the same measurements as above are repeated (green and blue curves). The transmission spectra for these two cases are expected to be the same if polarizer 1 is aligned along one of the two PM axes. In Fig. 2 it is possible to notice a small difference between them and we believe that this is caused by the fact that the LC alignment does not have a perfect cylindrical symmetry in the holes of the fiber. A PER of 14 dB is measured at 1550 nm and a PER of 17 dB is measured at 1200 nm.

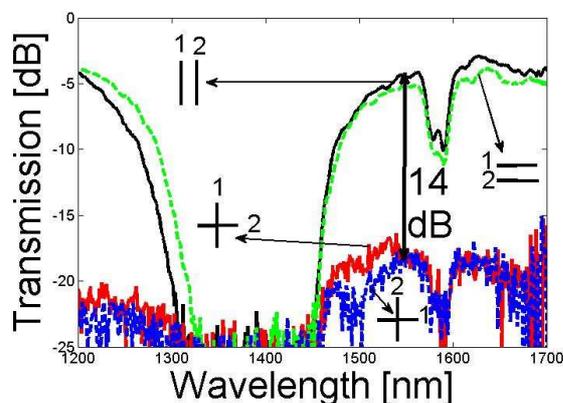


Figure 2 : Normalized transmission spectrum measured with crossed (red and blue curve) and in-line polarizers (black and green).

The thermal tunability of the PM LCPCF filter is investigated by positioning the part of the fiber filled with LC on a thermal plate. A standard SMF connected to a white light source is butt-coupled to the filter and the transmission spectrum is measured using an optical spectrum analyzer. The temperature of the thermal plate is varied from 30°C to 70°C and the transmission spectrum taken every 10°C. Fig.3 shows the wavelength of the notch in the bandgap

located between 1450-1700 nm as a function of temperature.

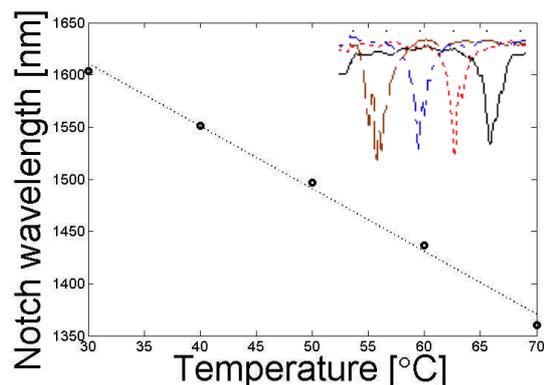


Figure 3 : Temperature tunability of the PM-LCPCF.

A tunability of 150 nm is achieved in this temperature range. The shift of the bandgaps as a function of temperature is almost linear. By choosing a different LC, the bandgaps can be shifted to specific wavelengths and the filter can be used for the required application. In the case of an all-PM mode-locked fiber laser, the tunable PM filter can be used for spectral shaping in the cavity, ASE filtering in the amplifiers, and for tunable dispersion control both inside and outside the cavity, thus allowing for monolithic tunable pulse shaping.

### Conclusions

An all-in-fiber polarization maintaining filter has been demonstrated by infiltrating a polarization maintaining PCF with LC. The PCF has two boron rods on each side of the core and maintains the polarization with a PER of 20 dB at 1550 nm. By infiltrating this fiber with a LC, bandgaps are achieved in the transmission spectrum. A PER of 14 dB at 1550 is measured, opening up the possibility of using this device as a polarization maintaining filter, for example, in the fabrication of fiber lasers. Tunability has also been explored and a wavelength shift of 150 nm has been measured in the temperature range 30°C-70°C.

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