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Highly Tunable Large Core Single-Mode Liquid Crystal Photonic Bandgap Fiber

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Abstract: We demonstrate a highly tunable photonic bandgap fiber, which has a core diameter of 2 µm, and a bandgap tuning sensitivity of 2 nm/°C at room temperature. The insertion loss is estimated to be less than 0. dB.

OCIS codes: 2 0. 0 Microstructure devices 0 0.2 0 Fiber optics components

1. Introduction

The presence of air holes in Photonic Crystal Fibers PCFs gives the possibility of infusing liquids into the fibers and in this way creating tunable fiber based devices using both index-guiding [1-] and bandgap-guiding fibers [-]. It has been demonstrated that an initial index-guiding PCF can be converted to a highly tunable bandgap-guiding type PCF by infiltrating the air holes with a Liquid Crystal LC , which allow for thermal [ ], electrical [,] and all-optical tuning [ ]. The spectral properties of LC PCFs can be thermally tuned using LCs having nematic, smectic A and cholesteric mesophases, which yield different functionalities such as threshold switching and tunable spectral filtering with a bandgap tuning sensitivity of nm/°C [ ] below phase transitions. In the latter case, thermal shifting of the bandgaps may for example be achieved by utilizing the temperature dependence of the ordinary refractive index of nematic LCs by resistive or optical pump induced heating [ ]. In this case, it is desirable to have a high tuning sensitivity around room temperature in order to decrease the power consumption and ease handling and packaging. Here, we present a tunable large-core single-mode photonic bandgap fiber, which has a core diameter of 2 µm, an effective mode area of 0µm^2 and a high bandgap tuning sensitivity of 2 nm/°C at room temperature. This is achieved with a specially synthesized LC exhibiting an extraordinary large thermo-optic effect [ ].

2. Device characterization

The fiber has a large central core surrounded by six rings of air holes arranged in a triangular lattice Fig. 1, right, inset . The hole diameter, inter hole distance, core diameter and outer fiber diameter are 2. µm, 11.2µm, 2 µm and 0µm, respectively. The large mode-area is obtained using a three-rod core design, giving a core having three-fold symmetry. The air holes were infiltrated with the specially synthesized LC called UCF-1 [ ] formulated by the University of Central Florida. The air holes were filled with UCF-1 over 10mm of the length using capillary forces. The LC was heated to isotropic phase and cooled down again slowly to achieve a homogenous alignment. Polarized microscopy observations on a single silica capillary tube, with an inner diameter of µm, indicated that the LC was planar aligned, i.e., with the LC director aligned along the fiber axis, and, therefore, with the ordinary index predominantly determining the spectral features of the fiber. Fig. 1 left shows the transmission spectrum for the LCPCF normalized to the unfilled PCF. The spectrum shows high transmission in two bandgaps, bandgap A centered around 11 0 nm and bandgap B centered around 1 00 nm. In between these two bandgaps, a weaker transmission peak appears. This feature is a direct consequence of the LC anisotropy, which causes a splitting of the EH$_{11}$ mode of an LC-infiltrated microchannel from the HE$_{12}$ and HE$_{1}$ modes, so that a narrow bandgap opens up between the cladding states derived from these modes. Simulations confirmed this and the modal cut-off wavelengths of the EH$_{11}$ and HE$_{12}$ mode, which represents the stopbands in the anti-resonant model [10], is also

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plotted for T 2 °C in Fig. 1. As observed from Fig. 1, the width and transmission level of the bandgap between A and B is reduced as the temperature of UCF-1 T_c 2 . °C is increased, which decreases the LC anisotropy and thereby reduces the splitting of the EH_{11}, HE_{12} and HE $_1$ cladding modes. The spectral tuning sensitivity of the UCF-1 infiltrated PCF at 2 °C was measured at the long wavelength edge of bandgap A to be 2 nm/°C, which is approximately . higher than when using the commercial available LC E Merck above 0°C [11]. Fig. 1 right shows a comparison between the measured normalized transmission spectrum of bandgap B and simulation of two-times the coupling loss between the index-guided mode unfilled PCF and the bandgap-guided mode LC filled PCF evaluated using overlap integrals. Insets show simulated mode fields of the index-guided mode in an unfilled PCF TIR mode and a PBG guided mode at the center wavelength of the bandgap. The mode profiles have been normalized to equal intensity and to exhibit same contour levels. The simulated coupling loss agrees well with the shape of the PBG spectrum, which indicates that coupling loss 0. dB is the dominant loss mechanism, as was also found by Steinvurzel et al.[12].

In conclusion, a highly tunable bandgap fiber has been demonstrated. The fiber exhibits a bandgap tuning sensitivity of 2 nm/°C at room temperature. The guided mode has an effective area of 0μm^2 with a device insertion loss of less than 0. dB.

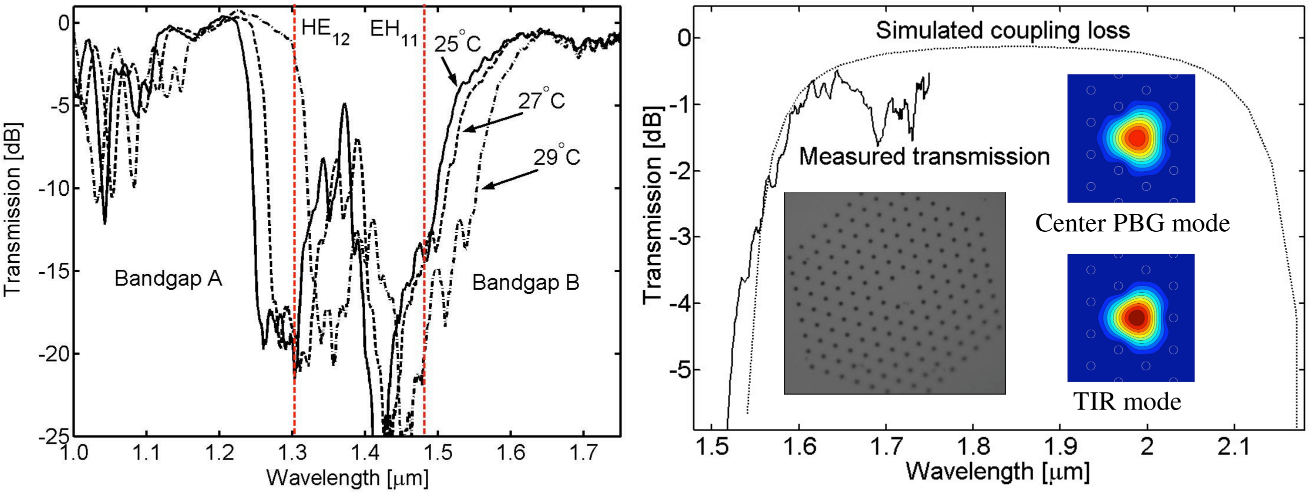

Fig. 1 Temperature dependent transmission spectra of the LCPCF at T 2 °C, 2 °C and 2 °C left . Also plotted are the calculated modal cut-offs of the HE_{12} and EH_{11} modes of a single LC capillary dashed vertical lines . Simulated coupling loss between filled and unfilled section compared to measured transmission spectrum Right . Insets show an optical micrograph of the PCF end facet, simulated mode fields of the PBG mode at the center of the bandgap and the index-guided mode of the unfilled section.

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