Tunable attenuation in photonic liquid crystal fibers

Marzena M. Tefelska[11], Miłosz S. Chychłowski[1],Tomasz R. Woliński[1], Roman Dąbrowski[2], J. Wójcik[3]

[1]Faculty of Physics, Warsaw University of Technology, Koszykowa 75, 00-662 Warszawa,
[2]Military University of Technology, Warszawa, Poland
[3]Maria Curie Sklodowska University, Lublin, Poland

Received June 15, 2009; accepted June 26, 2009; published June 30, 2009

Abstract—This paper presents initial experimental results on the influence of temperature on propagation properties of a new photonic crystal fiber filled with a novel low-birefringence NLC 1800B. The results obtained suggest great potential of LC-filled photonic crystal fibers for fiber attenuators or modulators.

In recent years one of the most dynamically developing branches of fiber optics are photonic crystal fibers [1,2] in which silica core is surrounded by periodically distributed micro-holes with a diameter of several micrometers. The propagation of light in these structures can be guided by two different mechanisms: index guiding and the photonic bandgap effect (PBG) [3,4]. Changing the arrangement and diameter of micro-holes in photonic crystal fibers can modify parameters such as birefringence, dispersion and nonlinearity in a wide range. Another way of changing the properties of PCFs is to fill their holes with various materials which optical properties can be dynamically modified. An especially interesting effect is obtained when micro-holes of photonic crystal fibers are filled with a liquid crystal (LC) [4,5] which refractive index (as most of LC) strongly depends on temperature. Moreover, the refractive index of liquid crystals depends on molecules orientation, which can be changed by external electric, magnetic and even optical fields [5,6].

If photonic crystal fibers are filled with liquid crystals they start guiding light by the photonic bandgap effect [7], since liquid crystals have in principle refractive indices higher than the refractive index of the silica core. In this paper propose a new low-birefringence LC mixture 1800B that is a modification of the well-known 1550 LC mixture described in [8] and was synthesized at the Military University of Technology (Warsaw, Poland). The chemical structure of the 1800B mixture is shown in Fig. 1a. This LC has phase transitions at S_B 10 N 71.5 Iso temperatures. The most important feature of the 1800B LC is that in a wide range of the nematic phase (10°C-71.5°C) ordinary refractive index n_o is below the refractive index of fused silica n_{silica}=1.458 (at λ = 588 nm) [9] while its extraordinary index is still higher than n_{silica} (Fig.1b). The birefringence of the 1800B LC at 20°C is very low Δn = 0.0596. In our experiment as a host we used the 081120 LMA PCF with 5 rings of holes manufactured at the Maria Curie Skłodowska University (UMCS, Lublin, Poland) (Fig 2.). This fiber has low attenuation and the diameter of about 125µm.

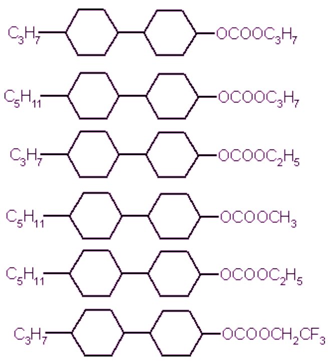


Fig. 1a. Chemical structure of the 1800B mixture.

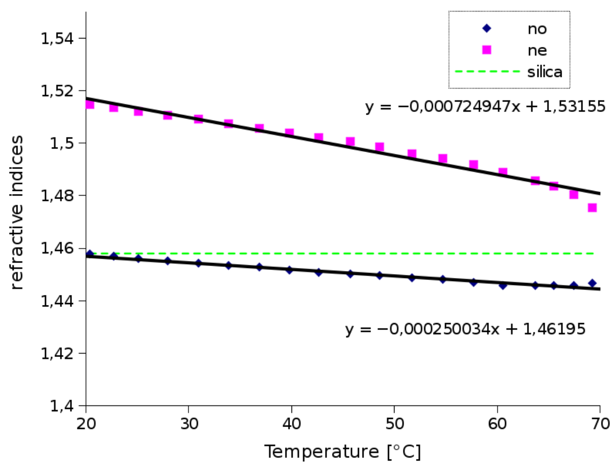


Fig. 1b. Refractive indices as a function of temperature for 1800B liquid crystal.

[1] E-mail: martef@if.pw.edu.pl

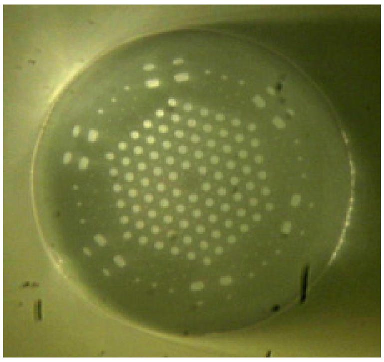


Fig. 2. Photonic crystal fiber with 5 rings of holes manufactured at the UMCS.

The solid-core PCF used in this experiment was ~90 cm long with 5 rings of holes filled with 1800B LC (section of ~3 cm). As a light source we used a halogen lamp (Mikropack Halogen LightSource) and a laser diode operating at the wavelength 633nm. As a light intensity detector was used spectrometer HR4000 Ocean Optics. The temperature range was changing from 21°C to 71°C by using the Peltier module. The intensity of output light increased when we increased the temperature as shown in Fig.3.

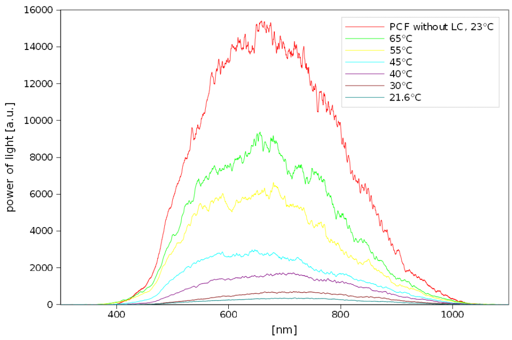
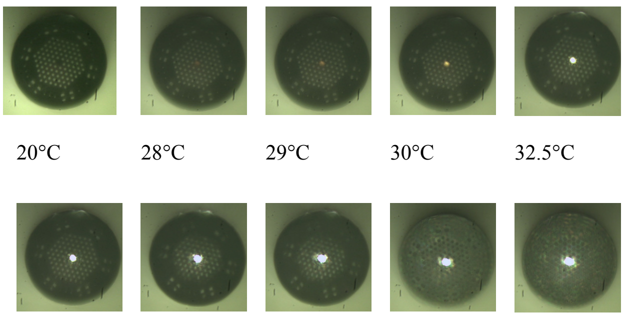


Fig. 3. Transmission spectra for PCF filled with LC 1800B under the influence of temperature.



20°C 28°C 29°C 30°C 32.5°C

35°C 42.2°C 50°C 65°C 71.5°C

Fig.4 a) Light propagation in PLCF under the influence of temperature – cross sections at the output of the fiber.

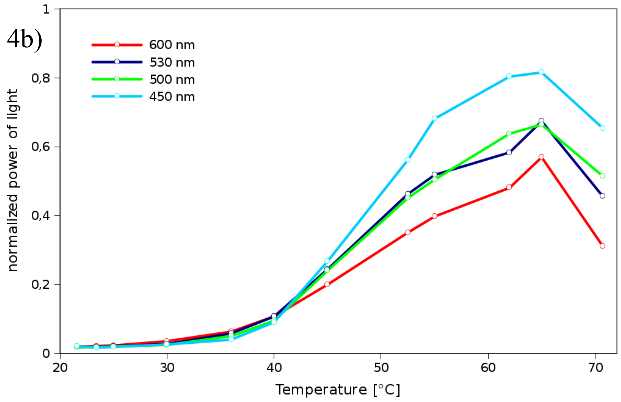


Fig.4 b) Normalized optical power for selected wavelengths in function of temperature.

As can be seen in Fig. 4a,b, the operating wavelength depends on temperature and we observed a significant increase in the output power while the temperature raised from 36°C to 65°C. For 70.7°C, close to the isotropic phase of LC the output power rapidly decreased. Hence a type of PLCF can be used as a fiber with a wide range of tunable attenuation.

We also measured the output power of the fiber by using a power meter (Newport Model 1918-C) for a laser diode operating at the wavelength 633nm (Fig.5). The PCF was 80 cm long with 5 rings of holes filled with 1800B (section of ~1.9 cm). The output power of light increased linearly under the influence of temperature.

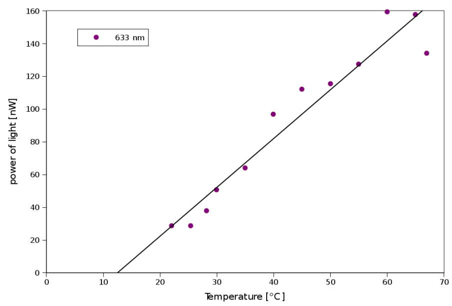
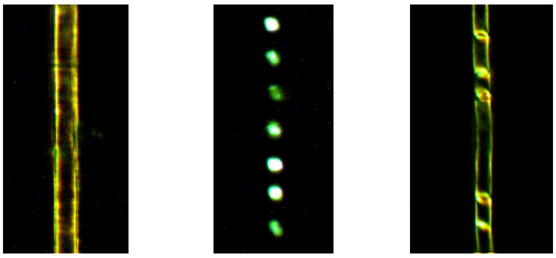


Fig.5 Power of light measured for a laser diode operating at the wavelength 633nm (Newport Power Meter)

We have also observed the behavior of the 1800B LC in a single capillary with a 10µm diameter, heating it to phase transition. The observed results under a polarizing microscope (Carl Zeiss Jena, Jenapol) are shown in Fig.6a,b.



Nematic phase 25°C   Nematic-isotropic phase transition 71.5°C   Nematic phase cooled from isotropic.<71.5°C

Fig.6 a) Capillary (10μm) with 1800B (microscope with lens x20)

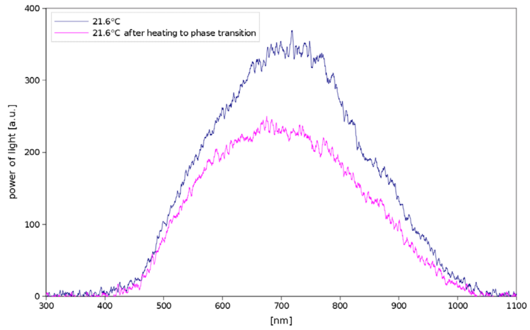


Fig.6 b) Transmission spectra for PLCF in room temperature and after heating to isotropic phase and cooling

Close to the phase transition we observed periodically distributed bubbles in the 1800B liquid crystal (Fig.6a). When we were cooling the capillary, some defects in the LC structure appeared. These defects could be attributed to molecules oriented in the opposite direction. They can be responsible for increased attenuation in the PLCF (Fig 6b). Further experiments are in progress.

Photonic liquid crystal fibers (PCFs) filled with various substances can be used as all-in-fiber tunable devices. We have demonstrated propagation effects in the PLCF composed of a PCF filled with a nematic liquid crystal 1800B. The investigated PLCF shows the posibility of attenuation tuning in the index guiding regime controlled by changes in temperature. Consequently, this property may be used to propose a fiber-optic attenuator.

This work has been supported by the European Union in the framework of European Social Fund through the Warsaw University of Technology Development Programme and by the Polish Ministry of Science and Education under the grant M517 056535

References

[1] P. St. J. Russell „Review: Photonic Crystal Fibers" Science 299, 358-362 (2003)
[2] C. Knight, "Photonic crystal fibres", Nature, 424, 847-851, 2003.
[3] Zhang, C., Kai, G., Wang, Z., Liu, Y., Sun, T., Yuan, S., Dong, X.: Tunable highly birefringent photonic bandgap fibers. Opt. Lett. 30, 2703–2705 (2005)
[4] T. R. Woliński et al., Meas. Sci. Technol., 17, 985-991 (2006)
[5] T.T. Larsen, A. Bjarklev, D.S. Hermann, and J. Broeng, "Optical devices based on liquid crystal photonic bandgap", Opt. Express 11, 2589–2596 (2003).
[6] T. R. Woliński, S. Ertman, P. Lesiak, A. W. Domański, A. Czapla, R. Dąbrowski, E. Nowinowski-Kruszelnicki, and J. Wójcik, „Photonic liquid crystal fibers – a new challenge for fiber optics and liquid crystals photonics", Opto-Electronics Review 14, 329-334, (2006)
[7] T. R. Woliński, A. Czapla, S. Ertman, M.Tefelska, A. W. Domański, E. Nowinowski-Kruszelnicki, R. Dąbrowski, „Tunable highly birefringent solid-core photonic liquid crystal fibers", Opt. Quantum Electron. 39, 1021-1032 (2007).
[8] T.R. Wolinski, K. Szaniawska, S. Ertman, P. Lesiak, A. W. Domanski, R. Dabrowski, E. Nowinowski-Kruszelnicki and J. Wojcik "Influence of temperature and electrical fields on propagation properties of photonic liquid-crystal fibres", Meas. Sci. Technol. 17 (2006) 985–991
[9] http://refractiveindex.info/index.php?group=GLASSES&material=F_SILICA&wavelength=0.5876

