

Optically Tunable Photonic Bandgap Fiber

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A new type of tunable optical fiber is based on photonic crystal fibers (PCFs), which have a cross-section that usually consists of an air/silica microstructure that is invariant along the fiber axis. Light can be guided either by modified total internal reflection (mTIR) or by the photonic band gap (PBG) effect. In both cases, the guided light is surrounded by a number of capillaries ranging from a few to several hundred; they have unique advantages compared to standard fiber technology with respect to tunability.

For example, the capillaries allow for a high interaction between guided light and an infused liquid material. Tunable PCFs based on mTIR have been demonstrated by pumping a liquid plug across a tapered region of a PCF.¹ Tunability has been explored using the PBG effect by thermally tuning the refractive index of a high-index liquid² or a liquid crystal³ (LC) or by reorienting LCs by external electrical fields.⁴ These devices exhibit response time in the range of 10 ms to 1 s.

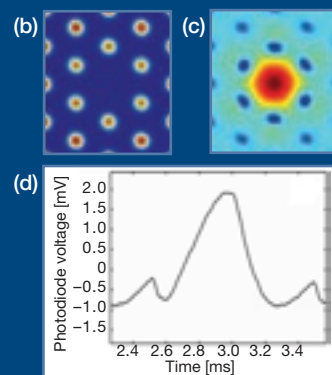
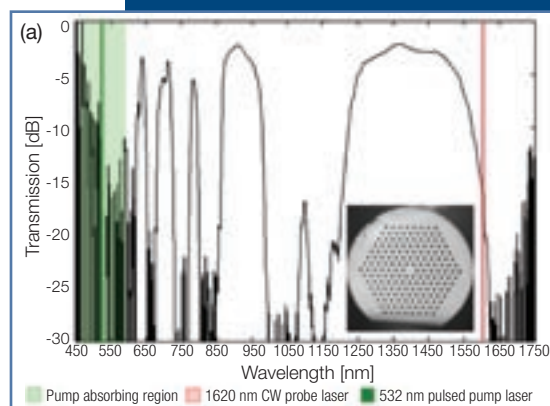
Here, we describe an optically tunable photonic bandgap fiber that has a faster response time and requires no electrical wiring, because the controlling signal (the pump) is guided in the fiber together with the signal (the probe) allowing for remote tuning.⁵ The PCF consists of a 10 μm silica core surrounded by 7 periods of 3 μm air holes [figure, part (a), inset], which are infiltrated for 10 mm with an LC. The presence of an LC in the air holes transforms the PCF from an mTIR type into a PBG guiding type waveguide exhibiting a series of transmission bands (PBGs) within the wavelength span of 400 to 1700 nm [part (a)].

The fiber acts as a spectral filter that screens out wavelengths that are not supported as guided modes by the cladding structure. These modes couple to the cladding and propagate in the LC (b), while the transmitted modes propagate in the core (c). Doping the LC with an absorbing dye increases the optical absorption of the modes propagating in the LC cladding. Using a $\lambda=532$ nm pump laser and an azobenzene dye-doped nematic LC absorbing at this wavelength, we demonstrated that varying the power of the pump laser could optically control the spectral position of the PBGs so that all-optical modulation is feasible.

The absorption locally raises the temperature of the LC and the PBGs shift accordingly. The tuning dynamics of the PBGs are in this case limited by the thermal diffusion time of the individual LC capillaries, which is the time for the thermal energy to diffuse from the LC to the surrounding silica. In this design, it is around 100-200 μs (d) for a low pump power of 2-3 mW. The pump tunes the fiber properties within the entire 400 to 1700 nm wavelength span, whereby the pump signal can modulate the power and the effective mode index of a guided mode with a wavelength lying within one of the PBGs, as shown in (d).

In conclusion, we have demonstrated an all-optical tunable photonic bandgap fiber that requires a very low pump power to be tuned. \blacktriangle

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Transmission spectrum of the dye-doped nematic liquid crystal photonic bandgap fiber, which absorbs light with wavelengths between 450 nm and 600 nm. (a) Inset shows an optical micrograph of the PCF end facet. Simulated mode profile of a short-wavelength cladding mode propagating in the LC (b) and guided mode in the core (c). The dynamic response is measured by placing a continuous-wave probe laser on a PBG edge and pumping the LC with a square-wave modulated 532 nm pump laser with a power of 2-3 mW. The probe rise and decay time was 250 μs and 120 μs , respectively, in response to a 500 μs pump pulse (d).

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