Higher order mode photonic bandgap fibers for dispersion control

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Abstract: We investigate the dispersion properties of solid core and hollow core photonic bandgap fibers and propose a novel, partial reflector layer around the core for dispersion control of femtosecond optical pulses.

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We calculate the dispersion and loss properties of solid core (SC) and hollow core (HC) Bragg photonic bandgap (PBG) fibers [1,2] based on the vector finite element modeling (FEM) and the Helmholtz eigenvalue equation with a surrounding perfectly matched layer (PML). We design PBG fibers with a bandgap around the Ytterbium wavelength with the aim of controlling the dispersion of ultrashort laser pulses both in amplifiers and in Yb doped fiber based oscillators.

The SC Bragg fiber will have a fused silica core which will comprise several periods of alternate higher and lower index layers. The refractive index of the higher index glass is chosen to be identical with the refractive index of an SF10 glass and the lower index layers are also designed from fused silica. Using the quarter-wavelength (QW) condition and an assumed propagation angle (~87º) at the core-cladding interface, we may calculate a structure which has a bandgap close to one micron. An iteration process is applied here with the calculated effective refractive index of the fundamental mode with the recalculation of the propagation angle to set the middle of the bandgap around the Yb wavelength. The periodic Bragg structure we were obtain has higher and lower index layers with thickness of 0.5 µm and 0.657 µm, respectively. The computed loss and dispersion profile of these fibers are shown in Fig. 1 (a). The dispersion of the canonical form is found to follow the familiar form for bandgap guidance, such that third and higher order dispersion is appreciable where the second order dispersion is low. Different core sizes do not change the dispersion and loss curves significantly but the higher core size results lower dispersion slope and slightly wider bandgap. For a HC all-silica Bragg fiber the dispersion is showed in Fig. 1 (c) (red curve).

The dispersion slope of these fibers may limit the transmitted shortest duration of pulses because of temporal distortions. Therefore the demand on all-fiber dispersion compensation may emerge. This requirement may also be important in the case of HC Bragg fibers because the dispersion compensation of high-intensity delivered pulses can not be easily done by solid core fibers. Using an analogy of 1D PBG structures (such as dielectric mirrors) we claim that certain resonant or partial reflector layer forming a Gires-Tournois interferometer (GTI) [3] may oppose the dispersion slope that may yield anomalous dispersion with a flat cumulative dispersion profile in all-fiber devices. Partial reflector layers however work for only certain propagating modes in a 2D PBG structure. The appropriate modes form such a transversal distribution that can penetrate to the GTI around the core a wavelength dependent way which physical effect may yield the required dispersion compensation over the material dispersion and the dispersion of bandgap guidance. The LP_{02} mode has a suitable transversal distribution to show the required effect according to our calculations (see Fig. 1 (d)). The designed GTI in our model has a refractive index of 1.4737 at around 1.05 µm which is 0.02 higher than one of fused silica which can be achieved doping the silica glass by Germanium. The thickness of the GTI layer at the top of the core is 1.5 times larger than the low index (fused silica) layer. The effect of the designed GTI on the dispersion of the LP_{02} mode can be seen in Fig. 1 (b). This structure resulted a 170 nm negative dispersion slope (from 1005 nm to 1175 nm) and an anomalous group delay dispersion (GDD). This bandwidth is enough to cover the whole range of Yb wavelengths and the structure yields an effective solution for compensating the dispersion of PBG and other fibers. We also plotted in Fig. 2 (b) the loss belonging to different number of high and low index periods around the core and the GTI.

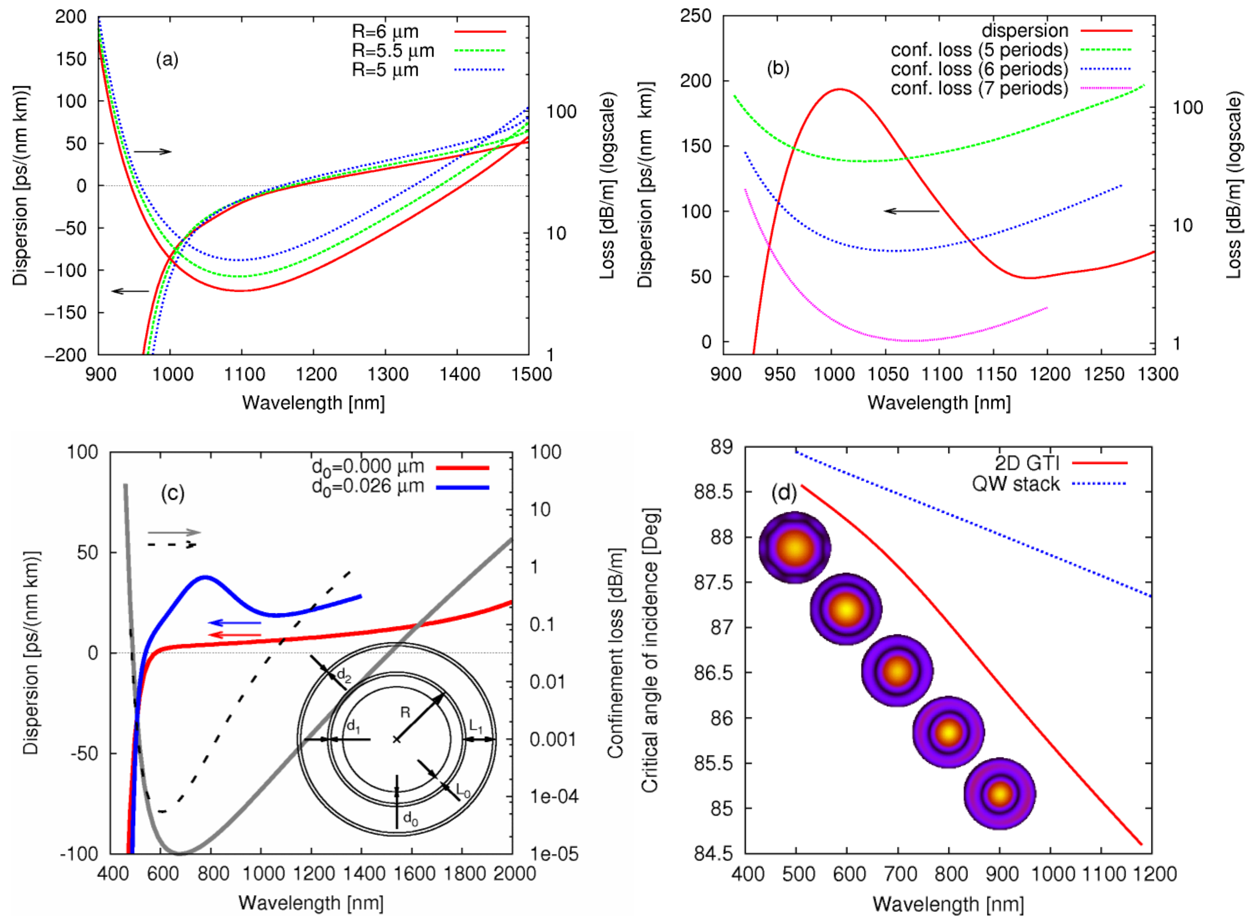

Fig. 1. Results of finite element modeling: (a) dispersion and loss of a solid core Bragg PBG fiber with 5 periods around different core sizes, (b) dispersion and loss properties of a solid core Bragg PBG fiber with a resonant Gires-Tournois layer at the top of the core, (c) dispersion and dispersion compensating HC all-silica Bragg fiber with a partial reflector (d_0=0.026 μm), (d) critical angle of incidence for the presented LP_{02} mode as a function of wavelength.

Using a GTI structure around a HC Bragg fiber is quite elaborate since a layer with slightly higher effective refractive index than the core (air) are hard to fabricate. A partial reflector layer however can also be installed around the core using a very thin silica layer with a spacer to the core wall (see Fig. 1 (c) inset; only two periods are drawn and three periods are simulated). From the theoretical point of view, these two structures are equivalent and have the same physical effect on the dispersion function [3]. The obtained dispersion for a HC all-silica Bragg fiber with and without a partial reflector is shown in Fig. 1 (c). 220 nm wide opposite dispersion slope is obtained around 900 nm (blue curve). We must note that mode anti-crossing events may harm the usable bandwidth of the device if silica struts are presented between the glass layers (detailed study is underway). Analyzing the mode field distributions (Fig. 1 (d)) we may claim that the reversed dispersion slope originates from the GTI effect in the case of this specific 2D GTI Bragg design: the longer the wavelength, the higher the energy stored in the GTI layer.

We reported on our FEM simulations on the dispersive properties of different SC and HC Bragg PBG fiber designs. We have shown that the dispersion slope of SC and HC Bragg PBG fibers can be changed by the addition of a partial reflector layer at the top of the core which design is a 2D equivalent of the 1D thin film Gires-Tournois interferometers. This design results a higher-order mode (HOM) PBG waveguide.

References

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