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Optical limiting in solid-core photonic crystal fibers

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Description
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Optical limiting in solid-core photonic crystal fibers

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Abstract: Optical limiting in solid-core photonic crystal fibers filled with reverse-saturable absorbers has been observed. A sharp change in limiting threshold was found for materials in the fiber holes with refractive indices near \( n = 1.44 \).

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Photonic crystal fibers (PCF) have tremendous potential for applications due to the inherent flexibility in engineering of their optical properties [1]. Recently, the evanescent field in the propagating mode of a PCF was used to detect the linear absorption of a material in the fiber holes [2], thus opening the door for a unique means to achieve optical limiting in PCF. We have observed optical limiting in solid-core PCF and found a sharp change in limiting threshold for materials in the fiber holes with refractive indices near \( n = 1.44 \).

The PCF under investigation were composed of a solid silica glass core \((n_d = 1.459)\) surrounded by an array of holes that were filled with solutions of bis[tri-(n-hexyl)siloxy] silicon naphthalocyanine (SiNc) which is a well-known reverse-saturable absorber (RSA). The PCF were approximately 1.8cm in length, the holes were approximately 1.4\( \mu \)m in diameter, and the pitch (center-center hole spacing) was approximately 3.2\( \mu \)m. SiNc was dissolved in mixtures of diethyl succinate (DES) \((n_d = 1.444)\) and dioctyl phthalate (DOP) \((n_d = 1.485)\) producing 3.25 x 10\(^{-4}\)mol/L concentration solutions with refractive indices slightly lower than that of the silica glass. Waveguiding was achieved because the matrix surrounding the solid core had an effective refractive index smaller than the solid core (see Figure 1). Optical pulses with a wavelength of 532nm and a 7ns duration were produced by a frequency-doubled Nd:YAG laser and coupled into the solid core of the PCF.

Figure 2 shows the measured relative transmission of the PCF as a function of energy coupled into the propagating mode. The input energy that corresponds to a relative transmission of 80% is approximately 4.7\( \mu \)J for a

![Fig. 1: False-color image showing the intensity distribution at the PCF output.](image-url)
hole refractive index of 1.438 (blue data points) and 480nJ for a hole refractive index of 1.447 (pink data points). It is clear that small changes in refractive index within the holes of the fiber can lead to significant changes in the observed optical limiting response. It is also apparent that a smaller refractive index difference between the glass and the holes leads to an enhanced optical limiting response. These observations can be understood through a consideration of the evanescent electric field of the guided mode.

The evanescent field extends out of the solid core into the surrounding holes where it interacts with the SiNc solutions. The distance that the evanescent field extends outside the solid core and the amount of energy carried by the evanescent field is extremely sensitive to the refractive index difference between the solid core and the surrounding holes. If the holes are filled with a solution that exhibits nonlinear absorption, then the guided mode will be limited. Figure 3 shows theoretical calculations of the percentage of power carried by the fraction of the optical mode in the holes of the PCF (blue curve) and the leakage loss (red curve) as a function of the refractive index of the solvent in the holes. The fraction of the optical mode in the holes is predicted to increase by approximately a factor of 3 when the refractive index of the solvent increases from 1.44 to 1.45. This trend is in qualitative agreement with the observed change in threshold energy for optical limiting. However, the limiting threshold was measured to decrease by nearly an order of magnitude when the refractive index of the material in the holes increased from 1.438 to 1.447. This sharp change in the limiting threshold may be due to differences in energy distribution within the holes at each refractive index.

In conclusion, we report the first observations of optical limiting in solid-core PCF. A sharp change in limiting threshold was observed when the fiber holes were filled with nonlinear materials that had refractive indices near n = 1.44. This is consistent with multipole method calculations of the mode profiles and mode energy distributions within the PCF.


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