Method for nonlinear refractive index estimation in photonic crystal fibers

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Photonic crystal fibers (PCFs) are a unique type of optical fiber that have a periodical microstructure region in the center through which light propagate [1]. During the manufacturing of these optical fiber, it is possible to adjust parameters of the microstructures regions, such as core diameter, air hole diameter and pitch [2]. This makes it possible to produce highly nonlinear solid-core PCF with a very small mode field diameter, which are perfect nonlinear media for nonlinear optics research. The nonlinear refractive index n_2 is the material parameter used to describe the strength of phenomena caused by third-order nonlinearity. Therefore, investigating this parameter is one of the key task in nonlinear optics. To estimate the nonlinear refractive index, several techniques have been shown, such as Z-scan [3] and methods based on either four-wave mixing [4], self-phase modulation [5] or cross-phase modulation [6] phenomena. Unfortunately, Z-scan allows to estimate n_2 not of the PCF itself, but of the material perform from which it is made. However, the nonlinear properties of the material can change during the manufacturing process of the optical fiber. The other mentioned methods allow a qualitatively good estimation of n_2 only when pump wavelength is close to the zero-dispersion wavelength (ZDW) of the optical fiber.

In this report, a new method for estimating the nonlinear refractive index of polarization-maintaining PCF using phase shift between orthogonal polarization modes is presented. The Yb:KGW “Flint” oscillator, generating pulses at a wavelength of 1.04 µm, whit a repetition rate of 76 MHz and a duration of 50 fs was used as a pump source for nonlinear spectrum broadening. During the experiment, the nonlinear response of PCF material was estimated by measuring the rotation of the output light polarization states. A 14.5 cm length highly nonlinear polarization-maintaining solid-core PCF was used, with a ZDW of approximately 1087.4 nm ± 10 nm (similar for both polarization modes). The PCF core diameter and pitch were 4.8 µm and 3.25 µm, respectively. An optical attenuator positioned before PCF was employed to adjust the energy of the pump pulses. It consisted of a half-wave plate and a Brewster-type polarizer. Another half-wave plate, placed after the attenuator, rotated the polarization plane of the light directed into the PCF. During the experiment, the average power of the light emitted from the PCF was measured by employing a power meter positioned after the Glan-Taylor prism, which was used as an analyzer. These measurements were performed by changing the pump pulse average power and gradually rotating the analyzer. Additionally, spectra measurements of the light coming out from the PCF at different pump pulse average power were performed.

We discuss results, when the polarization plane of the light directed into the PCF was rotated to a position between the diagonal and fast axis of the fiber, as well as to a position between the diagonal and slow axis of the fiber. During numerical simulation, the phase difference between orthogonal polarization modes was determined by approximating experimentally measured normalized average power after Glan-Taylor prism dependence on Glan-Taylor prism orientation at different pump pulse average power with Eq. 1.

$$\hat{P}_{GT} = \frac{P_{GT}}{P} = \frac{1}{2}\left(1 + b\cos(2\alpha) + \sqrt{1-b^2}\sin(2\alpha)\cos(\Delta\Phi_l + \kappa P)\right) \tag{1}$$

Here P is average pump pulse power, $b = \Delta P/P$ where $\Delta P = P_x - P_y$, α is Glan-Taylor prism orientation angle. The phase difference consists of linear and nonlinear phase differences $\Delta\Phi = \Delta\Phi_l + \Delta\Phi_n = \Delta\Phi_l + \kappa P$ The power after Glan-Taylor (Eq. 1) prism depends not only on the α but also on the nonlinear phase difference $\Delta\Phi_n$. The coefficient κ was determined from slope coefficient of $\Delta\Phi$ dependence on the pump power in the PCF (Fig. 1) and then it is possible to calculate the nonlinear refractive index $n_{2,1221}$using Eq. 2.

$$n_{2,1221} = \frac{\kappa}{b}\frac{\lambda_0}{z}\left(\frac{2}{\pi}\right)^{1/2} v_L S\tau \tag{2}$$

Where λ_0 is pump pulse central wavelength, $v_L$is laser pulse repetition rate, S is cross-sectional area of the PCF core, and τ is pulse duration at $1/e^2$ level. When birefringence of the PCF is very small, the calculated nonlinear refractive index tensor component $n_{2,1221}$ is essentially the nonlinear refractive index n_2. The presented experimental technique will be a reliable tool to estimate nonlinear refractive index in optical fibers.

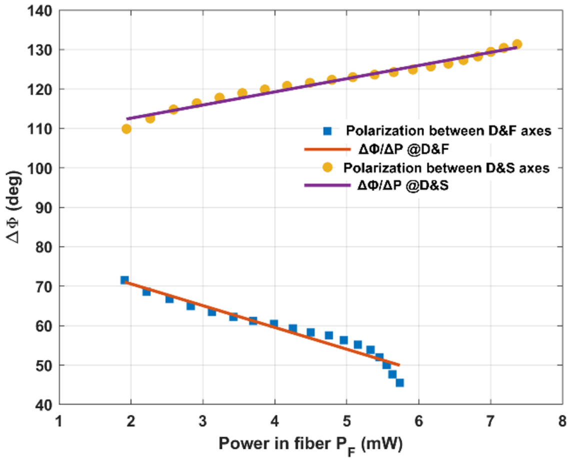

Fig. 1: Phase difference ΔΦ dependence on the pump power in PCF when the polarization plane of light was oriented approximately between the diagonal (D) and fast (F) axes, and between the diagonal (D) and slow (S) PCF axes.

References:

[1] Philip St. John Russel "Photonic-crystal fibers," J. Lightwave Technol **24,** 4729-4749 (2006).

[2] W. Wang, Z. lun Liu, Y. Han. L. tian Hou, "Novel design of highly nonlinear photonic crystal fibers with flattened dispersion", Optoelectron. Lett. **8,** 363-367 (2012).

[3] S. R. Flom, G. Beadie, S.S. Bayya, B. Shaw, J. M. Auxier, "Ultrafast Z-scan measurements of nonlinear optical constants of window materials at 772, 1030 and 1550 nm" Appl. Opt. **54,** F123-F128 (2015).

[4] P.S Andre, J. L. Pinto, "Simultaneous measurement of the nonlinear refractive index and chromatic dispersion of optical fibers by four-wave mixing, Microw. Opt. Technol. Lett. **34,** 305-307 (2002).

[5] Y. Namihira, A. Miyata, N. Tanahashi, "Nonlinear coefficients measurements for dispersion shifted fibers using self-phase modulation method at 1.55 µm", Electron. Lett. **30,** 1171-1172 (1994).

[6] T. Kato, Y. Suetsugu, M. Nishimura, "Estimation of nonlinear refractive index on various silica-based glasses for optical fibers, Opt. Lett. **20,** 2279-2281 (1995).