

Measurement of Higher Order Dispersion in a Photonic Fiber Using Spectral Interferometry

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Abstract. We measured the dispersion of a 37 cm long photonic fiber up to fifth order by the use of the stationary phase point, the cosine function fit and the Fourier transform methods. The highest precision for the dispersion coefficients was obtained by the Fourier transform method. At visual dispersion control of the fiber the stationary phase point method proved to be the most useful one.

Keywords: photonic crystal fiber, dispersion, spectral interferometry, ultrashort laser pulses.

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INTRODUCTION

Photonic bandgap (PBG) fibers have recently obtained considerable attention since their dispersion coefficients can be tailored in a wide range. Because of the uncertainties of modeling and manufacturing, it is necessary to measure the dispersion of the fibers. Spectral interferometry has proved to be an effective tool for measuring the spectral phase of optical fibers. For evaluating the interferograms the stationary phase point (SPP) [1], the minima-maxima [2], the cosine function fit (CFF) [3] and the Fourier transform (FT) [4] methods are generally used. The coefficients of the Taylor-expansion of the spectral phase function are often used to characterize the dispersion of optical elements. So far the dispersion coefficients of optical fibers have been measured only up to third order dispersion (TOD) term. Contrary to conventional optical fibers, however, the forth (FOD) and the fifth order (QOD) dispersion terms of the PBG fibers may also be significant. In this work our aim is to investigate which spectral interferometric method provides higher order dispersion terms (TOD, FOD, QOD) of a PBG fiber with the highest precision. For this purpose we compare the precision of the SPP, CFF and FT method when a 37 cm long PBG fiber is the sample.

EXPERIMENTAL

The experimental setup (Fig. 1) is the combination of a Mach-Zehnder interferometer and an Ocean Optics spectrometer. The interferometer is illuminated by a Ti:sapphire oscillator, and the PBG fiber to be studied is inserted in one arm. To produce proper interferograms for the various evaluation methods, the delay τ between

the reference and the sample pulses is adjusted by changing the length of the reference arm.

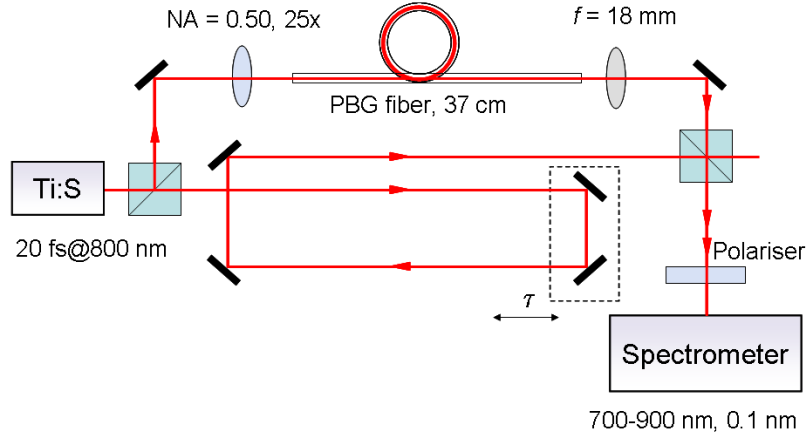


FIGURE 1. Experimental setup

EVALUATION OF THE INTERFEROGRAMS

Cosine function fit method

To measure the dispersion coefficients of the PBG fiber a phase modulated cosine function was fit to the normalized spectrally resolved interferogram [3]. In case of the significant TOD the fit is more sensitive to higher order terms, if the delay is adjusted in a way that double SPPs [5] appear in the interferogram. It can be seen well that the use of the fifth order polynomial in the argument of the cosine function gives much better fit than the fourth order polynomial (Fig. 2.a,b).

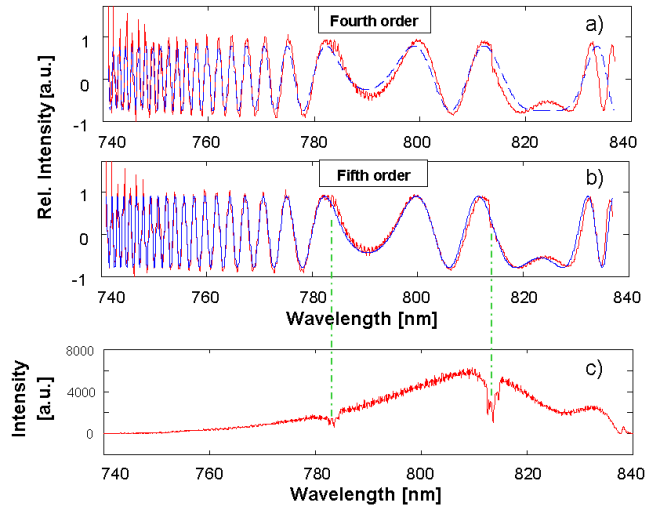


FIGURE 2. Normalized spectrally resolved interferogram of the PBG fiber (red line) with the fitted curves (blue lines) obtained from the (a) fourth and the (b) fifth order polynomial regression (c) The spectrum of the sample pulse after the PBG fiber.

The spectral transmission of the PBG fiber shows resonances at 785 nm and 815 nm (see Fig. 2.c). In these regions the spectral phase function has sharp peaks. Although a small difference between the normalized interferogram and the fitted curve can be seen in the vicinity of the resonance (see Fig. 2.b), this method is not suitable for measuring such type of irregularity.

Stationary phase point method

The group delay caused by the PBG fiber was measured by determining the spectral position of the stationary phase point [1] in 30 interferograms recorded at different delays in the reference arm. Figure 3 shows the difference between the measured and fitted group delay function. The SPP method is also sensitive to higher order dispersion terms, since the difference between the measured and the fitted values are significantly smaller at the use of the fourth order polynomial.

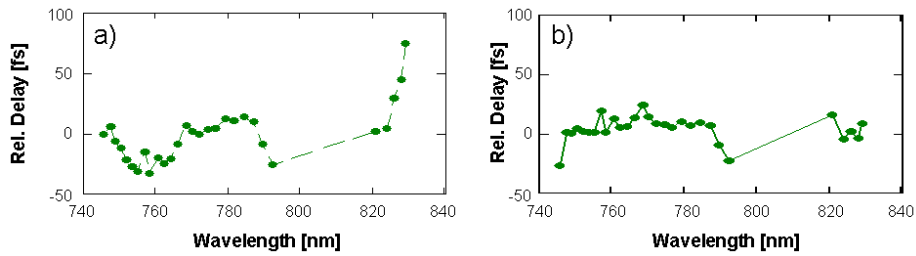


FIGURE 3. The difference between the measured (points) and the fitted (line) group delay function when (a) a third and (b) a fourth order polynomial were fitted to the measured values.

The movement of the SPP changes in the vicinity of the resonances of the fiber, however, the poor wavelength resolution does not allow measuring the peaks in the spectral phase in this region.

Fourier transform method

The spectral interferograms were also evaluated by the use of the Fourier transform procedure [4]. The result of the evaluation procedure is the spectral phase function, to which a fourth and a fifth order polynomial was fitted. Figure 4 shows the phase difference between the measured and the fitted spectral phase function.

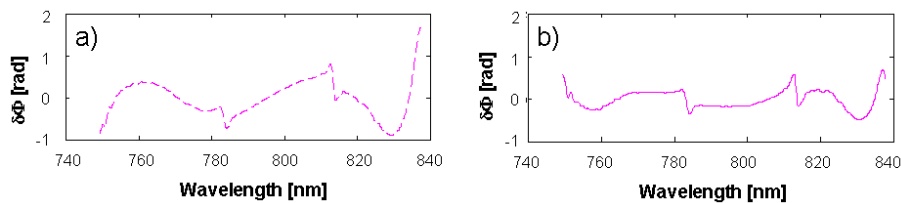


FIGURE 4. The difference between the measured and the fitted values of the spectral phase when (a) a fourth and (b) a fifth order polynomial were fitted.

The FT method proved to be the most precise one, since it provided the dispersion coefficients with the highest accuracy (Table 1). When the fifth order polynomial is fitted, even the sharp peaks of the spectral phase can be seen well (Fig. 4.b).

TABLE 1. Measured dispersion coefficients of the optical system consisting of the PBG fiber and the two lenses. The values refer to 800 nm.

Dispersion terms	Cosine Function Fit Method	Stationary Phase Point Method	Fourier Transform Method
GDD (fs ²)	3680 ± 45	3710 ± 260	3670 ± 30
TOD (fs ³)	1.28·10 ⁵ ± 3.1·10 ³	1.33·10 ⁵ ± 4.5·10 ³	1.25·10 ⁵ ± 2.3·10 ³
FOD (fs ⁴)	-1.94·10 ⁶ ± 7.7·10 ⁴	-1.94·10 ⁶ ± 3.4·10 ⁵	-1.89·10 ⁶ ± 6.0·10 ⁴
QOD (fs ⁵)	2.1·10 ⁷ ± 1.5·10 ⁶	1.9·10 ⁷ ± 5.3·10 ⁶	2.2·10 ⁷ ± 1.3·10 ⁶

SUMMARY

The precision of the dispersion coefficients is the highest at the Fourier transform method (Table 1). The FT method can also determine the spectral phase even in the vicinity of the resonance of a PBG fiber. Each method is sensitive to higher order dispersion terms, however, at visual dispersion control the SPP method is the most useful one.

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