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PHOTONICS AND NANOSTRUCTURES
Fundamentals and Applications

Photonics and Nanostructures – Fundamentals and Applications 10 (2012) 594–601

www.elsevier.com/locate/photonics

Femtosecond pulse compression in a hollow-core photonic bandgap fiber by tuning its cross section

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Received 3 February 2012; received in revised form 5 May 2012; accepted 8 May 2012
Available online 19 May 2012

Abstract

We present a numerical study of soliton pulse compression in a seven-cell hollow-core photonic bandgap fiber. We analyze the enhancement of both the compression factor and the pulse shape quality of 360 nJ femtosecond pulses at the wavelength of 800 nm by tuning the cross section size of the fiber. We use the generalized non-linear Schrödinger equation in order to modeled the propagation of light pulses along the fiber. Our numerical results show that output compressed pulses can be obtained, in a propagation length of 31 cm, with a compression factor of 5.7 and pulse shape quality of 77% for a reduction of 4.5% of the cross section size of the fiber. The predicted compression factor is 3 times larger than that experimentally obtained in such propagation length of the pulse in a hollow-core photonic bandgap fiber.

MSC : 78A60; 78A25

Keywords: Hollow-core fiber; Pulse compression; Soliton

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1. Introduction

Non-linear optical effects in hollow-core photonic bandgap fibers (HC-PBGFs) are an active research topic [1]. These fibers allow the propagation of light in an air core and have the property that their guided modes are only permitted for a range of wavelengths that are within the photonic bandgap of the cladding. Recently, HC-PBGFs have been used to deliver and compress high-intensity pulses due to the nature of their air core, which presents low non-linearity. These characteristics make HC-PBGFs efficient non-linear tools to be used as soliton fiber compressors [2,3]. In these fibers optical pulses propagate in the anomalous group velocity dispersion (GVD) regime of the fiber, in such a way compression takes place due to an interplay between the effects of self-phase modulation (SPM) and GVD. The compression factor depends on the peak power of the pulse which, in turn, determines the soliton order [4].

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http://dx.doi.org/10.1016/j.photonics.2012.05.007

Several research groups have made important advances both experimentally and theoretically in the understanding of soliton formation in HC-PBGFs [5–7]. Pulse compression is among the phenomena involving the soliton propagation in HC-PBGs and it is the main subject of this work. For instance, Ouzounov et al. reported an experimentally soliton compression of megawatt peak-power pulses in Xe-filled HC-PBGFs [2]. They used a 24 cm fiber and successfully compressed a 120 fs input pulse into a 50 fs pulse. They stated that the third-order dispersion (TOD) of the fibers degraded the optimal compression ratio and prevented the formation of shorter pulses. Besides, they showed numerically that picosecond input pulses could be compressed to less than 100 fs. Gérôme et al. [3,8] also reported the existence of soliton compression in HC-PBGFs. They used 8 m of tapered fiber and obtained an output pulse of 90 fs from a 195 fs input pulse at a wavelength of 800 nm. Lægsgaard and Roberts studied numerically the soliton formation during the compression of chirped gaussian pulses in HC-PBGFs [9,10]. In particular, they investigated the dependence of soliton duration on the chirp, power of the input pulse and dispersion slope of the fiber. They concluded that compression of input pulses of several picoseconds of duration and sub-megawatt peak power can lead to a formation of solitons with ∼ 100 fs of duration. Moreover they also concluded that TOD is a crucial parameter that prevents the formation of shorter soliton pulses. Welch and collaborators [11] demonstrated the soliton effect compression of picosecond input pulses in a seven-cell hollow-core tapered fiber with a length of 35 m. They could achieve a temporal compression factor of 12. Gorbach and Skryabin studied the dynamics that accompany the solitons propagation in the femtosecond regime in these fibers. Their model includes nonlinear responses of silica in the cladding and of the air-filled core [12]. Meng et al. [13] numerically studied the soliton formation during the compression of unchirped femtosecond pulses in HC-PBGFs by using the Gorbach–Skryabin model. They concluded that the combined effects of intrapulse stimulated Raman scattering and negative TOD can form shorter pulses than those formed by only considering intrapulse stimulated Raman scattering.

In this paper, we perform a numerical study of the compression of femtosecond unchirped pulses in HC-PBGFs by solving the generalized non-linear Schrödinger equation. Unlike the previous numerical works listed above, we study numerically the effects of tuning the cross section size of a HC-PBGFs on the modal parameters in order to have a fiber structure which promotes pulse compression. Our study includes an analysis of the pulse shape quality of the compressed pulse as it propagates along the fiber. All the studied fiber structures have their fundamental guided mode at 800 nm. In the model, we consider the contributions of air and silica to the non-linear parameter, the interplay of the effects of second- and third-order dispersion and the intrapulse stimulated Raman scattering. The paper is organized as follows: in Section 2, the characteristics of the fiber as well as the theory and the details of the numerical model to obtain the modal parameters and propagation of the pulse are presented. In Section 3 we present results for pulse compression and, finally we give conclusions in Section 4.

2. Theory and numerical modeling

The modeled fiber structure consists of a triangular lattice of rounded hexagonal holes and an air core formed by seven-missing hexagonal unit cells (seven-cell fiber) as it is shown in Fig. 1. The fiber transmission behavior is ruled by its geometry parameters, such as the hole diameter, d, the pitch, Λ, the diameter of curvature at the corners, d_c, the circle diameter, d_p, the silica ring thickness, t, and the core size, R_c. The core design of the fiber has a direct impact on the modal properties of the fiber. In this way the rounded hexagonal holes in the structure of the fiber were chosen mainly for two important reasons: firstly, the shape of the holes is typically that founded in commercial fibers and, secondly, the rounded hexagons increase the width of the band transmission of HC-PBGFs [14]. We find the fundamental guided mode and its respective effective refractive index for HC-PBGFs with different cross section sizes. Once the effective refractive index of the mode has been obtained, we compute their corresponding non-linear and dispersion

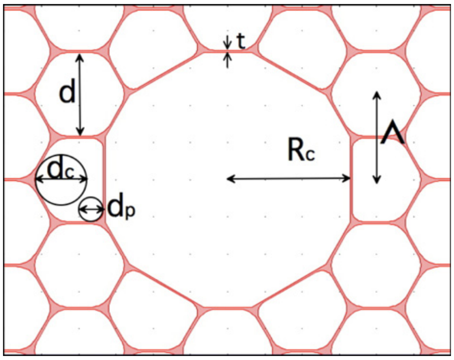

Fig. 1. Cross section of the modeled HC-PBGF. The colored (white) areas indicate silica (air) regions.