Optics Communications 401 (2017) 75–79

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Efficient generation of linearly polarized Cerenkov radiation in a photonic crystal fiber with suspended rectangle core

Xing Luo [a], Lan Cheng [a], Jinggang Peng [a], Luyun Yang [a], Nengli Dai [a], Haiqing Li [a], Jinyan Li [a,b,*]

[a] Wuhan National Laboratory of Optoelectronic, Huazhong University of Science and Technology, Wuhan 430074, China
[b] School of Optical and Electronic Information, Huazhong University of Science and Technology, Wuhan 430074, China

ARTICLE INFO

Keywords:
Cerenkov radiation
Photonic crystal fiber
High efficiency
Linearly polarized

ABSTRACT

We report high efficiency linearly polarized Cerenkov radiation (CR) generation in a photonic crystal fiber with suspended rectangle core. The frequency up-conversion via the Cerenkov radiation upon pumping of Yb-doped femtosecond fiber laser is discussed in details. Experiment results show that the output spectrum contains, besides the infrared supercontinuum, intense green Cerenkov radiation around 536 nm, which carry about 43% of the pump energy at best. The influence of the high birefringence and dispersion character on the Cerenkov radiation generation is discussed. Experiment and simulation results indicate that the rectangle core photonic crystal fiber acts like single-mode single-polarization fiber at the pump wavelength. Only the pulse component along with the slow axis could be confined in the rectangle core well and release Cerenkov radiation efficiently. The Output green Cerenkov radiation is also demonstrated to be linearly polarized. Experiments results agree well with the theoretical predictions.

1. Introduction

Cherenkov radiation (CR) generation in optical fiber is a kind of phenomenon that optical soliton propagating in the anomalous dispersion regime release CR in normal dispersion regime. It has been confirmed that, a resonance condition would be satisfied if the optical soliton and the CR have the same phase in the fiber. And then, the CR could coupling with the soliton and obtain enhancement coherently during the propagation. This phenomenon have been theoretically studied [1], and experimentally demonstrated in recent years [2–7]. Due to controllable dispersion of the photonic crystal, the resonance condition for CR generation could be satisfied in the visible region [8,9]. It provides an excellent way to obtain visible light pulse, which is difficult to obtain directly in fiber, upon the pumping of infrared pulse [9–12]. Newly-developed gas-filled hollow-core photonic crystal fibers providing pressure-adjustable dispersion are also demonstrated to be resultful for CR and supercontinuum generation [13,14]. This fiber-based CR generation has found many applications in many fields such as biophotonics, carrier envelope control of ultra-short pulses and so on [15]. However, many previous experiment results show narrowband spectra and relatively low conversion efficiency of visible CR generation upon pumping of infrared short pulses which is available from mode-lock laser. Many efforts have been made to obtain broad and high efficiency CR in the visible region. For example, Tartara et al. realized high efficiency (~24%) CR generation, but with relatively narrow bandwidth (~10 nm) [10]. In fact, the parameters of the pump pulse, such as pulse width, central wavelength, pulse energy and so on, have great impact on the CR generation. Guoqing Chang et al. did much work about it [16,17]. They realized highly efficient, broadband CR in the visible region with a threshold energy less than 100 pJ and a tuning range over 100 nm upon pumping of a Ti:sapphire laser which deliver 10 fs pulses. Using mode locked Ti:sapphire laser as the pump source for high efficiency CR generation have advantages of narrow pulse width and high peak power. Meanwhile the central wavelength of the mode locked Ti:sapphire laser is close to the visible region which also benefit for high efficiency CR generation [4,11,18–21]. But mode locked Ti:sapphire laser suffers from some disadvantages as well. For instance, mode locked Ti:sapphire laser is bulky and very pensive; It is hard to be maintained because of its complex structure. On the contrary, mode-locked Yb-doped fiber laser is cheap relatively and hopeful to realize compact all-fiber CR generation in the visible region. So realizing high efficiency visible CR generation upon pumping of mode-locked Yb-doped fiber laser is very meaningful. Researchers found a way to obtain supercontinuum-free high efficiency CR generation in the visible region, i.e., pump high nonlinear photonic crystal fibers (PCF) with relative

* Corresponding author.
E-mail address: ljy@mail.hust.edu.cn (J. Li).

http://dx.doi.org/10.1016/j.optcom.2017.05.008
Received 22 January 2017; Received in revised form 16 April 2017; Accepted 5 May 2017
Available online 30 May 2017
0030-4018/

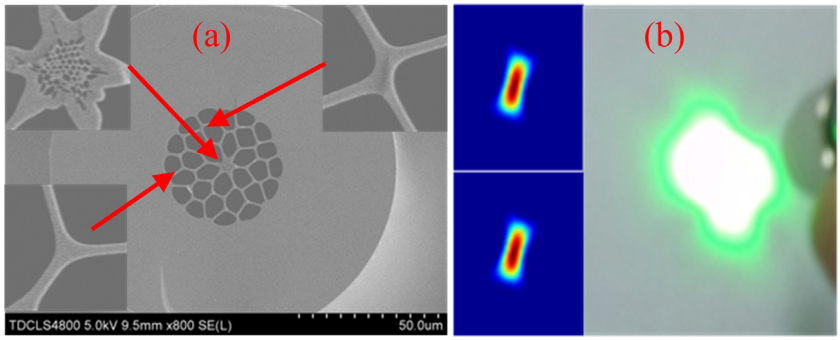

Fig. 1. (a) Scanning electron microscope (SEM) image of the PCF. The insets are the enlarged images for certain positions. (b) Simulated fundamental modes in the rectangle core and the output spot in the experiments.

large negative GVD parameter β_2. However, most experiments do not take the polarization property of the CR into consideration which may play an important role in some applications.

In this paper, we investigate high efficiency linearly polarized CR generation in a photonic crystal fiber with suspended rectangle core upon pumping of 150 fs mode locked Yb-doped fiber laser. The pump-to-CR conversion efficiency in fundamental mode reaches up to about 43% with the bandwidth of about 56 nm at maximum. This is an amazing results achieved upon pumping of Yb-doped fiber laser. The influence of the high birefringence and dispersion characters on the CR generation is discussed. Experiment and simulation results indicate that the rectangle core PCF acts like single-mode single-polarization fiber at the pump wavelength. Only the pulses component along with the slow axis could be confined in the rectangle core well and release CR efficiently. Output green CR is demonstrated to be linearly polarized. Experiment results agree well with the theoretical predictions. The high efficient and linearly polarized CR generated using easily obtained mode locked Yb-doped fiber laser will find many applications. The suspended rectangle core in the PCF offers unique characteristics such as high birefringence, high nonlinear coefficient, single mode in wide range wavelength, dispersion. The influence of these characteristics on the nonlinear process is discussed in details.

2. Fiber fabrication and properties

The homemade PCF used in the experiments was fabricated by the versatile stack-and-draw procedure. Fig. 1(a) shows the scanning electron microscope (SEM) image of the PCF and the insets are the enlarged images for certain positions. The secondary sleeving draw-stretching technique was adopted to draw this fiber. Some deformation occurred in the drawing and silica islands between the big air holes formed some suspended cores with various shapes. The final fiber contains a series of irregular triangle and rectangle cores with high air-fill fraction. The insets of Fig. 1(a) are a typical triangular silica island and a special rectangle silica island. Actually, we would found that in our experiments, the laser beam was focused into the special rectangle silica island which forms a unique suspended rectangle core. The mode and dispersion properties of the PCF are calculated using a finite difference frequency domain (FDFD) method. The mode properties of the fiber are calculated basing on the real structure obtained from the scanning electron micrographs. Therefore the deformations of the structure have been taken into account. Fig. 1(b) shows the two simulated orthogonal polarized modes of the rectangular core. We find the rectangular core only support fundamental mode. The size of the rectangle core is about 1.4 μm × 3.0 μm. The image at the right side of Fig. 1(b) is the photograph of the output spot in our experiments, and it shows nearly rectangular shape, which is in good agreement with the simulation. We can confirm that, in our experiments, the efficient CR is generated in this suspended rectangle core. Meanwhile, the far-field images of the output also indicate that generated CR propagates in the fundamental mode.

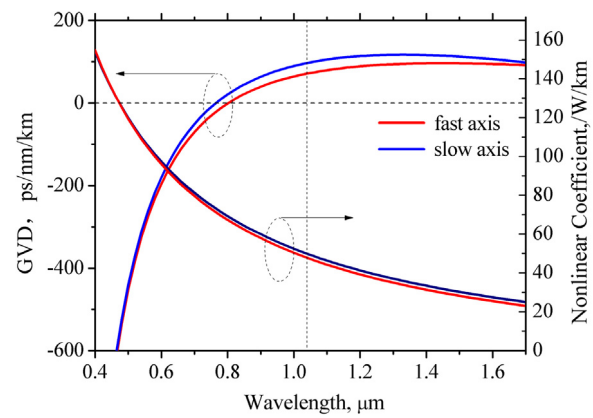

Fig. 2. Calculated GVD curves and nonlinear coefficients for the two non-degenerate orthogonal fundamental modes of the PCF (red line represent fast axis mode and blue line represent slow axis mode). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Fig. 2 shows the calculated GVD curves and nonlinear coefficients of the two non-degenerate orthogonal fundamental modes of the suspended rectangle core. The horizontal dashed line indicates the zero dispersion and the vertical dashed line indicates the central wavelength of pump laser. The zero-dispersion wavelengths (ZDWs) of the two non-degenerate orthogonal fundamental modes are 765 nm and 802 nm respectively. The peculiar suspended rectangle core is very small with a size of about 1.4 × 3.0 μm and the surrounding air holes are very large. These result in high nonlinear coefficient. Actually, the nonlinear coefficients at 1040 nm are 48 W^{-1} km^{-1} and 49 W^{-1} km^{-1} for the two non-degenerate orthogonal fundamental modes respectively.

3. Experiments results and discussion

The high efficiency CR generation experiments were performed with a 150 fs Yb-doped large mode area PCF laser amplifier with a 49 MHz repetition rate at 1040 nm. The output pulses of the femtosecond laser are linearly polarized and a half wave plate was used to adjust the polarization direction of the pump pulse. We coupled the pump pulses into the rectangle core with the help of a micro-objective with a coupling efficiency of ~33%. The output light of the PCF was coupled into a high-resolution spectrometer (ANDO 6315A) using an achromatic lens to record spectra

Fig. 3 shows the spectra evolution as a function of the pump power in 1 m PCF. As the central wavelength of the pump pulse located in the deep anomalous regime, the nonlinear process is well-known for the characteristics of solitons formation and CR generation. The balance between dispersion and self-phase modulation results in the formation of high-order solitons. And then higher order soliton will split into