



Few cycle pulse compressor based on hollow-core fiber waveguide results in pulse tails

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ABSTRACT

The hollow-core fiber structure influence of few-cycle pulse compressor on pulse contrast is investigated experimentally. It is found that a periodic structure of pulses at the tail of the main pulse extended hundreds of picoseconds away. It can be due to the fiber structure and could be eliminated by modifying the structure.

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1. Introduction

Optical pulse compression through hollow-core fibers (HCFs) has been developed as a powerful technique for generating intense few-cycle pulses in the visible and near-infrared spectral range [1,2], which is driven by the requirement of generating isolated attosecond pulses via high harmonic generation (HHG) [3]. The hollow core structure has the advantages of supporting large energies as well as optimizing the transverse profile, which is very important in high field research. For these reason, the hollow fiber has also been used in pulse contrast enhancement [4], in which a technique based on nonlinear ellipse rotation in a hollow waveguide filled with a noble gas to achieve high pulse contrast for a range of relatively high energies was proposed. In their experiment, the pulse contrast has been improved from 10^1 to 10^4 , and theoretical simulations show that a prepulse 6 orders of magnitude lower than the main peak will be reduced to 11 orders of magnitude, more than that is necessary for the ultra-intense laser system.

Due to the importance of an extreme clean intense pulse [5], various other ways have been proposed to improve the pulse contrast [6–10]. Despite the difference of implementations, they make use of nonlinear phenomena of interaction between laser pulse and bulk medium. The higher the order of nonlinearity is, the higher the contrast will be in principle. However, this high contrast is usually accompanied by the deterioration of transverse profile induced by self-focusing. Therefore,

reshaping the transverse profile while preserving the high contrast is a key step. In this paper, we experimentally study the influence of hollow-core fiber structure on pulse contrast, since this structure can select the fundamental mode and optimize the transverse profile after the pulse passes through it. It is found that a periodic structure of pulse train at the tail of the main pulse extending hundreds of picoseconds away appears after the pulse passes the fiber. Detailed analysis suggests that it is caused by the energy exchange between inner core and fiber clad and this effect could be eliminated by introducing roughness to the outer surface.

2. Experimental results and discussion

In the experiment, the laser source is a commercial laser system (Spectro-Physics) with a regenerative amplification stage, delivering 0.46 mJ, 48 fs (FWHM) pulses at 1 kHz repetition rate. The hollow-core fiber (Femtolasers) has an inner diameter of 250 μm and an outer diameter of 1.6 mm. It is 1 m long and made of synthetic silica. This fiber is supported on a V-groove aluminum bar and placed in a chamber with Brewster-angle windows at both sides. The chamber is evacuated to below 1 Pa pressure, so that the nonlinear influence induced by gas medium and the mismatch of group velocities between different modes will be minimized. These two factors could also deteriorate the pulse contrast if not suppressed. The pulses are coupled into the fiber with a lens of 1 m focal length. The pulse contrast is measured by a third-order autocorrelator (Sequoia, Amplitude). Fig. 1 shows the contrast profiles before and after passing through the hollow fiber. It is found that at the tail of the pulse there are many small pulses coming out after the fiber. An explanation

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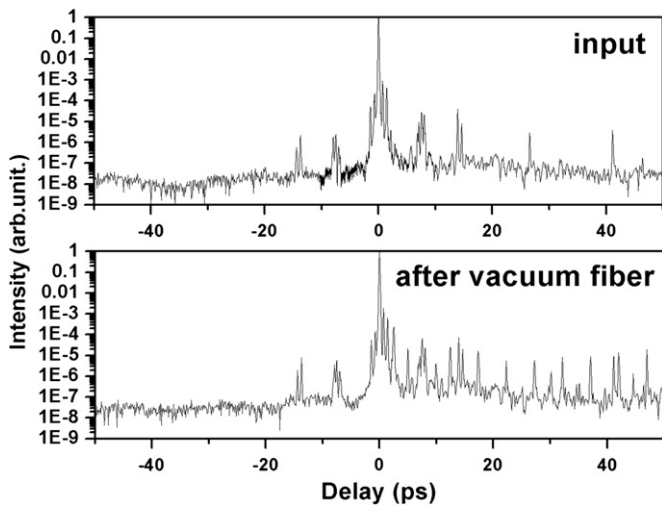


Fig. 1. Pulse contrast profile for input pulse (above) and output pulse (below). After propagating through the fiber, many small pulses appear at the tail of the pulse.

quickly emerges with the picture of geometric rays propagating along different routes in the inner core. However, further analysis reveals something else.

In Fig. 2(a), the input and output show almost overlapping contrast profiles near the peak, except that there is another small peak at about 2.5 ps after the peak. From the couple-mode view, the input beam will excite fundamental and high-order modes when coupled into the fiber. The high-order mode will propagate a little slower than the fundamental mode. Calculations show that the second high-order mode is 5 fs slower than the fundamental mode after 1 m fiber and the third mode is 80 fs slower than the fundamental mode. Passing through the fiber only induces a linear phase shift and waveguide attenuation on the modes under the experimental conditions. However, when we only consider 3 modes and reconstruct the pulse intensity at the end of the fiber and calculate the three order autocorrelation signal, there is no small peak at the tail at all (not shown here). Besides, the periodic pattern in Fig. 2(b) further suggests that it is not induced by mode delay, or geometric rays along different routes in the core.

The structure in Fig. 2(b) shows two characteristics, i.e. it is periodic on the whole with a 5 ps period and the small peaks have almost the same intensity. We attribute this pattern to the energy exchange between inner core and fiber clad because the leaky modes in the fiber will lose energy to the clad and the light in the clad will transmit to the core. Rigorous analysis would be too complex since the

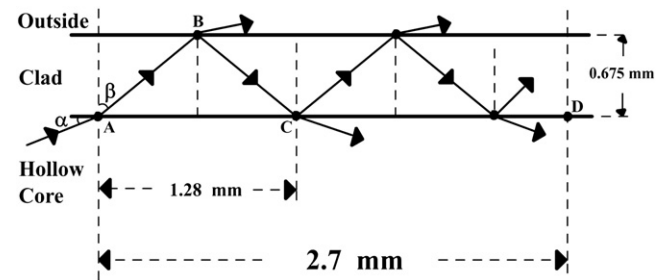


Fig. 3. Light rays propagating along the inner core and clad of the hollow fiber. The clad is treated as a plain waveguide of thickness 675 μm . The light ray from the inner core is grazing-incident on the surface point A and partially transmits into the clad. After reflecting from point B, the ray gets C and partially transmits into the core.

polarization of the laser relative to the inner surface is dependent on the azimuthal angle. Thus we use a simple picture based on geometric rays. This is justified by the fact that the wavelength centered at 800 nm is small compared to the inner core 250 μm and the thickness of the clad 675 μm . We treat the clad as a plain waveguide and the light in the core is grazing-incident on the surface point A as shown in Fig. 3. The angle α is near zero, therefore β is about the total-reflection angle 43.5° with the clad refractive index 1.45. The light ray at point A partially transmits into the clad and propagates along the route ABC, where at point B the light will lose some energy to the outside and at point C part of the energy will return to the inner core. This process repeats until the light ray in the clad dies out for loss of energy.

For the light ray that enters the clad at A and comes back to the core at C, the time it takes to cover the route ABC is about 4.7 ps more than that needed for the route AC in the core. Thus this ray lags behind the main peak in the core by 4.7 ps. When it comes out to the core at C, the main peak has reached to point D and at this point the same energy exchange process will also happen. When the ray entering the clad at D comes back to the core at some farther point, it will join the ray coming to core at point C and thus the energy of the small peak increases. For the ray bouncing back to the clad at point C, it will form another small peak 4.7 ps behind the former peak when part of the energy enters the core next time it meets the interface. This peak will also be enhanced in energy by other rays in the clad. The time interval of 4.7 ps is about the same as that of the small peaks in Fig. 2(b) and the energy accumulation at different points explains the relative equal intensity of the small peaks. The energy efficiency is very low due to the grazing-incidence, so local peak with low power in the core will not form small peaks after it. This can be seen in Fig. 1 that there are no

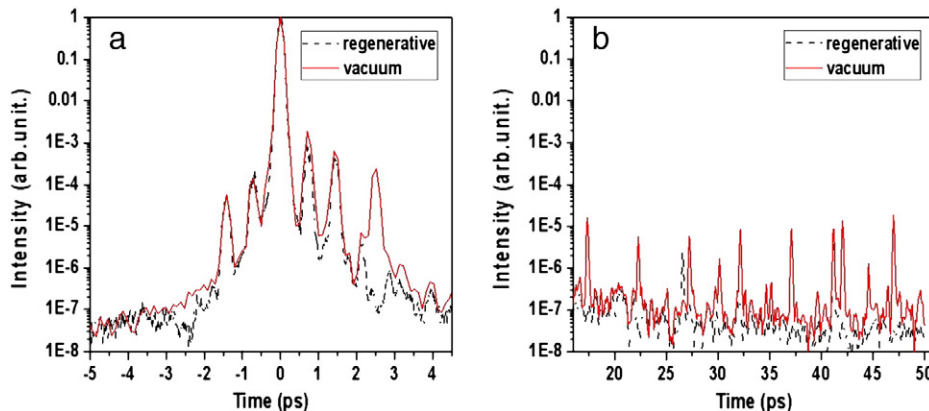


Fig. 2. Pulse contrast profiles near the main peak (a) and far at the tail (b). The black dashed line indicates the input and the red solid line indicates the output.

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