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Laser chirp controlled relativistic few-cycle mid-infrared pulse generation

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Relativistic few-cycle mid-infrared (Mid-IR) pulses are unique tools for strong-field physics and ultrafast science. At present, the traditional nonlinear optical methods can generate tens of GW, several mJ Mid-IR pulses. However, due to the limit of optical crystals, it is still very challenging to directly generate Mid-IR pulses with relativistic intensity (a > 1), few-cycle and long carrier wavelengths (λ > 5 μm) by using nonlinear optical methods. This seriously limits their potential applications in relativistic THz emission, coherent keV X-ray generation, and the zeptosecond waveform generation. Thus, there is an urgent need for a relativistic, long carrier wavelength Mid-IR source for both fundamental and applied research.

In recent years, plasma-based optical modulation has received significant attention, which has been considered for generating relativistic few-cycle Mid-IR pulses[1,2]. However, the energy conversion efficiency is limited to about 1% at long carrier wavelengths (> 5 μm) until now.

In this paper, we propose a scheme to generate relativistic long wavelength few-cycle Mid-IR pulses with higher efficiency by using a negatively chirped laser pulse (NCLP). The NCLP is rapidly compressed longitudinally due to plasma dispersion, and its central frequency downshifted via photon deceleration due to the enhanced laser intensity and plasma density modulations. The Mid-IR pulse is produced with a much higher energy conversion efficiency as compared to the case without chirp. In our scheme, a relativistic few-cycle Mid-IR pulse with a=2.9, the center wavelength of 8 μm, the energy conversion efficiency of 3% can be generated at a propagation distance of about 3 mm. Meanwhile, the laser chirp can control the beam parameters of the generated Mid-IR pulse.

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References
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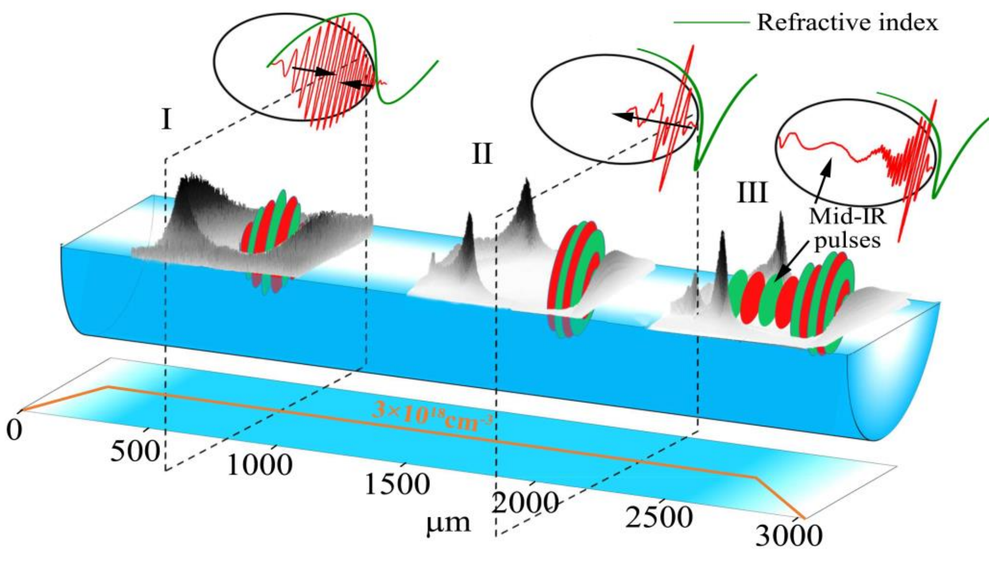

Figure 1. Schematic of laser chirp controlled few-cycle Mid-IR generation. Due to the special curving profile of refractive index of NCLP, the pulse is rapidly compressed longitudinally. As a result, a large number of photons approach the photon deceleration phase, and produce the mid-infrared frequency component, which then slip backwards into the bubble and moves forward together with the bubble. The red curves represent the distribution of laser electric field at on-axis, and the green curves represent the corresponding distribution of refractive index of NCLP. The black arrows denote the photon emission directions relative to the bubble.