Femtosecond hundred-terawatts tunable infrared laser reflection from hydrogen-filled tube via doppler red-shifting

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High power femtosecond laser has extensive applications in physics, material science, chemistry, and many other fields. Specially, the mid-infrared (MIR) light (3~40 μm) has far-ranging utility in molecular "finger-print region" (7~16 μm), infrared spectroscopy, time-resolved imaging of molecular structures, and coherent control of lattice displacement, since its frequency is situated among the range of molecular vibration. It also has an inherent advantage for producing high-order harmonics as the emission efficiency is positively correlated with the quadratic product of laser field intensity and wavelength. High power MIR laser pulse provides a suitable source for the generation of incoherent femtosecond hard X-rays and makes it possible to obtain atto- or even zetta-second X-ray pulses.

Significant progress has been made on optical methods with nonlinear crystals or gases in order to obtain high power coherent mid-infrared pulses. However, technical bottlenecks like lack of high-power pump sources, strong material absorption, and phase mismatch limit the pulse energy to submillijoule. Recently, plasma-based methods without damage threshold limit have been demonstrated to be able to solve this problem. It has been proposed that photon deceleration in wakefield, Doppler upshift from terahertz light, and low frequency radiation by refluxing electrons are feasible to produce mid-infrared sources. Nevertheless, the achieved MIR light energy in the above methods still stays at millijoule-level.

In this letter, a multi-hundred terawatts few-cycle tunable mid-infrared laser pulse generation is proposed for the first time through the optical reflection of an ultra-intense laser interaction with near-critical-density (NCD) plasma-filled tube via Doppler red-shifting effect. The sketch of the laser-plasma interaction and MIR pulse generation process is visualized in Fig. 1(a). According to the Doppler effect, the reflected laser wavelength exceeds that of the incident laser when the incident laser co-propagates with the mirror formed by an electron spike. The scheme can realize the central wavelength of the generated high-power infrared light tunable from 3 μm to 17.5 μm by adjusting the ratio of laser intensity and plasma density in this scheme. In addition, the carrier-envelope phase of the infrared pulse is back-locked to that of the drive laser with a consistent phase shift, and the energy conversion efficiency is as high as nearly 10%. Relying on the worldwide 10 PW laser facilities, we look forward to multi-hundreds-of terawatts mid-infrared laser pulse coming into being.

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References

[1] A. Einstein, Phys. (Leipzig). **11**, 8911 (1905)
[2] S. V. Bulanov *et al,* PHYS-USP+. **56**, 429 (2013)
[3] S. Gu´erin *et al,* Phys. Plasmas. **3**, 2693 (1996)

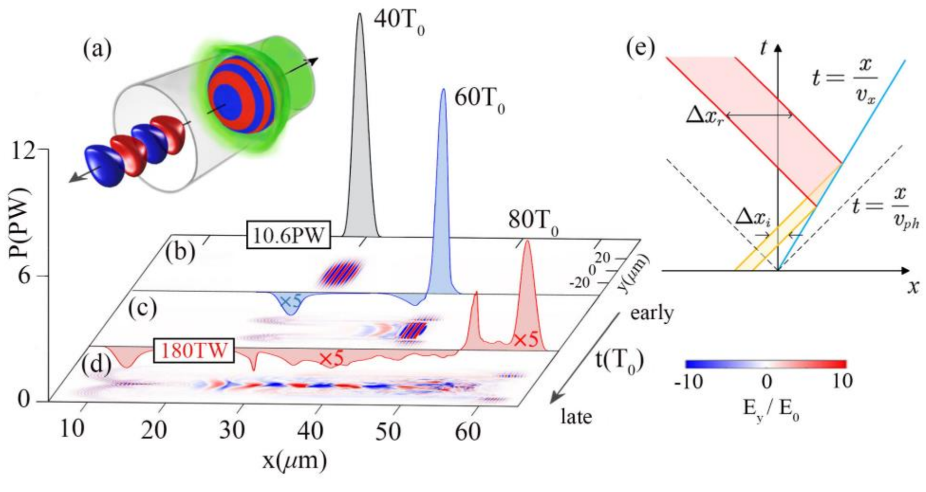

Figure 1. (a) The sketch of the laser-plasma interaction and MIR pulse generation. (b-d) The evolution of the laser electric field projections on x-y plane and the beam power distribution on the shaded area. The intensities of the reflected light in (c) and the whole light in (d) are magnified by five times. By means of 10.6 PW laser pulse, a few-cycle mid-infrared pulse in 180TW is available. (e) The schematic of Doppler effect theory, with the incident light (yellow) reflected by plasma mirror (blue) moving in v_x to infrared light (red).