Studies of Powerful Terahertz Radiation from Laser-Produced Plasmas

Yu-Tong Li[1], Guo-Qian Liao[1], Chun Li[1], Wei-Min Wang[1], and Zheng-Ming Sheng[2]

[1]Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China

[2]Key Laboratory for Laser Plasmas (MoE) and Department of Physics, Shanghai Jiao Tong University, Shanghai 200240, China

***Abstract*—Recently Terahertz (THz) radiation from laser-produced plasmas has attracted much interest since plasmas can work at an arbitrarily high laser intensity. We will present the generation of strong THz radiation from femtosecond and picosecond relativistic laser-plasma interactions. THz pulses with energies up to >200 μJ/sr have been demonstrated. The temporal waveform, polarization, and angular distribution are measured. We find that the radiation depends on the preplasma density scale length. The THz radiation is probably attributed to the self-organized transient fast electron currents formed along the target surface when the plasma density profile is steep, while, the linear mode conversion when a large preplasma is formed.**

I. INTRODUCTION

Terahertz radiation has arose much attention due to increasingly wide applications in material science, medical imaging, communications, *etc*. Though THz radiation can be generated with various ways, it is still a big challenge to obtain strong-field tabletop sources. Plasmas, with an advantage of no damage limit, are a promising medium to generate strong THz radiation. THz radiation from femtosecond laser-induced plasma filaments in low density gases (particularly in air) has been reported. However, the radiation is found to be saturated with increasing pump laser intensity. Recently THz radiation from intense laser-solid interactions has also been demonstrated. In principle, for solid targets the laser intensity can be arbitrarily high. The typical intensity of a multi-terawatt laser system is higher than 10^{18} W/cm^2 (up to 10^{21} W/cm^2 with a Petawatt laser). Using such ultra-intense lasers, strong THz radiation with energies hundreds of μJ is expected. On the other hand, the THz radiation can also be used as a new way to diagnose the interactions.

We have systematically studied strong THz radiation from solid targets driven by relativistic laser pulses. The experiments were carried out using femtosecond and picosecond laser systems, respectively. THz radiation with a pulse energy of tens μJ/sr (driven by femtosecond laser), even hundreds of μJ/sr (driven by picosecond laser) is observed. In this talk, the THz polarization, temporal waveform, angular distribution and energy dependence on the laser energy will be presented. We find that the radiation is dependent on the preplasma density scale length. The THz radiation is probably attributed to the self-organized transient electron current formed along the target surface for a steep plasma density profile and to the linear mode conversion mechanism when a large scale preplasma is present.

II. RESULTS

The experiments were carried out using the Xtreme Light II (XL-II) Ti: sapphire femtosecond laser system at the Institute of Physics, Chinese Academy of Sciences, and the COMET sub-picosecond laser system at the Lawrence Livermore National Laboratory, respectively.

In the interactions of fs laser pulses with a 30 μm thick copper foil, the THz energy is measured to be up to 5.5 μJ in 0.11 sr when the laser energy is 130 mJ. Measured with a modified spectral-encoding detection method, the THz radiation is mainly dominated between 0.3-1 THz. A large incidence angle and steep density gradients are found to be beneficial for the strong THz radiation. In the interactions, due to the confinement of the spontaneous quasi-static magnetic and electrostatic fields at target surface, a net lateral current can be formed along the surface. Two-dimensional PIC simulations clearly show the presence of the surface current. The THz radiation observed may originate from the lateral current.

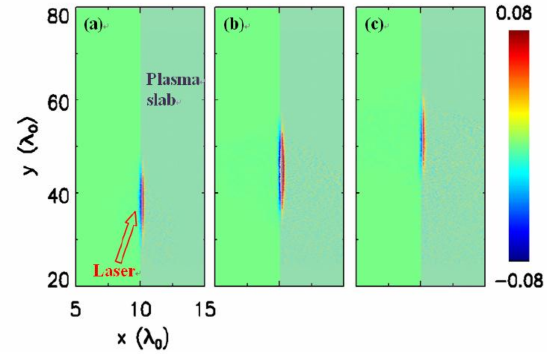

Fig. 1. Simulated surface current distribution when a *p*-polarized laser pulse is incident onto a steep-density-gradient plasma with an incidence angle of 60 °.

In the ps experiments, a prepulse was used to adjust the preplasma in advance of the main pulse. We have measured the THz radiation in the specular direction as a function of the main laser energy, and the preplasma scale length *L*, systematically. The THz pulse energy increases nonlinearly with the laser energy. The corresponding power index is fitted to be ~ 3 ± 0.5. At the laser energy of 9 J, the THz energy is measured to be ~11.5 μJ in 0.05 sr, corresponding to 230 μJ/sr. On the other hand, the THz radiation is very sensitive to the plasma density scale length. There exists an optimal scale length ~45 μm observed in the experiment.

It has been proposed that strong THz radiation with a broad frequency range can be produced via linear mode conversion (LMC) when large-amplitude laser wakefields are excited by an ultrashort intense laser pulse, which is obliquely incident into an inhomogeneous underdense plasma. In the present case, even though there is a large nonuniform preplasma, the laser pulse duration in our experiments is so long (0.5 ps) that large-amplitude laser wakefields with high frequency (higher than 2 THz) cannot be driven directly by the laser ponderomotive force. However, there are still two ways to excite electron plasma waves (EPWs) by a long laser pulse. One is the self-modulated laser wakefields (SM-LWF) excitation, which occurs as a result of relativistic self-modulation instability (SMI). Another is by stimulated Raman backward scattering (SRBS), which occurs spontaneously during the laser propagation in a large-scale plasma. EPWs driven by both processes could be partially converted into electromagnetic waves in the THz range via the LMC mechanism.

Particle-in-cell simulations verifies the above ideas. It shows that the THz radiation generation can be divided into three stages. First, when the laser pulse just goes into the plasma, a weak single-cycle low-frequency THz pulse is emitted due to the transient currents at the vacuum-plasma interface driven by the laser ponderomotive force. When the laser pulse propagates deep into the plasma with higher densities, multi-cycle *p*-polarized THz radiation is generated from the SRBS-induced plasma waves through the LMC mechanism. With the further laser propagation, LMC from SM-LWF to THz radiation occurs.

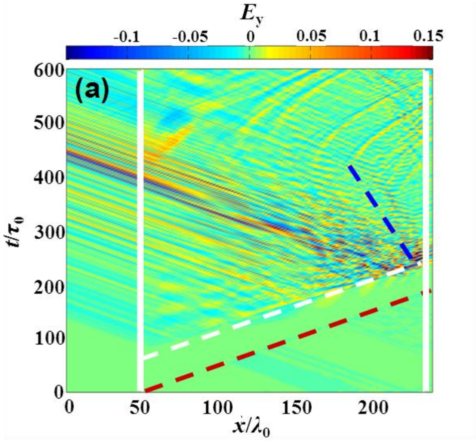

Fig. 2. Simulated spatio-temporal evolution of transverse field (THz field) when a picosecond laser pulse is incident into a large-scale nonuniform plasma.

For the THz radiation generated via LMC, the THz field could be further improved by enhancing the EPWs amplitude in controlled ways. It can also be applied to the gas or cluster targets. By tailoring the gas density, tunable spectra and operation at a high repetition rate are possible. The THz radiation may also provide an alternative diagnostic of parametric instabilities during laser propagation in plasmas, which will help to understand the mechanisms of saturation of parametric instabilities, a topic of significant interest and importance for inertial confined fusion.

III. SUMMARY

THz radiation from solid targets irradiated by relativistic fs or ps laser pulses has been studied systematically. A self-organized fast electron current model is proposed to explain the THz radiation from solid targets with a steep plasma density gradient. Spectral measurement of the specularly reflected light suggests the positive correlation between resonance absorption and THz yield. While when the large-scale plasma is present, the linear mode conversion mechanism may become dominant. For the ps relativistic laser pulses interacting large-scale plasmas, the THz radiation is mainly attributed to the linear mode conversion from electron plasma waves, excited successively via stimulated Raman scattering instability and self-modulated laser wakefields during the laser propagation in the preplasma. This radiation can be used not only as a powerful source for applications, but also as a unique diagnostic for laser-plasma interactions.

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