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TERAHERTZ RADIATION FROM LASER INDUCED PLASMAS

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Several applications in spectroscopy and sensing require sources in the terahertz (THz) domain. Among others, gases are promising media for generation of THz radiation by the interaction with ionizing intense laser pulses, as has already been established by various theoretical and experimental works. In particular, THz emission from laser generated micro-plasmas was demonstrated recently [1]. Multiple mechanisms responsible for the THz emission are proposed in the literature. The ionization current (IC) mechanism is mostly discussed in the context of two-color pump pulses, but also for one-color lasers it predicts THz radiation [2]. In contrast, the transition-Cherenkov (TC) mechanism was employed to explain the THz emission observed in [3]. We propose an approach explaining both mechanisms consistently, in excellent agreement with rigorous particle-in-cell (PIC) simulations accounting for ionization as well as collisions using the codes OCEAN and CALDER.

Our model is based on the Vlasov equation for electrons and ions coupled to Maxwell's equations. We assume the ions to be fixed and take into account elastic collisions, heating as well as multiple ionization using quasi-static ADK ionization rates. In a first attempt, we resort to a one-dimensional (1D) configuration with translational invariance in x and y direction, and the laser propagates in z. In 1D, the excitation by the IC and TC mechanisms can be clearly separated. The IC mechanism creates a transverse low frequency (THz) current, thus a current normal to the laser propagation direction. The TC mechanism creates a longitudinal THz current in the laser propagation direction. We compare the model based THz currents for an initially neutral Argon gas at ambient pressure irradiated by a Gaussian pulse. We find the TC mechanism associated with the parallel current dominating for sufficiently long pulses and not too high intensities: Fig. (a) identifies pulse durations and peak intensities, where the IC mechanism dominates (blue), where both mechanisms are equally important (green) and where the TC mechanism dominates (red). It is quite tempting to use these 1D results for the z-dependent current and compute a hypothetical far-field spectrum by assuming the plasma having a transverse shape of a thin wire and evaluating Jefimenko's equations [4]. Such a wire-model has been already proposed in [3]. Here, we want to use it to compare the 1D model with PIC simulations and to corroborate the domination range of the IC and TC mechanisms by the simulations. The 1D far-field spectra of 5-fs and a 50-fs laser pulse are presented in Figs. (b,c). In excellent agreement with the PIC simulations (solid lines), the model (dashed lines) shows the power spectrum P from the IC mechanism (blue lines) to dominate the power spectrum from the TC mechanism (red lines) for the short pump pulse (i), and vice versa for the long pulse (ii), where P even falls below the noise level.

However, one has to be careful with these 1D far-field spectra. On the one hand, we assume translation invariance in the transverse directions when computing the current, on the other hand, we impose later a thin transverse shape of the plasma wire when computing the radiation in the far field. It turns out that not all currents created by the laser in the plasma can actually couple to radiation modes of the surrounding free space. In particular, the eigen-oscillations of the plasma at the so-called plasma frequency ω_p do not radiate. Thus, in order to predict experimentally accessible far-field spectra a higher dimensional treatment is inevitable. To this end, we consider a strongly focused Gaussian beam with the temporal pulse parameters from (ii) and concentrate on the TC

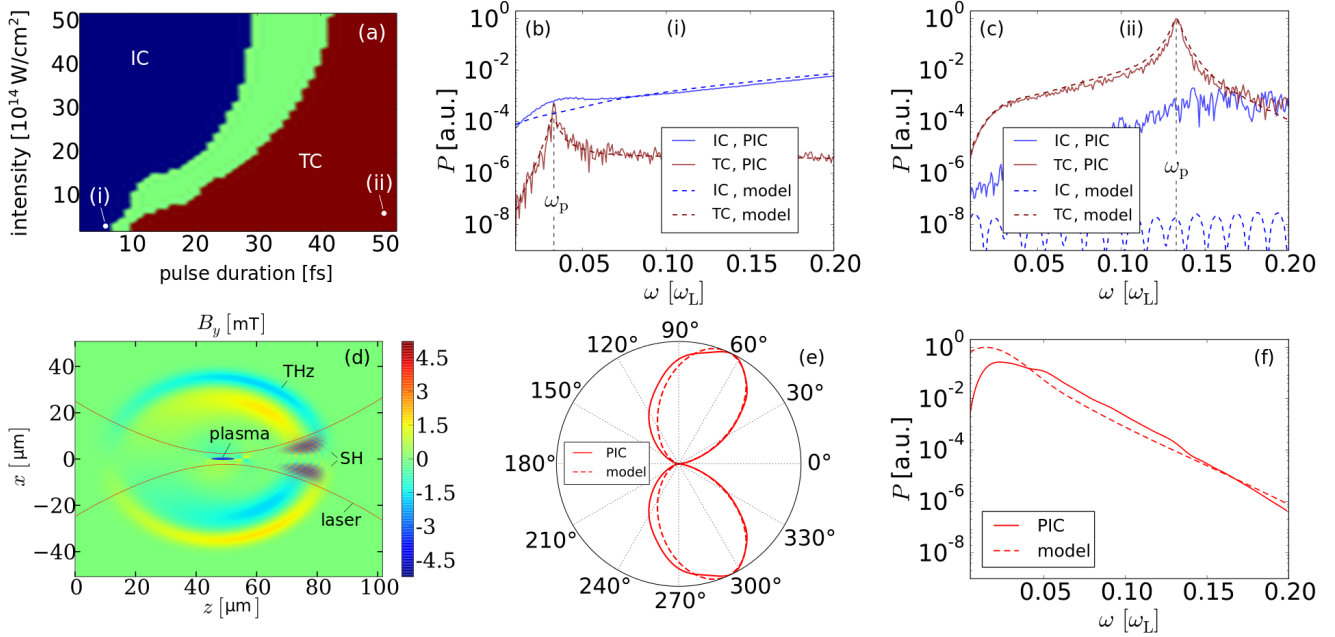


Figure 1: In (a) THz mechanisms are compared for different pulse durations and intensities interacting with argon. In the blue region the integrated THz power spectrum for the transverse current (IC) dominates the longitudinal current (TC) by one order of magnitude, while in the red region the longitudinal current dominates the transverse current. In the green region both mechanisms are important. In (b,c) the angularly integrated 1D far-field spectrum P (see text for details) is shown for a few cycle (i) and a multi cycle pulse (ii). Power spectra are presented from the PIC simulation and the model according to the legend. A snapshot of the THz magnetic field from a 2D PIC simulation with a strongly focused Gaussian beam and pulse parameters (ii) is presented in (d). The corresponding normalized THz radiation profiles are shown in (e). In (f) the angularly integrated power spectra are presented. The laser wavelength is $0.8 \mu\text{m}$, and the corresponding laser frequency ω_L is used as the frequency unit.

mechanism. The input intensity is chosen such that at focus the former 1D field configuration is restored, i.e., in particular the peak plasma densities in 1D and 2D are the same. In two-dimensional (2D) configuration with translation invariance in y and a E_y -polarized laser field, the magnetic field component B_y contains the information about the TC radiation. The configuration is shown schematically by a snapshot of B_y in Fig. (d): The strongly focused pulsed laser beam creates a microplasma ionizing the outer valence electrons of the argon gas at focus. The excited plasma leads to a current that partially radiates a second harmonic field (SH) under low angles and THz field under the angle of $\pm 70^\circ$ that is shown in Fig. (e). The THz spectrum in Fig. (f) evidences that the oscillations at the plasma frequency (here $\omega_p = 0.13\omega_L$, where ω_L is the laser frequency) do not radiate and THz radiation is detected at lower frequencies around $0.02\omega_L$ (6 THz) only. We identify the non-radiating plasma oscillations as electrostatic oscillations. A simplified 2D model which allows semi-analytical treatment gives a good approximation of the radiation profiles and spectra (dashed line) compared to the PIC simulation (solid line) as shown in Figs. (e,f).

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