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Study of Plasma Oscillator as a Radiation Source for Compact Electron Accelerators

Min Sup Hur[1]
[1] Dept. Physics, UNIST
e-mail (speaker): mshur@unist.ac.kr

Introduction

Plasma is a medium equipped with rich optical properties due to its electromagnetic susceptibility. Among them, plasma oscillation is a simple and fundamental characteristic of a plasma. One good example of its successful application might be the wakefield electron acceleration in a plasma, whereas its usefulness as a radiation source has been overlooked. Recently several ideas for using the plasma oscillation as a THz radiation source have emerged, such as inverse mode conversion [1] or superluminous plasma wave [2]. In our research, we devised a couple of exotic ideas for isolating a single plasma oscillator, which can directly emit a radiation with almost a hundred percent (actually, theoretically) coupling efficiency between radiation and oscillator. In this presentation, I will brief a couple of ideas to accomplish the isolation of a plasma oscillator and THz emission from that. Also, though it is not quite on the context of radiation source, I will brief our recent study for compression of laser pulses in a density gradient plasma.

Idea

We make two laser pulses collide in the plasma. The lasers are slightly detuned in their frequencies by an amount of plasma frequency, but they need not exactly the same to each other. Because of the detuning, in the overlapped region of the two laser pulses, a slowly moving ponderomotive beat potential is formed. When the beat potential is deep enough (say, by using intense laser pulses such that $a_0 > 0.1$), the background electrons are trapped into the beat potential train. As the trapped electrons, riding on the potential train, move together slowly in the direction of the higher frequency laser pulse (but much slower), i.e. a bunch of electrons (trapped electrons) is *dragged* slowly by the laser pulses. As the laser pulses pass by each other, the beat potential is weakened, and the displaced bunch of electrons gets no more displacing force and is released to commence the plasma oscillation. The overall procedure is like a drag-and-release of a mass attached to a spring.

The plasma oscillation generated in this way is unique. The plasma oscillation exists usually in the form of a plasma wave; electrons oscillate around their equilibrium positions but with different phases (mostly sinusoidally distributed phase). In contrast, our plasma oscillation is an oscillator rather than a wave; all the electrons in the oscillating bunch have the same phase. In that sense, we call it a plasma dipole oscillator (PDO). PDO electrons move in-phase, so it can emit electromagnetic wave as in the dipole antenna, with a very high coupling efficiency between the oscillator and emission.

As the radiation is emitted from the plasma oscillation, the emission frequency is well collimated to the plasma frequency. Furthermore, the plasma frequency of typical under-dense laser-produced plasma is in the terahertz (THz) range. Hence the emission from PDO can be ideal for THz-driven compact electron accelerators.

Results

We conducted simulation studies on PDO-THz using particle-in-cell (PIC) codes. From 2D PIC simulations, we obtained up to 1.5 % conversion efficiency from the energy of the driving laser pulses to the THz emission. The peak field strength of the emitted THz reaches several GV/m with total energy of order mJ. Such a highly efficient, strong THz emission could be obtained by optimal shaping of the driving laser pulses, which I brief in this presentation.

Other than this result, I also present another novel idea for generation of a similarly isolated bunch of electron plasma oscillation, using the resonance driving of the plasma motion. In this new configuration, the emission is considerably more directional, radially polarized, and highly narrowbanded, especially useful for the THz accelerators.

At the same time, I brief a bit different concept for using the plasma as a pulse compression grating [3]. The idea can be a potentially useful candidate for the compact exawatt laser systems.

Conclusion

In this presentation, I introduce a couple of novel ideas for generating narrowband, high-efficiency THz emission from plasma oscillation. The idea is expected to be useful in development of THz-driven, next-generation electron accelerating scheme. Along with that, I brief our newly conceived idea for getting compression of ultraintense laser pulses in a plasma. peak power is expected.

References
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