Modeling the Formation of Nanometer-Scale High-Density Electron Bunches in Relativistic Laser-Solid Interaction: Effects of Numerical Resolution

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Abstract: With numerical simulations we demonstrate that laser-driven electrons near solid targets bunch together and travel along a synchrotron-like trajectories. The effect of numerical resolution on the formation of these nanoscale bunches is studied.
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1. Introduction

Interaction of relativistic-intensity laser waveforms with solid targets results in the formation of high-energy-density plasmas at the target surface. Extremely fast, attosecond collective dynamics of electrons — release, bunching, and acceleration — driven by the combined action of the laser and plasma potentials in such plasmas give rise to coherent ultraviolet and soft x-ray radiation; these high-order harmonics of the driving laser can be phase-locked to produce attosecond pulses [1-7].

2. Resolving Dense Nanobunches of Electrons

The PIC code EPOCH [8], was used to study the structure and evolution of these electron nanobunches. Here we consider a laser pulse normally incident on a steep, fully ionized plasma with a peak density of $100n_c$, where $n_c = m\omega_o^2/(4\pi e^2)$ is the critical density. The single-cycle laser had a normalized laser amplitude of $a_o = 20.$ For all simulations, 200 particles per cell were used and ions were considered motionless.

To begin characterizing these electron bunches we first track the peak of a bunch as it evolves in time over a half cycle of the main pulse. In figure 1a we see that the electron nanobunch oscillates on a time-scale comparable to a plasma period because of the plasma oscillations induced by the displacement of electrons from the uniform ion background. We wish to accurately resolve the nanobunch profile at t/T_o ≈ 2.52 which corresponds to the maximum displacement of the plasma-vacuum interface. Figure 1b shows the density bunch in space for various resolutions determined by the number of cells per wavelength (CPW). Notice that although the electron bunch forms for all resolutions, the peak of this bunch grows by more than a factor of four. This result could be attributed to a numerical artifact caused by the inability of 1D PIC to capture space charge forces within a grid cell.

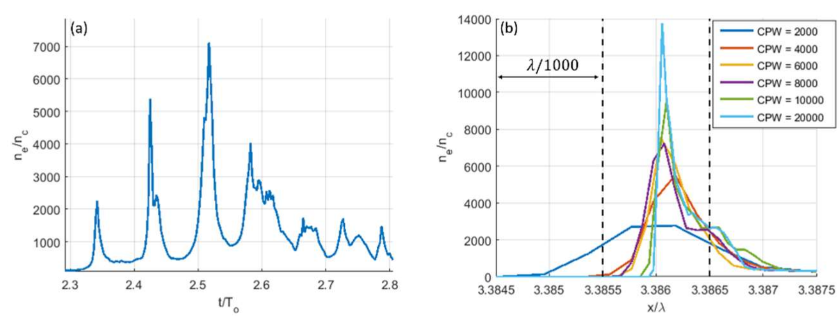

Figure 1. (a) Evolution of peak density of nanobunch over one half laser cycle. The simulation was run at 6000 CPW. (b) The nanobunch plotted as a function of position for various resolutions at time t/T_o = 2.52 which is the time of maximal displacement of the plasma.

Since this electron bunch is directly responsible for the generation of high-order harmonics in the reflected field, the lack of convergence could also mean that the properties of the reflected field change with different resolution. Fortunately, this is not the case as is shown in figure 2. Here we see little change with increasing resolution of the reflected attosecond pulse and spectrum.

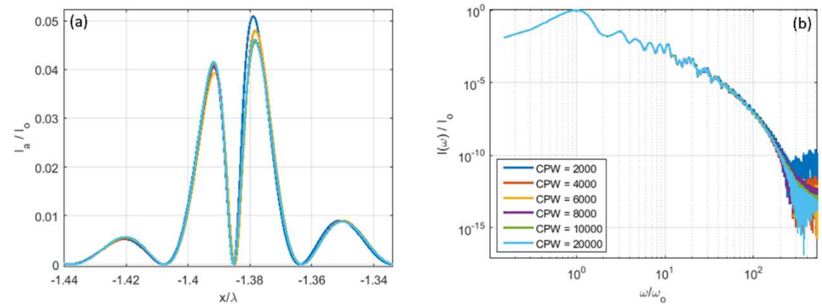

Figure 2. (a) Reflected field intensity filtered to include 15-100 harmonics for different spatial resolutions. (b) The full reflected spectrum for various resolutions. Both plots show convergence with increasing resolution and correspond to the simulations described in figure 1.

3. Conclusion

In this study the formation of dense electron nanobunches was studied in time and space. It was found that with increasing grid resolution, the peak of a single electron bunch did not converge for reasonable resolutions. This does not have a detrimental result on the ability to study the reflected field at lower resolutions. This suggests that for the parameters considered here, the maximum value of the nanobunch density is not critically important in the harmonic generation process.

4. Acknowledgements and References

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