§40. PIC Simulations of Attosecond Pulse Generation in Ultra-Relativistic Laser-Plasma Interaction

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Over the past decade there has been growing evidence of exciting physics in short (femtosecond) laser−matter interactions [1]. As the lasers reach record peak power, the challenges to concentrate electromagnetic (EM) wave energy within shorter times continue to be a topic of research that can lead to investigations of physical phenomena on attosecond scale (10^{-18}s). The crucial point to achieve this goal is to generate coherent waves with extremely short wavelengths - in the XUV range of the EM spectrum. The odd-harmonic frequency upshift of coherent EM waves has been demonstrated in a number of laser−gas target experiments. However, this nonlinear atomic mechanism of the harmonic generation is relatively inefficient at relativistic laser intensities due to the gas ionization. Recently, generation of high-order harmonics, attosecond light and electron pulses through the interaction of high-intensity laser light with solid targets has received an increasing amount of attention [1−2]. The theory and simulations suggest that, in contrast to the harmonic generation from the gas targets, laser beam tightly focused on solids generate high-order harmonics with a high conversion efficiency without limitations on the incident laser intensity and harmonic number.

In order to better understand processes and support experiments planned at INRS-ÉMT with a new 200 TW laser system (Advanced Laser Light Source-ALLS), a series of 2D relativistic EM PIC simulations was carried out to study generation of high harmonics and attosecond pulses in the interaction of high intensity ($a_0 = v_0/c = 1 - 20$) laser beams with overdense plasmas ($n = 10 - 100n_{cr}$). In Fig. 1 we display the distribution of magnetic field cB_z in the laser-plasma interaction region at the peak of the interaction. During the interaction relativistic oscillations of the sharp plasma surface driven by intense EM waves, give in turn periodic modulations of the reflected laser beam [3]. As we can see from Fig. 2, where we show the time evolution of the reflected magnetic field, a train of short (attosecond) asymmetrically compressed pulsations is the result of this relativistic modulations.

In addition to single-laser simulations, a number of runs was carried out to explore the interaction of two laser beams focused onto the target. These results show generation of subfemtosecond light pulses scattered out of the incident beam propagation axes, with a possibility to create single attosecond pulse.

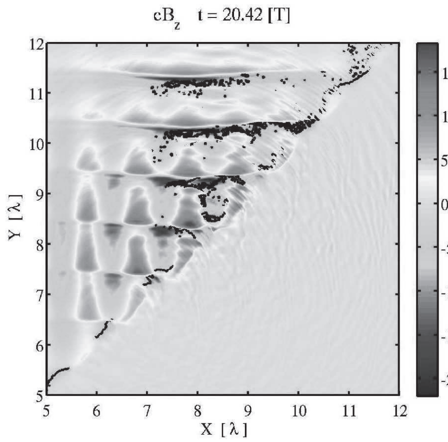

Fig. 1. Snapshot of spatial distribution of the magnetic field (cB_z) and low density ($n = 0.25n_{cr}$) electron plasma jets (black contoures). The laser strength is $a_0 = 10$, the angle of laser incidence and plasma density are 45° and $n = 20n_{cr}$, respectively.

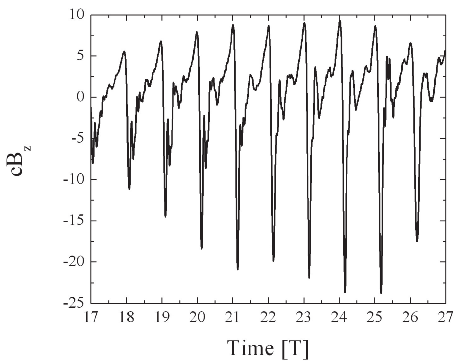

Fig. 2. Time evolution of the magnetic field (cB_z) of the reflected light. The parameters are as in Fig. 1.

The phenomenon of harmonic generation is followed by production of high energy electrons [4] (see Fig. 1). During the interaction a driven surface wave of electron jets is formed at the front of the target while a majority of electrons propagate into the target due to the Brunel heating. A part of electrons is stripped off from the surface forming dense islands well confined in the minima of the reflected field (i.e. on an attosecond length), with a separation $\sim \lambda_0$. The direction of propagation of these relativistic electron bunches is slightly shifted from the optical axis of the reflected light.

1) Mourou G. et al., Rev. Mod. Phys. **78**, (2006) 309
2) Nees J. et al., J. Mod. Opt. **52**, (2005) 305
3) Pirozhkov A. S. et al., Phys. Plasmas **13**, (2006) 013107
4) Nikolić, Lj. et al., J. Phys.: Conf. Series **112**, (2008) 022086