§47. Acceleration of High-Quality, Well-Collimated Return Beam of Relativistic Electrons by Intense Laser Interacting with Under-Dense Plasma

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When an intense laser electromagnetic (EM) wave propagates inside under-dense plasma, by stimulated Raman scattering (SRS) and other nonlinear laser-plasma processes, e.g., the ponderomotive force of an intense laser EM field, a large amplitude electron plasma wave (EPW) can be excited. This large amplitude EPW has a very high phase velocity close to the group velocity of a laser pulse and can be used to accelerate particles to high energies. High-energy particles and/or particle beams with high-quality and high-energy have wide potential applications, for example, in the concept of fast ignition of inertial confinement fusion [1], laser induced nuclear reaction [2], radiography and so on.

In this report we present the simulation results on a new phenomenon of short high-quality and well-collimated return relativistic electron beam, induced by intense laser EM wave interacting with an under-dense plasma layer.

In our simulations, one-dimensional fully relativistic EM particle-in-cell code is used. The length of simulation system in x direction is 5000 c/\omega_b, plasma length is 1000 c/\omega_b, in the front and rear side of plasma layer, there are two 2000 c/\omega_b long vacuum regions, where c and \omega_b are the speed and frequency of laser EM wave, respectively. Ions are initially placed as a neutralizing background and are kept immobile. The plasma density and temperature are 0.01 n_cr and 350 eV, where n_cr is the critical density of laser pulse. The linearly-polarized laser with its electric field E_0 along y direction and normalized amplitude \beta = eE_0/m_e\omega_b = 1.0 is launched at the position where 500 c/\omega_b long distance before plasma, where e and m_e are the electron charge and mass, respectively. The electrons which are blown-off into vacuum, build a potential barrier that prevents electrons to leave from bulk plasma. For fast escaping electrons as well as for EM waves, two additional numerical damping regions at system ends are used.

When the intense laser EM wave propagates inside under-dense plasma, the SRS takes place. In our simulation parameters, the SRS is dominated by forward SRS (F-SRS) [3, 4]. Due to the F-SRS, a large-amplitude EPW with its phase velocity close to the group velocity of laser pulse can be excited; it can accelerate electrons to high energies after its breaking. At an early stage, large parts of the electrons start to interact with this forward propagating EPW and are accelerated to high energies, in this case, the maximum energy obtained by an electron is E_{max} = 46 MeV. These accelerated electrons move forward to the right plasma-vacuum boundary, where they escape from plasma layer into vacuum region to build a potential barrier, a large electrostatic (ES) field that is formed quickly. This sheath ES field gradually decreases from plasma-vacuum interface to vacuum region. The accelerated electrons, which enter this sheath ES field region, first experience deceleration to be eventually stopped. Further, these electrons reverse their motion to be accelerated backwards into the bulk plasma. These electrons are out of phase with the counter-propagating large EPW and will travel without much interaction toward the front plasma-vacuum interface. During some time interval, as shown in fig. 1, a high-quality and well-collimated return relativistic electron beam bunch, with the beam energy is nearly between 12 and 17 MeV, is eventually formed.

Based on our simulation result, we propose that, this process can be divided into two phases, i.e., the initial rapid electron acceleration by F-SRS and the second electron acceleration due to the large sheath ES field formed at right vacuum region. The second phase corresponds to the formation of high-quality and well-collimated return relativistic electron beam.

If we take ion mass to be M_{ion} = 1836m_e, the ion plasma wave period is T_{ion} = 430T_0, where, T_0 is laser period. The electron acceleration and formation of high-quality and well-collimated return relativistic electron beam are taken place before 900T_0. Thus, it is plausible to neglect the ion dynamics. Our additional simulation has proved that this assertion is correct.

![Fig.1. Snapshots for electron phase-space in the case of plasma density n = 0.01n_cr and laser amplitude \beta = 1.0. The time t is normalized to the laser period 2\pi/\omega_b.](image)

References
4) Li Baiwen, S. Ishiguro, et al., Laser and Particle Beam to be published.