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

Li, B.W. (Graduate University for Advance Studies)
Ishiguro, S.
Skoric, M.M. (Vinca Institute of Nuclear Sciences)
Takamaru, H. (Chubu University)

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 $5000c/\omega_0$, plasma length is $1000\,c/\omega_0$, in the front and rear side of plasma layer, there are two $2000\,c/\omega_0$ long vacuum regions, where $c$ and $\omega_0$ 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 $0.01n_{cr}$ and $350\ \mathrm{eV}$, 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 $\beta = eE_0/m_e\omega_0 c = 1.0$ is launched at the position where $500\,c/\omega_0$ 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 $E^{\max} \approx 46\,\mathrm{MeV}$. 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 $17\,\mathrm{MeV}$, 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 $T_{ion} \approx 430T_0$, 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.

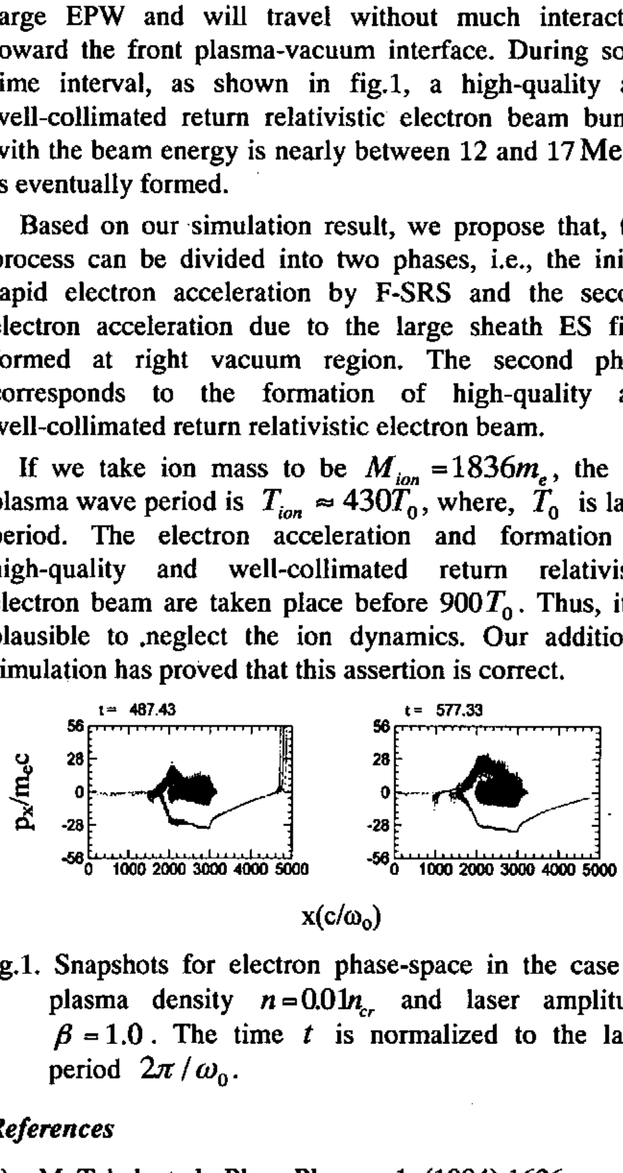


Fig.1. Snapshots for electron phase-space in the case of plasma density $n = 0.01n_{cr}$ and laser amplitude $\beta = 1.0$. The time $t$ is normalized to the laser period $2\pi/\omega_0$.

***References***

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