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Propagation of high-current fast electron beam in a dielectric target

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A relativistic electron beam with very high current density may be produced during the interaction of a short high intensity laser pulse with a solid target. In Fast Ignition approach to Inertial Confinement Fusion, such beam is supposed to heat a part of the precompressed DT fuel pellet to the conditions of an efficient ignition. For successful implementation of Fast Ignition understanding the propagation and energy deposition of the beam is crucial. A number of processes, mostly associated with the return current, are dissipating the energy of the beam or inhibiting its collimated transport, namely the filamentation, Weibel, two-stream or the recently proposed ionization instability. Ionization instability may develop in a solid dielectric target due to the dependence of the propagation velocity of the beam on the beam density.

To study the propagation of high current electron beam in dielectric target, we use a one-dimensional relativistic electrostatic simulation code based on the Particle in Cell method. The code includes ionization processes in dielectric material and collisions of newly generated cold electrons. The current density of the relativistic electron beam used in this work is in the range 3-300 GA/cm^2, while its length roughly corresponds to the beam, produced by a 40 fs laser pulse. Propagation of the beam in the polyethylene target is studied. The code is complemented by an analytical model, which is applicable to a wider range of beam parameters that are currently beyond our computational possibilities.

When the head of the beam enters the plastic target, electric field grows rapidly in consequence of the charge separation and it starts to ionize atoms. In the maximum of the field, which is less than 10% of the atomic field, the density of new free electrons is two orders of magnitude higher than the beam density, which is enough for the current neutralization. Cold electrons are accelerated by the field, until they acquire enough energy for efficient collisional ionization. Then, the avalanche ionization starts and the further increase of cold electron density reduces plasma resistivity. The current of the rest of the electron beam is neutralized relatively easily. The electric field inside the beam is order of magnitude lower than in the ionization front and it drops to zero behind the beam.

The evolution of the beam distribution along its propagation and the plasma produced inside the plastic target are studied. The propagation velocity of the ionization front is faster for higher beam densities in agreement with analytical model. The energy loss of the beam due to Ohmic heating influences its propagation significantly on the distance of order of tens of ěm. The losses are stronger for lower density beams and the average energy lost per beam electron is significantly higher than the collisional losses. For the higher beam density, the two-stream instability may develop behind the ionization front.

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