Computational Challenge of the Hybrid PIC-Fluid-FP Code for Simulation of Dynamical Processes in Plasma

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Processes in plasma, involved high energy release in a matter (Z-pinch compression, interaction of laser pulses with target, etc.), are characterized by different scales in time and space. Two main approaches, kinetic and hydrodynamic, are employed to describe these phenomena. The kinetic approach gives more detailed information, but it more expensive for the simulation. The hydrodynamic equations are more simple and convenient for modeling, but their domain of application is limited. Usually it is necessary to calculate the evolution both of fast and hydrodynamic (thermal) particles. Developed hybrid approach combines the description of motion of relativistic fast particles, electrons and ions, in self-consistent electromagnetic fields and MHD treatment of electron and ion plasma components in common magnetic field. Fast particles while propagating in a matter interact with it. Boltzmann equation is used for weak-collision electrons with low energy. Relativistic kinetic PIC-approach is applied for electrons with high energy, which interact with other electrons, ions, and neutral atoms (high-collision electrons). MHD approach is used for thermal particles. It accounts wide range resistivity including effects due to the development of micro-instabilities in plasma. Wide range EOS is matched with transport coefficients. Processes of plasma ionization connecting with thermal particles and with particles beam propagation are also considered.

The hybrid approach is illustrated for the task of obliquely incident laser pulse at near relativistic intensity focused onto solid-density SiO_2 plasma (see Fig. 1). Main *p*-polarized pulse has parameters as follows: intensity $I = 2.5\acute{}\ 10^{18}$ W/cm^2, pulse duration t = 30 fs, focal spot diameter d = 1.5 μm. Moderate intensity prepulse with $I = 2\acute{}\ 10^{14}$ W/cm^2, t = 30 fs, d = 30 μm falls on the target starting with specified delay before the main interaction.

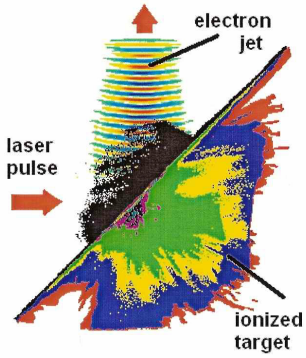

Figure 1. Sketch of laser pulse interaction with solid target. Electrons are emitted between the laser specular and the target normal directions.

Eulerian MHD simulations of targets heated by prepulse were performed. Prepulse-target interaction was described by Maxwell equations coupled with the Fokker-Planck (FP) equation for density distribution of free electrons [1], the electron energy balance equation, and material equation based on Drude model. Two mechanisms were taken into account to describe transition of an initially neutral dielectric into a plasma: the ionization by electron impact and multiphoton ionization. In the electron energy balance equation Ohmic heating of free electrons, the losses due to ionization collisions and atomic excitations have been accounted [2]. For description of field ionization the approach from [3] relevant to tunnel ionization of an atom in a laser electric field has been used.

The part of equation of state responsible for the ionization has been modified to account for withdrawal of energy from the electrons by the recombination photons. Photon energy is reabsorbed by neighbour atoms. The radiative transfer equation in multi-group approach with photon mean free paths and mean emission coefficient for each group was solved. Radiation transport was treated self-consistently with ion state calculation from equations for balance kinetics of level population.

An adaptive mesh refinement (AMR) approach [4] is used to optimize the quite cumbersome numerical calculation.

The hybrid code simulation shows that the target electrons absorb laser energy in a thin skin layer while the matter remains cold initially. In the heated skin layer the temperature of electron is higher than the ionization potential so the electron impact ionization occurs and lasts after the pulse has terminated. The electrons transfer their energy from the skin layer throughout the electron heat penetration depth. Ions are heated through the Coulomb collisions and accelerated by the gradient of electron pressure. Electron beam formed due to such complex interaction of reflected electromagnetic field with expanding matter has a spectrum close to the Michigan experimental data [5].

References

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