3rd Asia-Pacific Conference on Plasma Physics, 4-8,11.2019, Hefei, China

High energy density plasma produced by the interaction between high intensity laser and structured medium ─ A new platform studying MCF plasmas using laser ─

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High energy density plasmas produced by high intensity laser have been widely utilized for exploring medical/industrial applications and innovative academic sciences, e.g. high energy particle acceleration, generation of high intensity X-rays and gamma-rays, neutron source, scaled interstellar plasma jets, etc. Depending on the application, one needs to choose the target properly, e.g. gas, bulk solid and/or solid thin film, their composite, etc., and control the interaction with the laser, resulting in high energy density plasmas. Here, the characteristics of plasma are of specific importance.

One of them is the life time, which is generally short in the order of "inertia time" due to the high-pressure nature of plasmas. If such plasmas can be sustained with longer time exceeding the inertia time, such as magnetically confined fusion (MCF) plasmas, one can extend the class of application to wider area [1].

Here, we propose a new concept of target irradiated by high intensity laser. We refer to it as **structured medium** consisting of structured materials with the size from several tens nm to μm and continuous medium such as gas/plasma, magnetic field, which contacts with each other across boundary layer.

Cluster target, an aggregation consisting of a tiny granular spherical solid, is one of examples, which exhibits prominent characteristics and functions with the interaction of high intensity laser [2,3]. Recently, a new scheme of proton acceleration using hydrogen clusters with the μm size irradiated by high intensity lasers has been proposed, referred to as CSBA (Converging Shock induced Blow-off Acceleration). The proton acceleration over 200 MeV/u is found to be realized by utilizing an internal/external degree of freedom of a cluster and by synchronizing multiple complex processes [4].

Here, we extended the scheme to more sophisticated structured target. This is a designed lattice-like rod target with sub-μm size using combined technologies of beam lithography and chemical etching [5]. We have successfully created a rod target made of silicon with 15×15 arrays with an interval of 1 μm, where the diameter and length of each rod are around 0.5 μm and 13 μm, respectively. For characterizing the dynamics of the interaction, the target was irradiated by the high intensity laser of around 7×10^{17} W/cm^2 with pulse length of 50 fs (FWHM) and the interaction was probed by the SACLA X-ray laser with the photon energy of 7 keV and pulse length shorter than 10 fs (FWHM) [5]. We successfully observed small angle X-ray scattering (SAXS) diffraction pattern and identified the expansion process of the plasma.

We have also studied the interaction between above rod target and high intensity laser using EPIC simulations which includes ionization and relaxation processes in two cases, i.e. (a) the case immersed in a high pressure ambient gas and (b) that in strong magnetic field around kT order.

In case (a), a collision-less electrostatic shock is found to be induced around the boundary layer and compress/ reflect the ambient gas ions, leading to a high energy ambient gas ion spectrum with a limited energy spread. More interestingly, ling like structure are found to be produced, which is sustained with a longer time scale as a quasi-stationary BGK type equilibrium incorporated with potential vortices in the phase space, which [6]. Similar structure is seen in the plasma sheet boundary layer in the Earth's magnetotail. We also found that quasi-coherent magnetic fields with the order of kT is generated by the current filaments induced among rods, which play a role in sustaining a high-pressure plasma with the beta-value of $\beta \sim 1$ (order of unity).

In case (b), we successfully sustain a high energy density plasma as mirror plasma, one of the magnetic confinement scheme. The quasi-static radial electric field is found to play an important role in confining plasma, such as H-mode in MCF system. Experiments for these simulation results have been planned using J-KAREN laser in the beginning of 2020 in QST.

The scheme sustaining high energy density plasma using structured medium with $\beta \sim 1$ opens new paradigm for plasma physics, which can contribute understandings of complex dynamics and structure of MCF plasmas.

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