1st Asia-Pacific Conference on Plasma Physics, 18-23, 09.2017, Chengdu, China

Acceleration of neutral atoms in laser produced plasmas

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Intense laser pulse focused on solid substrate are well known to generate high density high temperature plasma. Quasi-static fields generated on the target surface due to the instant removal of large number of electrons are well know for acceleration of charge particles. Electron and ion emission to a few MeV with laser intensities close to the relativistic intensities are well studied. The question we ask is about the possibility of tuning the compact charge particle acceleration schemes to generate neutral atoms beam of the energy same as that of ions. In such a case the emittance of the neutral atom beam would be similar to that expected for an ion beam. As intense laser-produced plasmas have been demonstrated to produce high-brightness-low-emittance beams, it is therefore possible to envisage generation of high-flux, low-emittance, high energy neutral atom beams in length scales of less than a millimeter. Feasibility of such a high energy neutral atom accelerator could significantly impact applications in neutral atom lithography and diagnostics.

We demonstrate[1] in this talk that it is possible to device a scheme where in nearly 80% of the accelerated ions of heavy atoms like Cu generated at the target front can be reduced to neutral atoms. An accelerated ion can be reduced to neutral atom by capture of bound electron in collision with a neutral atom or by recombination of free electrons. In a typical laser experiments with solid targets, the pressure in the target chamber is maintained low enough that there is little collisional charge transfer. There could be an ablative emission of the atoms but that will not be much later than the emission of fast ions from the surface. Consequently charge transfer by capture of bound electrons from neutral atoms is negligibly small especially when very intense short pulses (<50fs) are focused on a solid target. Electron ion recombination from the plasma plume is possible if the electron density is high and the electron temperature is low. In most short pulse lasers, a prepulse is invariably present and this can be exploited to modify the preplasma conditions so that the ions traversing the target surface pass through a suitably tailored pre-plasma and the neutralisation efficiency is larger. We find that adjusting the laser focal waist provides an optimal control of the pre-plasma and can be tuned to alter the neutralisation efficiency. Under the best focus conditions where in normally experiments are performed, neturalisaiton of heaviour ions like Cu is at best 20-25%. But if the focal waist is increased, neutralisaiton efficiency can be increased to 80%. The low electron temperatures is known to scale with the ponderomotive energy. By increasing the focal waist from about 10 microns to about 100 microns it is possible to reduced the temperature of the pre-plasma by nearly orders in magnitude and three body recombination is made very effective.

Generating and analysing a beam of high energy neutral atoms is a challenge that is important for many technological application. In lithographic applications, high energy neutral atoms result in higher finesse structures than those produced with charged particle beams. High energy hydrogen atom beams play an important role in Tokamak diagnostics. A 15 degree conical emission of neutral atoms with energy as large as MeV is likely impact the possible neutral atom beam applications.

References

1. Compact acceleration of energetic neutral atoms using high intensity laser-solid interaction, Malay DaluiT. Madhu Trivikram, James Colgan, John Pasley, and M. Krishnamurthy Sci. Rep. (2017)