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Physics of Microplasma for efficient particle acceleration

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Plasma generated by using liquid droplets are a viable high repetition rate laser targetry that be a suitable alternative to the conventional systems for efficient high temperature plasma generation and a on-spot source of high energy electrons/x-rays and ions. This talk demonstrates realization of such a source driven with mJ high repetition rate lasers for effective solutions to imaging and radiography. Experiments combined with particle-in-cell simulations are used to establish that plasma instabilities like two-plasmon decay offer viable solution to the high peak brightness laser plasma source that could compete with conventional sources.

Intense laser plasmas are envisaged as a novel alternative to conventional electron/X-ray/ion sources due to their orders of magnitude larger peak brightness. Electron energies can reach GeV if sufficiently intense laser pulses are used [1]. Laser intensity is the key parameter. Hotter plasma generation necessitates higher intensities. High intensity laser systems are expensive, complex, high demanding and most importantly the repetition rates of such laser system are lower. So while many applications are demonstrated a true world translation of these advancement to real world problems are not straightforward. mJ lasers with higher repetition rates are an important alternative to advance these issues. Focusing mJ lasers to relativistic intensities and optimization of the wake field acceleration mechanism for electron acceleration have brought in rich dividends in this endeavor [2]. But the ponderomotive scaling still demands than relativistic intensity is mandatory for relativistic temperature plasma generation.

In this talk, we will present experiments that are supported by PIC simulations to show the possibility of generating relativistic 1 MeV temperature plasma even when the intensities are 1/100th of the relativistic intensity[3]. The experiments use microparticles and/or liquid droplets embedded in low-density gas to generate hot electron distribution dominated by a two temperature distribution. An electron temperature of 200 keV with electron energies extending up to 1 MeV and a higher energy component with 1 MeV electron temperature and maximum electron energy extending up to 6 MeV even at laser intensities as low as 10^16 W/cm2. Electron emission from the microplasma is not isotropic. It is in the form of two beams directed at about 20-45 degrees to laser direction but on the rear side of the laser incidence. Conical electron emission is in the plane of laser polarization and can be manipulated by changing the laser polarization. Electron emission shows a threshold like behavior. At the threshold electron emission upto 50 keV can be achieved with laser pulses of as low energy as 60 micro Joules. The microplasma also generates x-rays with spectral features that correlate with the bremsstrahlung emission from the electron emission from the microplasma.

The low energy electron emission (200 keV to 1 MeV) is intense enough to be used for electron radiography even with 1-2 laser pulse exposition. Source size is small enough to acquire high-resolution(< 13.6 μm) electron radiographs. X-ray radiographs with competing resolution can easily be generated in short acquisition times due to the high repetition rates of the microplasma.

The microplasma is also a source of protons with energies extending 500 keV even with 1-2 mJ laser intensity used in these experiments. Ion emission is also directional especially for the high energy ions (200-500 keV) and the ion angular distribution follows the electron beam like emission in the direction back ward to the laser propagation. The ion emission is of adequate intensity to acquire ion beam radiogram with <50 μm spatial resolution is 1-2 min acquisition.

The key to generate such plasma is the use of appropriate pre-pulse that dynamically distorts the micro-particle suitably when the main pulse is incident. The low-density (0.01 nc) long scale length plasma is very important to this effective plasma generation. Particle-in-cell simulations are used to understand the underlying mechanism. Experiments guided by the computations show that two-plasma decay (TPD) is the main mechanism for driving such a plasma. Electrostatic wave generated in the long scale length low density grows in amplitude and breaks at the critical density surface to source the hot electron emission. Electrostatic fields akin to target normal sheath acceleration are generated at the surface of the microplasma and are responsible for the high-energy ion emission.

Demonstration that lasers of 1-2 mJ energy/pulse and 30-200fs pulse width are adequate to generate such a one-stop-source for high energy electrons/x-rays and ions, should be important for imaging applications using microscopy, radiography and tomography. The advanced lasers today can deliver the required pulse parameters with repetition rates that can be extend to even 1 MHz. The industrial touch-free lasers today with such laser parameters of 100 kHz can be used to drive the laser plasma source applications that can come close to competing with conventional source even for their average brightness, leave alone the high peak brightness possible due to ultra-short pulse features associated with the source.

References

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