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Electron acceleration by a transient intense-laser-plasma electrode

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Rapid strides in the technology of laser plasma-based acceleration of charged particles leading to high brightness, tunable, monochromatic energetic beams of electrons and ions has been driven by potential multidisciplinary applications in cancer therapy, isotope preparation, radiography and thermonuclear fusion. Hitherto laser plasma acceleration schemes were confined to large-scale facilities generating a few tens of terawatt to petawatt laser pulses at repetition rates of 10 Hz or less. However, the need to make viable systems using high-repetition-rate femtosecond lasers has impelled recent research into novel targetry [1,2].

Of contemporary importance is the generation of *supra thermal* electrons, beyond those predicted by the scaling relation, reflected in both theoretical and computational work [3,4]. In this work we present evidence of generation of relativistic electrons (temperature >200 keV, maximum energies >1 MeV) at intensities that are two orders of magnitude lower than the relativistic intensity threshold. The novel targets [6] are 15 micron sized crystals suspended as aerosols in a gas interacting with a kHz, few-mJ femtosecond laser focussed to intensities of 10 PW/cm^2. A pre-pulse with 1-5% of the intensity of the main pulse, arriving 4 ns early, is critical for hot electron generation. In addition to this unprecedented energy enhancement, we also characterize the dependence of X-ray spectra on the background gas of the aerosol. Intriguingly, easier the gas is to ionise, greater is the number of hot electrons observed, while the electron temperature remains the same.

2-D Radiation hydrodynamics and Particle-in-cell (PIC) simulations explain both the experimentally observed electron emission and the role of the low-density plasma in yield enhancement. We observe a two-temperature electron spectrum with about 50 and 240 keV temperatures consistent with the measurements made in the experiments. The simulations show that the following features contribute to the high-energy electron emission. The pre-pulse generates a hemispherical plasma-profile that enhances the coupling of the laser light. Overdense plasma is generated about the hemispherical cavity on the particle due to the main pulse interaction. The gradient in the plasma density in and around the cavity serves as a reservoir of low energy electrons to be injected into the particle potential and enables the hot electron generation observed in the experiments. Higher energy electron emission is dominantly from the edges of the hemispherical cavitation. The increase in total X-ray yield observed in the experiments scales with the number of electrons generated in the low density neighborhood surrounding the particle. In a simple-man picture, the laser interacts with the particle and ejects electrons from the particle. The particle acquires a strong positive potential that can only be brought down by ion expansion that occurs over 10's of picoseconds. The particle with strong positive potential acts as an 'accelerating electrode' for the electrons ionized in the low-density gas neighborhood.

These results assume importance in the context of applications such as fast fuel ignition [6] or in medical applications of laser plasmas [7] where high irradiance of energetic electrons is of consequence.

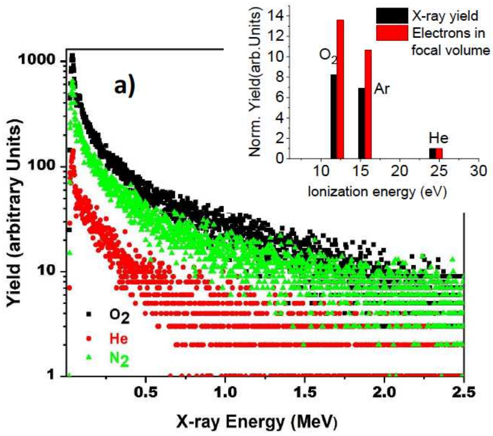

Fig. 1. X-ray spectra from interaction of laser with particles in different carrier gases. (inset) The X-ray yields (black) and normalized (to Helium) electron densities for the various carrier gases, with reference to their ionization potentials.

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