*34th EPS Conference on Plasma Phys. Warsaw, 2 - 6 July 2007 ECA Vol.**31F**, D-2.004 (2007)*

Relativistic Electron Acceleration in a Wake Field Generated by the Intense Femtosecond Laser Interaction with a Mid-size Deuterium Clusters Jet

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Generation of energetic electrons via laser-wakefield acceleration has been intensively studied both experimentally and theoretically[1-7]. The acceleration of electrons using laser-plasma interaction has attracted much attention due to the greater acceleration gradient (above 100 GV/m) than radio frequency accelerators. Capillary has been used to get a longer acceleration channel[8]. Different acceleration mechanisms including self-modulated laser wake-field (SMLWF) and direct laser acceleration (DLA) dominates at different laser intensities[9]. The monoenergetic features were observed in the electron energy spectrum for plasma densities just above a threshold required for breaking of the plasma wave[10,11]. In previous acceleration experiments, helium gas jet was usually used as the target. The acceleration length is limited.

We present the relativistic electrons accelerated by a wake field generated in fs laser cluster gas jet interaction. Pure gas jet is expected to exhibit very low absorption efficiency while the presence of clusters changes this situation dramatically[12,13], which makes it possible to observe electron signal shot by shot. Simultaneously, the clusters in the mixture jet enhance the filament of the laser. Relativistic electrons with 60 MeV energy were measured. Interestingly, the electrons split into two beams.

The photon pressure or ponderomotive force pushes plasma electrons out of the pulse while ions stay the original position due to their large mass. Then in the next half wavelength the electrons will come back because of the ions space charge field. Thus a plasma wave forms and propagates behind the laser pulse. The plasma wave can trap the background electrons and grow until nonlinear process wavebreaking takes place in the laser wake field. The energy is transferred from plasma wave to electrons by wavebreaking.

The experiment was performed using the SILEX-I Ti:sapphire laser system based on chirped-pulse amplification at Laser Fusion Research Center, China Academy of Engineering Physics, which produced pulses of 3 J in a duration of 30 fs. The laser is focused by an f/3 off-axis parabolic mirror to a 25 μm diameter (FWHM) spot with 80% energy enclosed in a Gaussian-fit profile at the edge of a supersonic cluster gas jet. The cryogenic pulsed valve is set to work at 100 K with the backing pressure 30~40 bar, which can assure deuterium cluster gas mixture jet is produced. A platinum resistance thermometer is employed to monitor the valve temperature. The density of the mixture is controlled by changing the backing pressure.

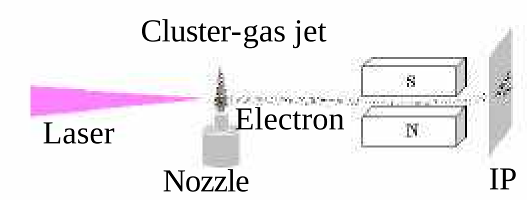

Fig.1 Experimental setup

The energy spectrum of electrons accelerated forward along the axis of laser propagation was measured by an electron spectrometer (ESM), which consists of a 70 mm diameter, 0.58 Tesla permanent dipole magnet and an imaging plate (IP) (Fuji BAS-SR 2040). The entrance of the ESM is a collimator with a 6 mm aperture. The IP covered with a 50 μm thick aluminum film to block laser beam and low energy electrons, is placed 160mm from the focal spot on the laser axis.

The radiated IP was scanned by the BAS-5000 reader and a Y-shape electron profile was obtained. It is noted that the electrons quiver with velocity closed to c for the plasma generated above the laser intensity $10^{18} W/cm^2$. The electron mass exceeds its rest mass greatly, which cause the plasma frequency decrease. Accordingly, the refractive index of the plasma, will increase, where ω_0 is the laser frequency. This is a positive feedback mechanism resulted in ununiformity profile of the laser intensity. Two main self-channels form and the electrons split into two groups when they escape the acceleration region. That is why two electron beams were observed.

The energy of the electrons is a function of the excursion away from the laser axis. For a plasma electron density of $1.2\times10^{19}\,cm^{-3}$, the wavelength of the plasma is about 9 μm, which approximates the laser pulse length ($c\tau$). Thus the plasma wave is nearly resonant with laser wake field and gain energy. The background electrons can be injected into the plasma at particular phase and experience acceleration. Actually, phase discrepancy always exists for some trapped electrons when they enter the plasma wave. So the measured spectrum of the high energy electrons is non-monoenergetic, as shown in Fig. 3.

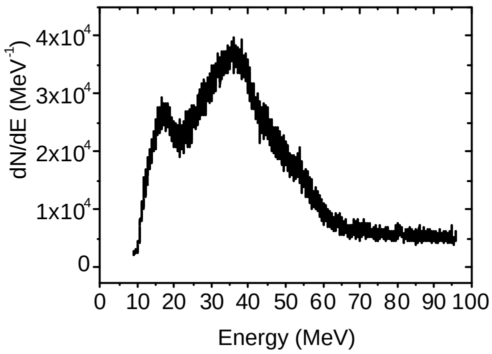

Fig.3 Energy spectrum of the relativistic electrons accelerated by the laser wake field, at $n_e = 1.2\times10^{19}/cm^3$

A charge-coupled device (CCD) camera with a gate time of 5 ms is used to observe the laser plasma fluorescence. The generation of the plasma wave causes self-focusing of the laser pulse away from its leading edge, owing to the radial density profile of the plasma wave. It is well known that for short pulses relativistic self-focusing is ineffective for the front of the pulse[9,14]. So the plasma becomes shaped like a cone, tapered towards the rear.

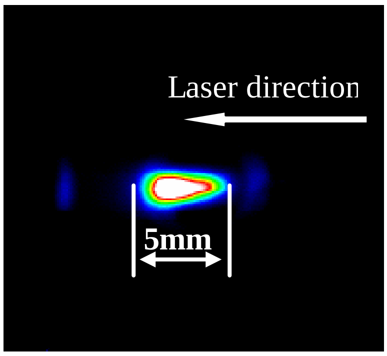

Fig.4 Typical fluorescence of the plasma formed in fs laser cluster gas jet interaction

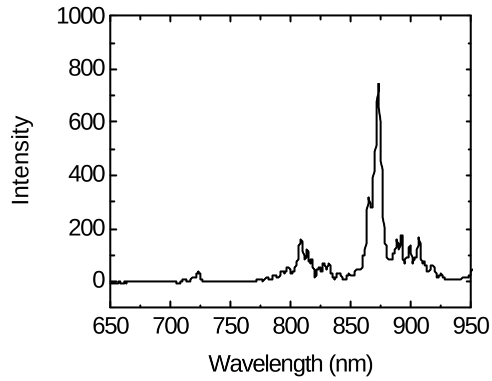

Fig.5 Backing Raman scatting spectrum

The electron density (n_e) as a function of backing pressure was determined by measuring the frequency shift of satellites generated by backward Raman scattering, which was measured by collecting and imaging the emission onto the entrance slit of an optical multi-channel analyzer (OMA). A band-pass filter was placed between the laser spot and the OMA to limit the light wavelength. Fig. 5 shows the red-shift of the backward scattering satellites. Multi-peak structure of the backward scattering spectrum is due to the laser wake field self-modulation.

In conclusion, cluster gas jet is also a good medium for laser plasma accelerator. High absorption efficiency of the laser energy and plasma channel formation are vitally important to electron acceleration. For practical application such as nondestructive material inspection, high-quality electron beams are required. Next we will explore the generation of electrons with good spatial quality and monoenergetic distribution.

The authors gratefully acknowledge Prof. Zhongli Liu and Mr. Zhiming Hu for their technical assistance.

References

[1] Tajima T and Dawson J M, 1979 *Phys. Rev. Lett.* **43** 267

[2] Esarey E and Pilloff M 1995 *Phys.Plasma* **2** 1432

[3] Fritzler S, Lefebvre E and Malka V et al 2004 *Phys. Rev. Lett.* **92** 165006

[4] Dodd E S, Kim J K and Umstadter D, 2004 *Phys. Rev.E.* **70** 056410

[5] Chien T Y, Chang C L, Lee C H et al 2005 *Phys. Rev. Lett.* **94** 115003

[6] Hogan M J, Barnes C D, Clayton C E et al. 2005 *Phys. Rev. Lett.* **95** 054802

[7] Kando M, Masuda S, Zhidlov A et al. 2005 *Phys. Rev.E.* **71** 015403

[8] Kitagawa Y, Sentoku Y and Akamatsu S et al. 2004 *Phys. Rev. Lett.* **92** 205002

[9] Mangles S P D, Walton B R and Tzoufras M et al. 2005 *Phys. Rev. Lett.* **94** 245001

[10] Mangles S P D, Murphy C D, Najmudin Z et al. 2004 *Nature.* **431** 535

[11] Faure J, Glinec.Y, Pukhov A et al. 2004 *Nature* **431** 541

[12] Ditmire T, Donnelly T et al. 1996 *Phys. Rev. A* **53** 3379

[13] Liu H J, Gu Y Q, Wang H B et. al. 2005 *Chin. Phys. Lett* **22** 1174

[14] Faure J et al. 2002 *Phys.Plasma* **9** 756