Electron Jet Generation by Laser Plasma

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Abstract

The generation of high energy electrons by high intense laser was examined. The laser pulses with 2 TW, 100 fs were used for generating plasma. They were focused in nitrogen gas, which generated thin plasma and electron jets transversely. We measured the radiation of the jets with imaging plates and emulsion track detectors. It was confirmed the radiation is transversely symmetrical x-ray and the mean energy of the x-ray is around 5 keV. The x-rays may be generated by bremsstrahlung of electrons of jets. The measurement of the radiation of the jets with imaging plate and emulsion track detector is discussed.

1 Introduction

We have already carried out an experiment of the laser acceleration of injected electrons[1]. In the process of the experiment, we found the generation of jets from plasma that spread transversely. The jets were visible to the naked eyes through a glass window. These jets were thought to be electron flows because they were bent in the external magnetic field. The length of the jets was from 10 to 20 mm long. Computer simulations also got results of the generation of jets from the laser plasma [2].

In order to measure the jets, we used some imaging plates(IP) and emulsion track detectors. The IP is a two-dimensional detector to measure radiation. Though it is used for measuring the two-dimensional distribution of radiation, it can be also used to estimate the energy of radiation with covering thin Al foils. The mean energy of x-rays is determined by the absorption coefficient in aluminum foil, while the energy of the electrons is estimated by the energy decrease of electrons in the foil.

The emulsion track detector is used to measure the tracks of high energy particles. Because the high energy electrons leave tracks in the emulsion while x-ray leave small dots or crumpled tracks of compton scatterings, it is possible to separate the electrons and x-rays by track shapes.

2 Experiments

The experimental setup for the measurement of the generation of laser plasma electrons is shown in fig.1. The plasma was generated in a gas chamber filled with Nitrogen gas by focusing laser pulses with a wavelength of 790 nm, a mean pulse energy of 200 mJ, a pulse length of 100 fs and a diameter of 40 mm. The laser pulses were generated by a Ti:Sa laser system with a chirped pulse amplification at 10 Hz. The laser pulses were injected into a vacuum chamber through a glass window and were focused by an off-axis parabolic mirror with a focal length of 480 mm. The radius of the beam waist in vacuum was estimated as 12 μm. The laser pulses ionized the gas at the focus and then generated thin plasma there. The images of plasma were taken through a window at the side of the chamber by a CCD camera synchronized with the laser system. In order to measure electrons or x-rays from the plasma, we set the several imaging plates on upper and lower sides or right and left sides of the focus. Their distances from the focus are around 23 mm long.

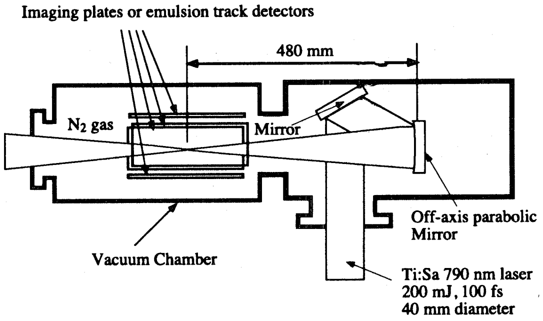

Fig. 1 Experimental setup for the generation of laser plasma electron.

2.1 Imaging plate

The IP is very useful for the measurement of x-rays and particles, because of its high resolution, wide dynamic range, and the possibility of computational analysis. It is very similar to the x-ray film, but it does not need to be developed. After the irradiation on IP, we can read it by an IP scanner. The profile of the IP is shown in Fig.2. The luminescence layer is made of $BaFBr:Eu^{2+}$ fine crystals of 3-5 μm which is photo-stimulated luminescent material. The $BaFBr:Eu^{2+}$ crystals emit light of the wavelength 400nm after the stimulation of He-Ne laser light from IP reader if they have been excited by x-ray or high energy electrons. The IP scanner can detects the photo-stimulated luminescence from the crystals with a photo multiplier tube. As the signals are taken by scanning the laser position and are converted to 8 bit or 16 bit digital data, the numerical radiation image information can be obtained. For the protection of the surface, there is a protection layer of 11 μm polyethylene terephthalate (PET) on the luminescent layer. As the IPs lose their information by even faint light, they must be covered with an envelope of black paper.

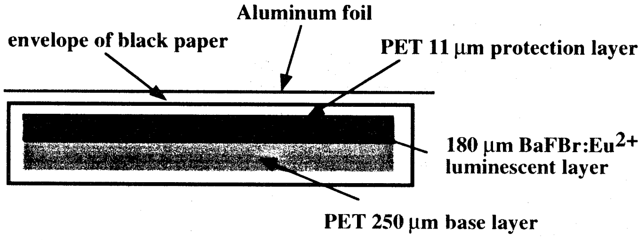

Fig. 2 Profile of Imaging Plate.

2.2 Energy loss of electron in material

In order to estimate the energy of the electrons or x-rays, we put some sheets of aluminum foil on the IP. The ionization energy loss of electrons in materials is given by

$$\frac{dE}{dx}=-\frac{4Cm_ec^2}{\beta^2}\ln\left[\frac{\beta^2m_ec^2}{2I}-\frac{1}{2}\ln 2+\frac{1}{2}\right] \qquad (1)$$

where $C=\pi r_e^2ZN/A=0.150Z/A$, Z is atomic number, A is mass number, r_e is classical radius of electron, N is Avogadro number, I is the mean ionization energy, m_e is mass of electron, c is the speed of light, β is the ratio of the speed of the electron to the speed of light c. The minimum energy of an electron that can penetrate in nitrogen gas, some sheets of aluminum foil, a paper envelope and a surface protection layer was calculated by eq. (1). Minimum penetration energy in materials are shown in Fig. 3.

	Material	Energy [MeV]
A	23 mm path length in N_2 gas at 40 Torr	6.75
B	A + Surface protection layer of IP	28.0
C	B + a sheet of black paper	93.2
D	C + 15 μm aluminum	106
E	C + 30 μm aluminum	117
F	C + 45 μm aluminum	128
G	C + 60 μm aluminum	139
H	C + 75 μm aluminum	149

Fig. 3 Minimum penetration energy of electron in materials.

2.3 Attenuation of x-ray intensity in aluminum foil

We can also estimate the x-ray energy from the intensity attenuation on an IP with several sheets of aluminum foil. The intensity of radiation depending on the thickness of aluminum foil is given by the following formula,

$$I=I_0\exp\left(-\frac{\mu}{\rho}x\right) \qquad (2)$$

where I, I_0, μ/ρ, x are radiation intensity, an incident intensity, mass attenuation coefficient and mass thickness of aluminum foil respectively. As μ/ρ is a function of energy of x-ray, we can estimate the energy of x-ray by μ/ρ. The function μ/ρ was calculated by the NIST x-ray mass attenuation database [3]. The calculated ratio I/I_0 is shown in Fig. 4. The strong attenuation at 2 MeV is due to the K-shell absorption at 1.56 MeV.

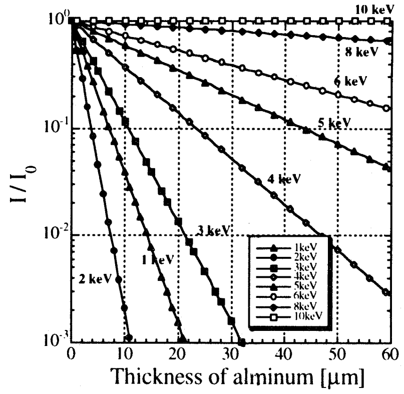

Fig. 4 The x-ray attenuation ratio for several x-ray energies as a function of the thickness of aluminum.

2.4 measurements of electron jets

Some images of the laser plasma for several gas pressures from 22 mTorr to 760 Torr were taken by a CCD camera as shown in Fig. 5. The plasma was the thinnest at 22 mTorr, but it got wider as the gas pressure was increased. The plasma was the widest at 50 Torr and generate jets transversely. The direction of the jet was not exactly transverse but somewhat tilted to forward. The jets were symmetrical but not stable and changed the tilt angle at every pulse. They seemed to have two modes of jet generation as they had two kinds of tilt angles. We thought jets were high energy electron's flow, because they were bent by magnetic field.

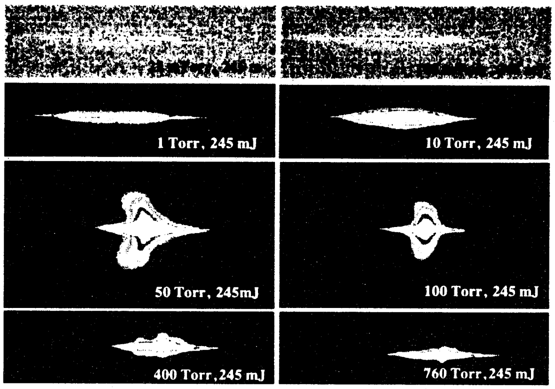

Fig. 5 The CCD images of laser plasma taken through a side window. The jets appeared from 10 torr to 100 Torr.

The radiation images of the jets were measured by IP at the bottom and side of plasma at 20 Torr. As the both images had almost same radiation intensity; the bottom one had 8.6 PSL (Photo-Stimulated luminescence per Square) and the side one had 7.8 PSL, the radiation from the jet was symmetric and did not depend on the direction of the laser polarization.

Then we measured the intensity on IP from 6 Torr to 150 Torr of nitrogen gas pressures. Any aluminum foil was not used in this measurement. The intensity at the maximum point for each gas pressure is shown in Fig.6. The intensity was the strongest at 40 Torr. Because the jet was the largest at 50 Torr as described above, the intensity of radiation and the generation of jets are closely related.

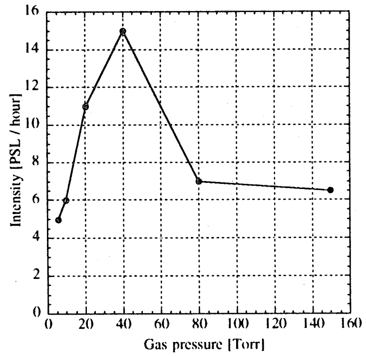

Fig. 6 Gas pressure dependence of the radiation from the plasma.

2.5 energy measurement of the radiation

We also measured the radiation from jet with IP covered with aluminum foil. The pressure of the nitrogen gas was fixed at 40 Torr and the number of the sheets of aluminum was changed from zero to four. The radiation images on IPs are shown in Fig. 7. There are radiation images except (e). If the radiation is electron, the energy is estimated above 139 keV, considering the range of electrons in the materials from the plasma to IP (see fig. 3). If they are x-rays, the energy of x-ray is estimated as much as 5 keV by eq.(2). We could not identify the radiation by the measurements only.

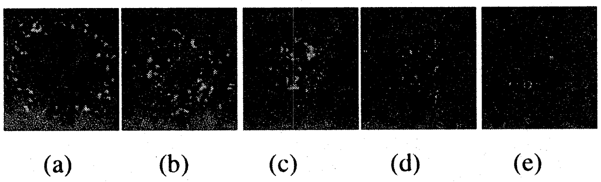

Fig. 7 The radiation intensity distribution on IP with and without aluminum foil. (a) reference measurement without aluminum foil, (b) with 1 sheet of 15μm aluminum foil, (c) 2 sheets, (d) 3 sheets (e) 4 sheets. The intensity on (e) is almost background level. The maximum intensities for each are 22, 6.5 4.5, 2.5 and 2.0 PSL respectively.

In order to identify the radiation, we measured the radiation with emulsion track detectors. The profile of an emulsion track detector is shown in Fig. 8. The emulsion was covered with an envelope made of aluminum and shading paper, because faint light could expose the emulsion. A window of thin aluminum foil was on a rectangular hole of the envelope. The emulsion detector has to be developed after the irradiation is finished. The track images can be obtained with a microscope operated automatically. The emulsion can measure not only the position but also the direction of the track.

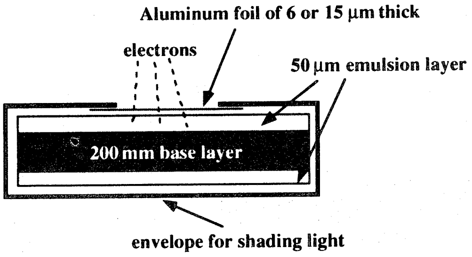

Fig. 8 Profile of an emulsion track detector. In order to reduce the energy decrease of electrons in material, a window with thin aluminum foil is on a hole of an envelope.

A image on the emulsion is shown in Fig.9. We could get only small dots and no connected chain-like tracks. It implies that high energy electron more than 100 keV did not go through the emulsion.

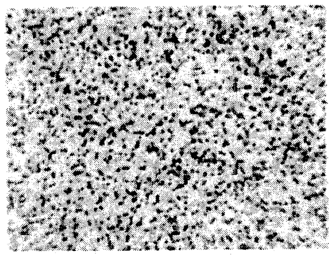

Fig. 9 Image of emulsion with radiation from jets of laser plasma. Dots are intrinsic fogs in emulsion or tracks of x-rays from jets.

Discussion

The electron jet of laser plasma was measured by three ways: CCD images, radiation images on IPs and emulsion track measurements. We could not measure the electron directly but the x-ray from the electron jet, because the electron energy from the jet was not high enough to penetrate nitrogen gases, an envelope and a protection layer of the IP or a sheet of Al foil for emulsion track detector. We think all of the electrons from the jet stopped in the materials. They should have emitted bremsstrahlung x-rays with the energy around 5 keV. As the gas jet image and the x-ray image on IP are symmetrical, the electron emission may be also symmetrical. The mean energy of electrons is estimated as about 10 keV nearly twice of the x-ray energy 5 keV considering an energy distribution of bremsstrahlung.

The process of the generation of electron jet is not still clear. Symmetrical radiation suggests it is due to transverse laser wake field. This interpretation may also supported by a large acceleration gradient of laser wake field acceleration at the gas pressure of helium larger than 20 Toor [1].

References

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[3] J. H. Hubbell and S. M. Seltzer. http://physics.nist.gov/