IMPROVEMENT OF ELECTRON GENERATION FROM A LASER PLASMA CATHODE THROUGH MODIFIED PREPLASMA CONDITIONS USING AN ARTIFICIAL PREPULSE

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Abstract

We are developing a laser plasma cathode, which is expected to enable us to realize a compact high-quality electron accelerator. A quasi-monoenergetic electron spectrum can be generated through ultraintense laser-plasma interaction. We investigated the correlation between the laser-plasma interaction and the generated electron properties via single shot measurement. We found that a preformed laser channel plays an important role to achieve the monoenergetic spectrum. We also carried out the modification of the preplasma conditions with an artificial prepulse and the external magnetic field to improve electron generation from a laser plasma cathode.

INTRODUCTION

Acceleration of plasma electrons using a laser wakefield is the most promising process to produce compact accelerators, because a very high acceleration gradient can be achieved through the interaction of ultraintense laser fields with plasmas. Applications of such a high field may include high-energy accelerators, compact medical accelerators, plasma physics, and laboratory astronomy. Recently, remarkable experimental results have been reported that a quasi-monoenergetic electron spectrum could be obtained through self-injected laser plasma acceleration. Moreover, the duration of such beams can be very short, ~50 fs. This fact, feasibility of the monoenergetic acceleration, has great significance for the future development of a high-quality compact electron source via laser-plasma interaction. In future, in order to realize a practical accelerator using laser plasma acceleration, stability of electron generation through the laser plasma interaction becomes very important.

MONOENERGETIC ELECTRON GENERATION

We have been studying the laser plasma acceleration with a table-top tera-watt laser system in our facility[1-4]. The laser system, which has been implemented for this experiment, generates ultrashort intense laser pulses on the basis of the chirped pulse amplification technique. The system consists of a laser oscillator, a pulse stretcher, a regenerative amplifier (REGEN), three multipass amplifiers, and a laser compressor. We use an acoustooptical crystal called DAZZLER (Thales Laser), which is installed between the stretcher and the REGEN, to modify the shape of the laser spectrum and phase correlation so as to optimize the pulse duration after compression. The specifications of the system are as follows. The pulse duration is 37 fs. The central wavelength is 790 nm. The maximum pulse energy is 600 mJ. The repetition rate is 10 Hz. The laser prepulse consists of three components. The first one is the amplified spontaneous emission (ASE) from the REGEN that has a nanosecond duration composing the laser pedestal, the second one is the leakage of the main pulse from the REGEN during amplification, and the third one is a satellite pulse that is generated one period before the main pulse from the oscillator. The ASE level in these experiments is estimated with a third-order cross-correlator as 5×10^{-7} at 150 ps before the main pulse. The length of the laser pedestal can be controlled through a Pockels cell after the REGEN that is called the pulse cleaner, with an extinction ratio of 1/400 and a rise time of 2 ns. The leakage pulse arises during round trips of the main pulse in the REGEN with a period of 8 ns. Thus, the leakage pulse arrives 8 ns before the main pulse. The contrast of the leakage pulse to the main pulse is approximately 2×10^{-5}. Then, 4 ns before the main pulse, there exists the satellite pulse, with a contrast of 1×10^{-4}. The leakage pulse and satellite pulse are compressed in the same manner as the main pulse; thus, they also have a femtosecond pulse duration.

The experimental setup is shown in Fig. 1. Approximately 0.5% of the energy of the main pulse is extracted through a splitter and is used as a probe pulse for the plasma diagnosis. The laser main pulse is focused on a gas jet using an off-axis parabolic mirror with a focal length of 178 mm. The gas jet assembles a shock-free gas nozzle with a Mach number of 5 and a fast gas valve. The probe pulse passes through the gas jet at a right angle to the propagation direction of the main pulse. The time delay of the probe pulse can be shifted through the delay path on a motorized slide stage. The probe pulse is then led to a CCD camera through an imaging lens. A Schlieren image or an interferogram can be taken when a wire target or a biprism is installed behind the imaging lens respectively. Emitted electrons irradiate on a fluorescent screen (DRZ) placed downstream from the gas jet. Light emissions from the screen are measured with another CCD camera combined with an image intensifier. In front of the screen, titanium foil with a thickness of 300 mm is placed to eliminate low-energy electrons. Electron energy spectra can be obtained when a deflection magnet is placed between the gas jet and the screen. An integrated current transformer (ICT) can measure the charge of electron beams. These measurements can be performed in one shot. A shadowgraph, interferogram, and Schlieren image can be taken with a femtosecond probe pulse. When the delay is adjusted so that the probe pulse arrives before the main pulse, we can observe the preplasma produced by the prepulse. The polarization of the laser main pulse at the target can be rotated to be vertical or horizontal with a height shifter within the laser path. When the polarization is set vertical, it allows us to observe Thomson scattering, with the same CCD camera to measure the shadowgraph.

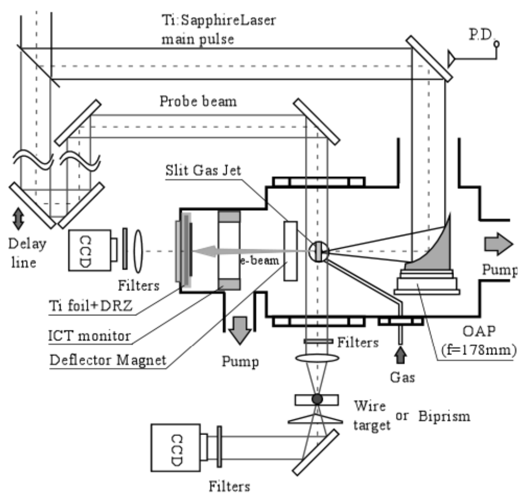

Figure 1: Experimental setup.

An energy spectrum can be obtained if we put a bending magnet behind the gasjet. Fig.2 shows energy spectra generated from a laser plasma cathode in the experiments. The experimental conditions are as follows. The gas density is 4×10^{19} cm^{-3}, the laser power 11 TW, the laser intensity 2×10^{19} W/cm^2 . As shown in Fig.2(a), in these conditions the energy spectrum shows 100% energy spread, though we could observe sometimes the quasi-monoenergetic spectrum as Fig.2(b). The energy peak was located at 11.5 MeV when we obtained the quasi-monoenergetic spectrum. The energy spread fluctuates shot by shot. The smallest energy spread we obtained in this experiment was $\Delta E/E \sim 10\%$(FWHM).

To investigate a mechanism of such monoenergetic electron generation, we observed the laser Thomson scattering in the plasma combined with a shadowgraph image. The polarization direction of the laser main pulse in this case is perpendicular to the propagation direction of the probe pulse. Therefore, the Thomson scattered light of the main pulse in the plasma comes into the same direction of the probe pulse propagation. Figure 3 shows the distribution of the Thomson scattered light in the plasma superimposed with a shadowgraph obtained at the same time. The arrival time of the probe pulse is 5.2 ps after the main pulse. This image can be obtained at the same time with the energy spectrum. Figure 3(a) and (b) correspond to fig. 2(a) and (b) respectively. The monoenergetic case, in fig.3 (b), we can see a line-shaped distribution in the Thomson scattering along the laser pulse propagation, beyond 300 μm length, around the focal point. If we magnify this image, we can know that this line-shaped distribution consists of periodically aligned dots. The reason of such distribution can be regarded that the main laser pulse undertakes focusing and defocusing several times in the plasma. In some numerical simulations, such focusing and defocusing are confirmed to be possible, if there exists a proper plasma density channel along the laser pulse propagation.

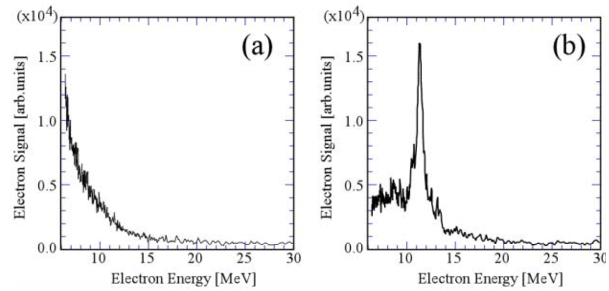

Figure 2: Electron energy spectra. (a) 100% energy spread. (b) Quasi-monoenergetic.

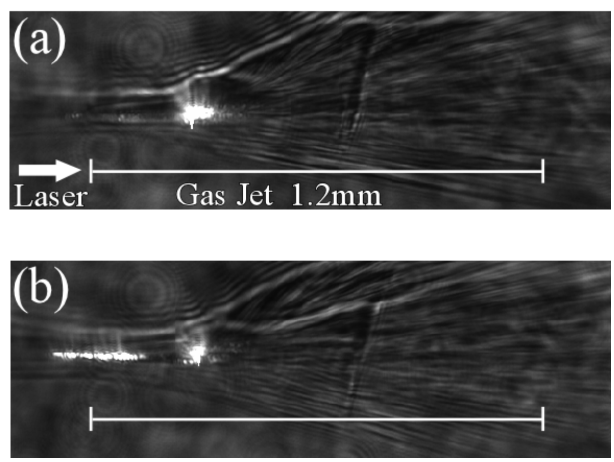

Figure 3: Distribution of Thomson scattered light of main laser pulse superimposed on shadowgraphs. (a) 100% energy spread case. (b) Quasi-monoenergetic case.

PREPLASMA CONTROL

In our previous studies, it has been shown that prepulse effects and consequent preplasma control play a very important role in the laser plasma acceleration. These effects determine generated electron properties such as emittance, energy spread, electric charge, and so on. Therefore, if we can control the preplasma conditions somehow, we can control the electron generation to some degree. And if we can find a scheme that makes electron generation less sensitive to fluctuations of various experimental conditions, such scheme can be used to stabilize the laser plasma acceleration. In order to search such kinds of schemes we investigated the effects of an artificial prepulse and of an external magnetic field.

Figure 4 shows the setup for the artificial prepulse. On the gasjet inside a vacuum chamber, an artificial prepulse carrying 10% energy relative to a main pulse is focused. The duration of the artificial prepulse is approximately 300 ps. This artificial pulse can make a preplasma, 0 ~ 2 ns before the main pulse arrival. Produced plasma can be observed with a probe pulse that travels through the gasjet on the same axis to the artificial pulse. The probe is separated from the artificial pulse through a colour selective mirror. The intensity of the artificial pulse on the gasjet is approximately 3×10^{14} W/cm^2.

Figure 5 shows shadowgraphs of the preplasma obtained with a probe pulse. We can see the preplasma produced by an artificial prepulse as well as line-shaped plasma produced by the intrinsic prepulse accompanied by the main pulse. The position of the artificial preplasma can be shifted by changing the focal point of the artificial prepulse.

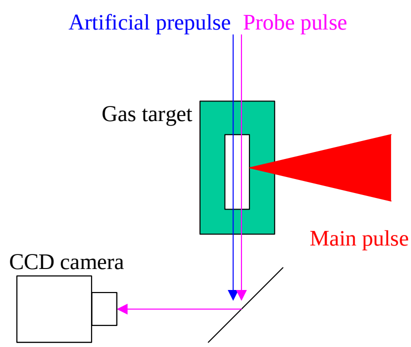

Figure 4: Experimental setup for an artificial prepulse.

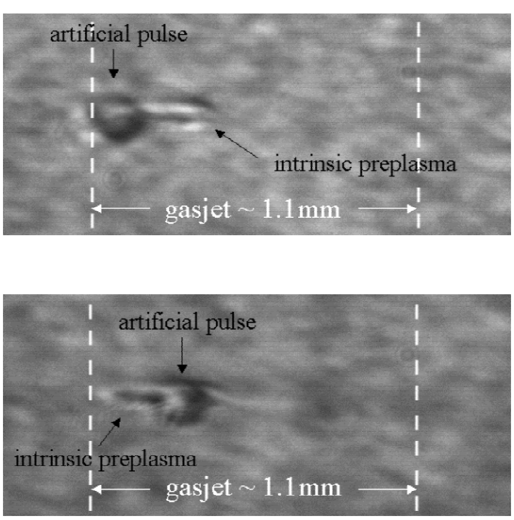

Figure 5: Shadowgraphs of preplasma distributions.

Figure 6 shows the effect of the external magnetic field applied on the gas jet coaxially to the main pulse propagation. The generated electron profiles obtained at 25 cm downstream from the gas jet are shown in Fig. 6. In case of no magnetic field, the size of electron profile is widely spread into approximately 60 mm diameter. In case that the magnetic field of 0.2 T is applied, the divergence of the electron ejection is greatly improved and the size of the profile shrinks into 3.6 mm diameter on the screen. Moreover, we observed great improvement of the stability and reproducibility of the electron generation from a laser plasma cathode when we applied the magnetic field on the laser plasma interaction point.

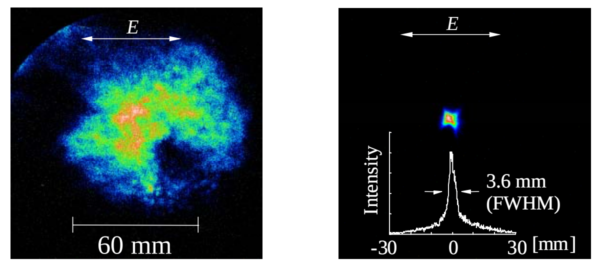

Figure 6: Effect of the magnetic field on electron generation from a laser plasma cathode.

CONCLUSIONS

We are developing a laser plasma cathode to realize a compact advanced accelerator. To improve the stability of the electron generation from the laser plasma cathode and to modify the electron beam properties, the control of the preplasma conditions is very important. By changing the prepulse conditions, we carried out single-shot plasma diagnosis and electron detection. We observed that quasi-monoenergetic electron spectrum could be generated frequently in a certain prepulse condition. Also we tried to control the preplasma conditions by means of an artificial prepulse. We constructed the setup to produce the artificial preplasma. Moreover, we examined the effects of the external magnetic field applied on the interaction point and we observed great improvement of the divergence and the stability of the generated electrons.

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