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Absolute calibration of imaging plate for GeV electrons

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An imaging plate has been used as a useful detector of energetic electrons in laser electron acceleration and laser fusion studies. The absolute sensitivity of an imaging plate was calibrated at 1 GeV electron energy using the injector Linac of SPring-8. The sensitivity curve obtained up to 100 MeV in a previous study was extended successfully to GeV range. © *2008 American Institute of Physics.* [DOI: 10.1063/1.2940217]

Recently, there has been remarkable development in the field of high-intensity short-pulse laser technology. By focusing such laser light on materials, interaction intensities of over 10^{18} W/cm^2 can be obtained. At such intensities, the laser-plasma interaction can produce strong x rays, γ rays, fast ions, and relativistic electrons. In laser fusion studies, the fast ignition scheme is a reliable method for achieving ignition. Relativistic electrons of a few MeV that are generated by the laser-plasma interaction play an important role in fast ignition scheme.[1,2] Moreover, in laser acceleration studies, extremely energetic electrons can be generated by exciting a coherent plasma wave with an ultraintense laser (known as a laser wakefield).[3] In the past few years, rapid progress has been made in laser acceleration studies. Quasimonoenergetic electron beams have been generated using laser wakefields.[4–7] Last year, Leemans *et al.* generated quasimonoenergetic electrons of over 1 GeV,[8] while our group observed electrons of over 600 MeV that had a continuous spectrum.[9] In these studies, electron spectrometers (ESMs) are used for estimating the absolute number of electrons in an energy spectrum. ESMs are subjected to very strong electromagnetic pulse (EMP) noise that originates from ultraintense laser-plasma interactions. Ultrashort high-peak-power lasers, which have pulse widths in the picosecond or femtosecond region, can generate a lot of energetic electrons within an extremely short time. This sudden generation of energetic electrons results in strong EMP noise. It is thus difficult to use electronic devices as detectors for ESM when they are placed in the vicinity of the electron-generation point. Then we have used an imaging plate (IP) that is nonelectronic detector such as photographic film.[10] IPs make use of the photostimulated luminescence (PSL) effect and are time-integrated detectors for radiation such as x rays, electrons, positrons, and ions. Calibration of IP sensitivity is essential in order to obtain the absolute electron number using ESM. In a previous study, an IP was calibrated for electron energies up to 100 MeV using a β-ray source (^{147}Pm) and a linear accelerator (Linac) in Osaka University. Even in this previous study, the sensitivity of IP was observed to be gradually decrease with increasing the electron energy from 10 to 100 MeV, while it should be flat from the energy deposition estimated by Monte Carlo simulation.[10] Then, IPs need to be experimentally calibrated above 100 MeV if we estimate the total number of GeV-class electrons with IP.

In this study, we performed the calibration of IP for 1 GeV electrons with SPring-8 Linac. To our knowledge, this is the first time that a film-type detector has been experimentally calibrated using GeV electrons. It was proved that IP is sufficiently sensitive for GeV electrons.

A 1 GeV electron beam was generated from a Linac, which was the electron injector of SPring-8, an 8 GeV synchrotron radiation facility.[11] The experiment was performed at the L3 beam transport line in SPring-8 Linac. The electron energy was tuned to 1.0 GeV. The error for the electron energy 1.0 GeV is $\pm 0.3\%$ or less. The total charge of a pulse was adjusted to be less than usual and tuned to be 0.01 nC in order to prevent the IP becoming saturated. The total charge was estimated by monitoring with a current transformer.[12] The measurement error for the total charge is $\pm 15\%$. The spot of the electron beam was also expanded as much as possible for avoiding the saturation and the diameter of this beam is ~ 1 cm. This diameter is small enough compared to a vacuum flight tube (3.2 cm). Therefore, the electron beam can pass through the flight tube without any significant charge loss in beam transport. The experimental setup is shown in Fig. 1. The electron beam generated from Linac makes a 90° turn to L3 beam transport line with bending magnet, as shown in Fig. 1(a). IP was irradiated after the 90° turn. To expose the IP, the electron beam was taken out from

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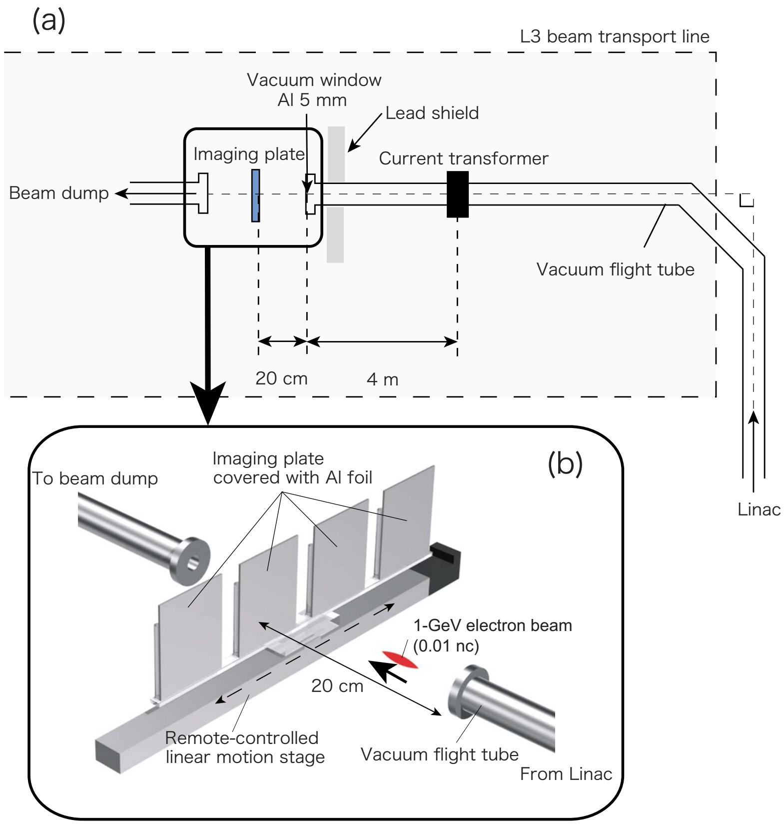

FIG. 1. (Color online) (a) Setup for the calibration of an imaging plate for 1 GeV electrons. (b) The close-up of the experiment at the vicinity of imaging plates.

the vacuum flight tube through a 5-mm-thick aluminum window. A motorized array of IPs was placed 20 cm away from the vacuum window, as shown in Fig. 1(b). The 1 GeV electron beam passed through the IP and entered the vacuum flight tube again, which was terminated by a beam dump. The current transformer measures the charge at 4 m in front of the vacuum windows. The energy spread of the electron beam is limited to less than 1% by the 90° turn and the size of the vacuum flight tube. The IP used for this calibration was BAS-SR2025 (FUJIFILM), and the reader was BAS-1800II (FUJIFILM). The IP was covered with a 15-μm-thick Al foil to ensure that it was not exposed to visible light, which can result in data stored on the IP being erased. 80 min after irradiation by a 1 GeV electron beam, the stored information was read out by the reader. During these 80 min (termed the fading time), the room temperature was maintained at 23 °C. Fading is the phenomenon in which the PSL value decreases in time after exposure to radiation. The damping rate of the PSL value has been already studied.[10,13] The sensitivity has been corrected for this fading time.

An obtained image in the calibration experiment is shown in Fig. 2. The spatial distribution of the electrons is nonuniform since the beam size was adjusted to be as large as possible to avoid saturation. The linear response of the output of the IP to electron number has already been shown for a different type of IP (FDL UR-V),[14] while our group verified the linear response of the IP used in this calibration (BAS-SR2025) by using a β-ray source. Therefore, the total PSL value can be evaluated by integrating the spatial distribution of PSL value. The total PSL value was 2.6×10^5 PSL. The statistical fluctuation of total PSL value is $\pm11\%$ (rms). There were three shots in this calibration experiment. The absolute sensitivity of an IP is defined as the PSL value per electron; it can thus be derived by dividing the integrated PSL value by the total number of electrons that irradiated the IP. The sensitivity for 1 GeV electron was 4.1×10^{-3} PSL/electron. The open circle indicates the sensitivity value with this error ($\pm18\%$) in Fig. 3. In Fig. 3, the sensitivity of an IP up to energies of 100 MeV is plotted by making use of data given in Ref. 10.

The contribution of bremsstrahlung x ray from aluminum vacuum window was checked using Monte Carlo simu-

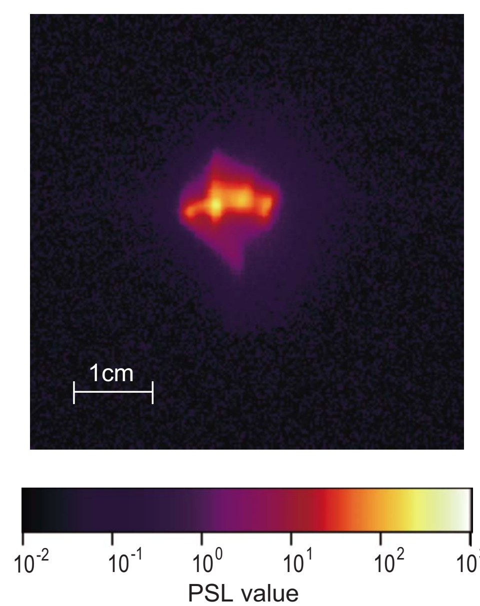

FIG. 2. (Color online) Electron beam profile recorded on the IP.

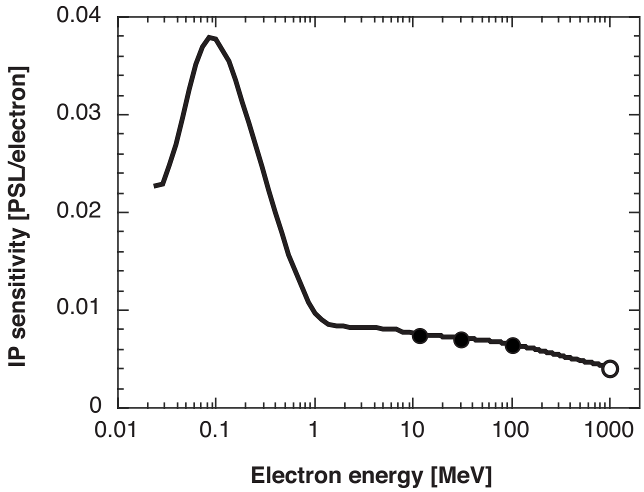

FIG. 3. Calibrated sensitivity curve for electrons up to 1 GeV. The sensitivity up to 100 MeV was plotted by using data given in Ref. 10. The absolute sensitivity for 1 GeV electron is shown as open circle. The solid line is an interpolation curve.

lation (EGSnrc code).[15] The effects for photon and electron were evaluated on IP. The IP sensitivity for photon was estimated at a separate experiment using gamma-ray sources.[16] The photon sensitivity is one order smaller at a few MeV and two orders smaller at 10 MeV than the electron. The energy spectra of photon and electron were obtained by Monte Carlo simulation when 1 GeV electron beam pass through the vacuum window. From estimated photon spectra, 97% of the photons is below 10 MeV. From these spectra and the sensitivities of electron and photon, the bremsstrahlung x-ray contribution to our absolute calibration can be estimated to be 3%.

We have examined possible reasons how to explain the sensitivity reduction at 1 GeV compared to the 10–100 MeV points. These could be (1) the contribution to charge from a low energy tail filtered by the aluminum vacuum window, (2) beam transport error, and (3) x-ray contribution. As described earlier in the text, we conclude that these sources do not explain the sensitivity reduction. This slow reduction in electron energy is left for a future study.

Phosphor screens such as Lanex (Kodak) are often used[8,17] as time-integrated detectors since they are not affected by EMP noise. The fluorescence image on the phosphor screen is detected using a second detector such as a charge-coupled-device camera. The fluorescence image is relayed to the second detector by relay optics. EMP noise can be avoided by inserting the second detector in the shield area. By using this detection system, it is possible to obtain a shot by shot spectrum by using an electronic device as the second detector; in contrast, an IP cannot monitor shot by shot. However, since relay optics have to be inserted between the phosphor screen and the second detector, an absolute calibration has to be performed for the total system.[18] It is thus very difficult to perform a universal calibration for the ESM using a phosphor screen. On the other hand, ESMs that use an IP as a detector are capable of providing an absolute calibration by estimating the sensitivity of the IP.

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