Generation of intense terahertz radiation from laser-produced plasma of metal foil target

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***Abstract*— We observed high-power terahertz (THz) radiation from a metal foil target excited by terawatt laser pulses. The radiated terahertz pulse spectrum obtained by a Martin-Puplett interferometer was distributed from 0.1 to 0.75 THz. We found that radiation power was significantly increased as the excitation laser power increased. A power-law correlation with an exponent of 2 - 4 was estimated using a curve fitting.**

I. Introduction And Background

RECENTLY, we reported strong THz radiation from a laser-produced plasma of a metal foil target by using an amplified femtosecond laser system [1-3]. These intense THz pulses are useful for advanced applications, e.g., single-shot THz imaging, and observing the far-infrared nonlinear optical effect, saturable phenomena, and ionization dynamics [4]. We also obtain a lot of information about laser-produced plasma dynamics by studying the radiation mechanisms necessary for several applications, e.g., a coherent X-ray laser and a compact ion accelerator to investigate laser-plasma interaction. We report the results of a radiated spectrum obtained by a Martin-Puplett interferometer and the dependence of radiation power on laser pulse energy.

II. Experimental Setup

i. Table-top terawatt laser system

We used a constructed table-top terawatt laser system (JLITE-X) that uses chirped pulse amplification and multipass amplifiers [6]. This system produces a peak power of 3 TW and a width of 35 fs (FWHM) at a wavelength of 800 nm. In this laser system, the temporal shape of the laser pulse is composed of prepulses of which the contrast ratio between the prepulse at about 12.5 ns before the main pulse is 10^{-5}.

ii. Terahertz wave detection system

Figure 1 shows a schematic diagram of the experimental setup (top view). The experiments were performed in a vacuum chamber, which was evacuated to pressures less than 10^{-5} Torr. The linearly polarized laser beam, which propagated in the vacuum chamber, was focused obliquely onto the 5-μm-thick Ti foil target surface by a 45º off-axis parabolic (OAP) mirror with an *f*-number of 640 mm. The peak intensity was estimated to be about 10^{17} W/cm^2. The THz radiation generated on the front surface was detected by a silicon bolometer via a Martin-Puplett interferometer. We confirmed that polarization of the THz radiation was almost parallel to the laser incident plane [2]. Therefore, we mounted a wire grid polarizer (WG 1), as shown in Fig. 1. The Martin-Puplett interferometer outside

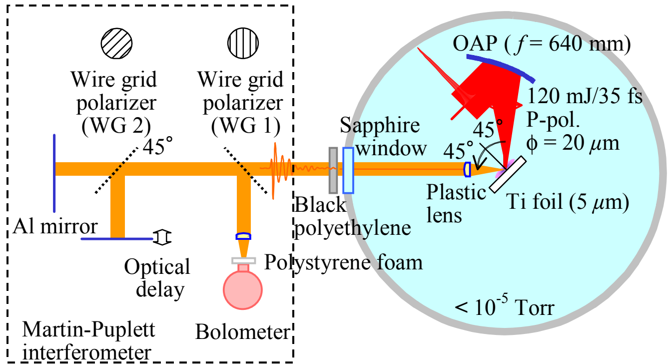

Figure 1. The schematic diagram of the measurement system.

of the vacuum chamber was mounted at 45˚ in the forward direction toward the target. The THz radiation propagated outside of the vacuum chamber through the view port. We used several two-color filters because the bolometer detected electromagnetic waves between microwaves to infrared waves [1-2]. The emitted radiation was collected by a plastic lens and focused onto the bolometer. The maximum frequency of detected THz radiation in this system was limited by a sapphire window of which the cutoff frequency was about 3 THz.

III. Results And Discussion

The interferogram of the detected terahertz radiation from the Ti foil target generated by the laser-produced plasma is shown in Fig. 2. The interferogram exhibits a monocyclic waveform, which has a pulse width of about 5 ps. This result shows that the detected terahertz radiation was composed of a broadband spectrum. The inset shows a Fourier spectrum transformed from the interferogram. The spectrum was distributed from 0.1 to 0.75 THz. The radiated THz wave had a pulse duration of about 2 ps seen in the measured spectrum assuming a transform-limited pulse. This value is similar to the accelerated electron bunch width near the laser plasma, which is predicted from a simulation [7].

We also investigated the radiation efficiency dependence on laser condition. The radiation power characteristics of the excitation laser pulse energy are shown in Fig. 3. Note that we used a DTGS detector in this measurement because the detected signal at the bolometer was overloaded. We found that radiation power was significantly increased as the excitation laser power increased. A power law correlation with an exponent of 2 - 4 was estimated using a curve fitting. This result is not similar to the results reported by Hamster *et al.* [8-9].

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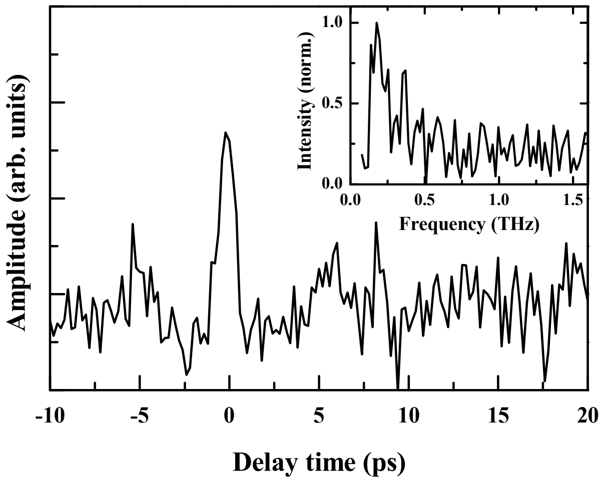

Figure 2: Interferogram of detected electromagnetic waves. Inset shows amplitude Fourier spectrum obtained from interferogram.

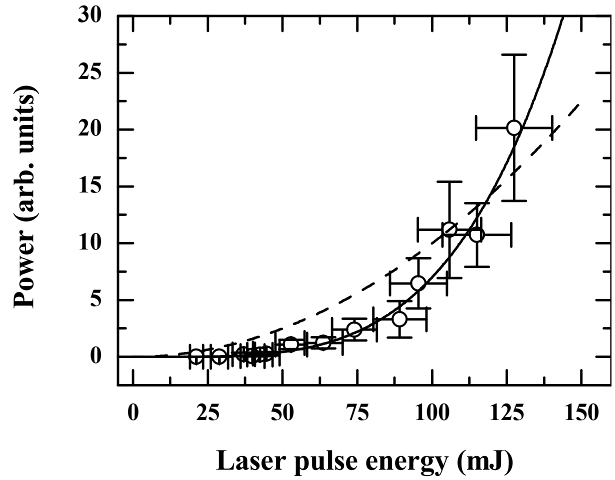

Figure 3. Radiation power characteristics vs. laser pulse energy. Solid line and dashed line show quadric curve fitting and square curve fitting as a function of laser pulse energy, respectively.

Generally, an electromagnetic wave $\mathbf{E}_{\mathrm{rad}}$ radiated by a relativistic electron is expressed as

$$\mathbf{E}_{\mathrm{rad}} = \frac{q_{\mathrm{e}}}{4\pi\varepsilon_0}\frac{\mathbf{n}\times\left\{(\mathbf{n}-\boldsymbol{\beta})\times\dot{\boldsymbol{\beta}}\right\}}{c\alpha^3 R}. \quad (1)$$

Here, q_{e}, ε_0, and c are electron charge, dielectric constant in vacuum, and speed of light, respectively, and $\mathbf{n}$ is a radius unit vector. The relative velocity vector and acceleration vector are $\boldsymbol{\beta}(=\mathbf{v}/c)$ and $\dot{\boldsymbol{\beta}}(=d\boldsymbol{\beta}/dt)$, respectively. α is expressed by $1-\mathbf{n}\cdot\boldsymbol{\beta}$, and R is the distance between the electron and observer. This formula means that the radiated field strength increases with increasing electron charge density and acceleration ratio. Moreover, the radiated field is significantly increased by the contribution of α^3 when the electron achieves relativistic motion. In our experiment, electrons with energies between 100 keV ($|\boldsymbol{\beta}| \approx 0.548$) to 1 MeV ($|\boldsymbol{\beta}| \approx 0.941$) were detected. There is also a report of relativistic electrons with a maximum energy of up to 3 MeV ($|\boldsymbol{\beta}| \approx 0.989$), which were generated by femtosecond laser pulses with an intensity of about 2×10^{18} W/cm^2 [10]. We think that the intense laser pulse generates a high density of electrons by tunnel ionization and accelerates relativistic electrons by laser-plasma interaction. Radiation power characteristics are explained by these contributions.

IV. Conclusion

Intense THz radiation from laser-produced plasma of a metal foil target was observed. We found that the radiated spectrum was distributed from 0.1 to 0.75 THz and significantly increased with increasing laser pulse energy. These results indicate that the radiation is caused by laser-induced relativistic electron bunch acceleration.

Acknowledgements

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