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THz emission in cluster plasma produced by two-color laser pulses
二色レーザーにより生成するクラスタープラズマからのTHz波発生

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We have studied THz emission from argon cluster plasmas produced by intense two-color laser pulses. The spatial distribution of THz radiation has been measured for the laser pulse durations of 200 fs and the laser energy of 10 mJ. The energy of THz waves emitted from cluster plasma in forward direction is enhanced by irradiating both pulses of the fundamental and second harmonics.

1. Introduction

The electromagnetic waves of the frequency 0.1~10 THz (herein after called "THz-wave" simply) are currently used for science and promising for more variety of applications such as information and communication technology, safety and security, biosensing, and medicine. To put these applications into practice, more intense THz-wave sources are desired. Some concepts and techniques to generate intense THz-wave pulses have been proposed [1][2]. By using optical reflection method in nonlinear crystal, THz-wave pulse of the energy of 0.4 mJ has been obtained [3]. However incident laser energy is limited by the damage threshold of the nonlinear crystal. Laser plasmas have benefit of damage-free as a THz-wave source. A. Gopal *et al.* show that 0.7 mJ THz-wave pulses have been obtained from the interaction between high power laser (>10^{19} W/cm^2) and plasmas [4]. THz-wave generation from gas plasmas produced by an intense laser has also studied. The gas target is easier for repetitive generation of THz-waves than solid targets. Minami *et al.* show that 1.4 MV/cm THz-wave pulses have been obtained from gas plasma by using four wave mixing method [5].

We have proposed the cluster plasma as the target, which combines both the advantages of the solid and the gas plasmas. Our preliminary study indicates that clustering-structure argon (simply, called "argon cluster") gas are more suitable for generating strong THz-wave than normal gases because of higher absorption [6][7]. Combining our results for cluster with the four wave method, the enhancement of THz-wave is promising. In this study cluster gas is irradiated with two laser pulses of different frequencies (here called two-color laser pulses).

2. Experiments

The experiment has been done with the T^6-laser, Kyoto University, a Ti:sapphire chirped-pulse amplification system operating with a central wavelength of 810 nm. The laser pulse duration is controlled by changing the distance between a pair of gratings composing of the pulse compressor in the laser system. The pulses are positively or negatively chirped beside the shortest pulse duration of 40fs. A BBO crystal is placed in the beam path to generate a second harmonic (SH) wave pulse together with fundamental wave. The laser pulses are focused by a spherical lens with a focal length of 200 mm into argon clusters. Argon clusters are generated in the center of a vacuum chamber by injecting argon gas with a backing pressure of 7 MPa [8]. The radius of a cluster is estimated to be ~ 10 nm, which corresponds to a number of ~ 10^4 atoms from the Hagena parameter. The chamber diameter and wall thickness are 100 mm and 4 mm, respectively. To measure angular distribution of THz emission, the chamber is made of fused silica glass with refractive index of 1.95

and transparency of 90 % at 0.5 THz [9]. THz emission from argon cluster plasma is collected and collimated by a polyethylene lens and detected by a helium-cooled InSb bolometer. A polystyrene foam plate and a thin black polypropylene filter are installed in front of the bolometer window, to exclude the laser pulses and unwanted lights emitted or scattered from the plasma. The angular distribution of THz waves is measured by rotating the detection setup about the center of the glass chamber. The spectrum is measured by a martin-puplett polarizing interferometer.

3. Results

Figure 1 shows the angular distribution of THz emission for the irradiations of (i) only the fundamental ($I_{\mathrm{THz}(\omega_0)}$) and (ii) the fundamental with SH waves ($I_{\mathrm{THz}(\omega_0+\omega_2)}$). The pulse duration of an incident laser pulse is 200 fs, of which pulse gives most intense THz in the last experiments. The energy of incident laser is 10 mJ. THz-wave energy is higher for two-color than that for only fundamental wave. THz-wave energy is enhanced especially in laser propagation direction. From the four wave mixing theory, the THz-wave field is

$$E_{\mathrm{THz}}(t) \propto \chi^{(3)} \sqrt{I_{2\omega}} I_{\omega} \cos(\phi) ,$$

where φ is the relative phase difference between the fundamental and SH pulses. $\chi^{(3)}$ is the third-order susceptibility tensor. $I_{2\omega}$ and I_{ω} are intensity of fundamental and SH pulses, respectively. Xu *et al.* show that $\chi^{(3)}$ varies with relative angle of polarization between fundamental and SH waves.

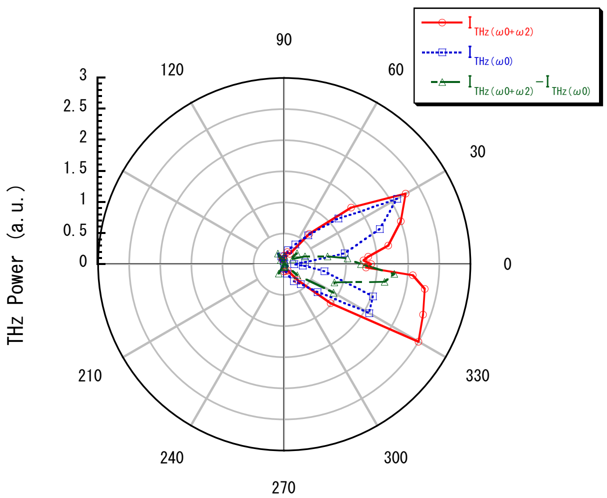

Fig.1. The angular distribution of THz emission for the irradiations of (i) only the fundamental ($I_{\mathrm{THz}(\omega_0)}$) and (ii) the fundamental with SH waves ($I_{\mathrm{THz}(\omega_0+\omega_2)}$).

Therefore there is potential for THz-wave to be enhanced much more by optimizing laser polarization.

4. Conclusions

The energy of THz-waves emitted from cluster plasma in forward direction is significantly enhanced by irradiating SH pulses besides the fundamental pules.

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