23P172-B

Characteristics of THz radiation from air plasma generated by two-color laser

二色レーザー励起大気プラズマからのテラヘルツ電磁波発生の諸特性

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Characteristics of THz radiation from air plasma generated by two-color laser, such as power, spectrum and angular dependency have been studied with particle-in-cell simulation. At low laser intensity, THz power increased nonlinearly against the laser intensity. As the laser intensity become higher than 10^{15} W/cm^2, it becomes slower than linear. Strong radiation at around 30 degree is found in addition to the radiation along laser propagation axis.

1. Introduction

Generation of intense THz electromagnetic wave has been of interest since its realization would allow new studies and applications in this direction. One of the promising approaches is to use plasma as the radiation source, especially using two-color laser [1-4], where a femtosecond laser pulse consisting of a fundamental frequency ω and its second harmonic 2ω which is usually obtained by second harmonic generation with nonlinear crystals such as type-*I* β-BaB_2O_4 (BBO) are focused to generate plasma in gas, which, during interaction with laser field radiates THz wave.

So far, most studies concerned with the method uses relatively low laser intensity at around 10^{14} W/cm^2. One obvious way to increase the THz power with this highly effective method is to increase the incident laser power. However, as the laser intensity increases, interaction between laser and plasma cannot be neglected.

At higher laser intensity region, there are a number of physical processes that would result in THz radiation, e.g., the processes of frequency up-shift in the front of a pulse and *k* vector downshift in its rear resulting in beat waves; pulse modulation owing to the refraction on the electron density ramp; steep plasma boundary, etc. It is therefore necessary to look into the interaction between femtosecond laser pulses and underdense plasma with kinetic simulations that self-consistently include plasma and atomic physics [5-8].

In this presentation, spectrum and power of broadband THz radiation from plasma generated by co-propagating laser pulses consisting of two frequency components, i.e., fundamental and second harmonics in air are studied for peak laser intensity of 10^{14}, 10^{15} and 10^{16} W/cm^2.

2. Simulations

To study characteristics of THz radiation, we perform PIC simulations using FPLaser2D [9, 10] with a moving window for a linearly polarized laser pulse propagating in air under normal pressure. The 2D calculations are performed for the laser intensity from 10^{14} (which is about the threshold intensity for air) to 10^{16} W/cm^2 and 90 fs FHWM duration. The calculation are performed both for a single pulse λ = 0.8 μm and for two laser pulses λ = 0.8 μm and λ_1 = 0.4 μm with total energy in the second harmonic ~ 0.3 times the energy of fundamental harmonic. The focus spot of fundamental harmonic is chosen to provide the Rayleigh length on the order of 1 mm; the focus spot of the second harmonic is same as that of fundamental harmonic. We use a 320 μm x 150 μm window and λ_1 / 10 spatial resolution; the kinetic cell is twice as large as the PIC one. The kinetic simulation was simplified by including only nitrogen molecules; the laser pulse is set as Gaussian.

Figure 1 shows the spectrum of radiation for the laser intensity at 10^{16} W/cm^2. There is a strong radiation at around 30^o, which is not seen in the spectra of radiation at lower intensities. Those spectra for lower intensity will be shown in the presentation.

Figure 2 shows the increase of THz power along laser propagation axis against the change in fundamental laser intensity. It is visible that there are two different slopes in the curves: up to the laser intensity I ~ 10^{15} W/cm^2, the power growth is faster than linear, while after the growth is slower than linear. An approximation function can be presented as following: $W \approx A(I/B)^{\alpha} e^{-B/I}$ with α = 0.7, A = 9 x 10^{-3}, and B = (2 - 3) x 1014 cm^2.

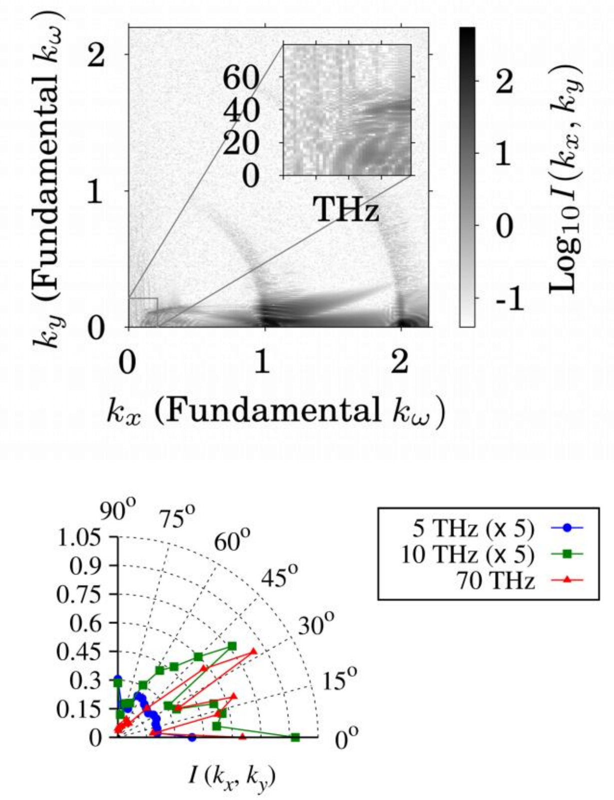

Fig. 1. 2D spectrum of p-polarized radiation in plasma and its angular distribution with the peak laser intensity of ω at 10^{16} W/cm^2. The label of inset indicates corresponding frequency in THz.

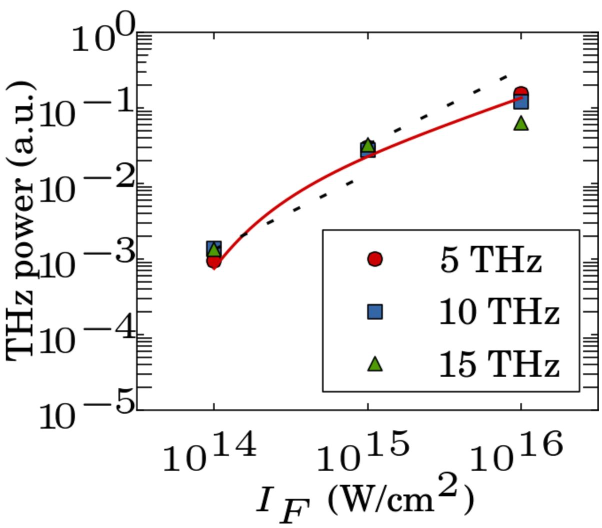

Fig. 2. The dependence of power of THz radiation on the laser pulse intensity at the emission angles at 0^o. Dotted lines indicate linear growth of THz power against the laser intensity.

4. Conclusion

In conclusion, we have studied numerically the radiation spectrum and the dependence of power of THz radiation from air plasma generated by femtosecond laser pulse consisting of fundamental and second harmonic components. In numerical simulations, we have found strong non-linear dependence of the THz power on the laser intensity. The power growth is faster than linear up to laser intensities on the order of $I \sim 10^{15}$ W/cm^2, then, the growth becomes slower than the linear; therefore the conversion efficiency reaches its maximum at $I \sim 10^{15}$ W/cm^2. This slowing in the growth rate may partly be attributed to the increase in the waist of beam, due to the refraction of the laser pulse by the induced plasma during its focusing in atmosphere.

Acknowledgments

Authors are grateful for the support of the computer room of ILE and the cybermedia center at Osaka University. This study was supported by Japan Science and Technology CREST and Global COE program in Ministry of Education, Culture, Sports, Science and Technology (Electronic Devices Innovation).

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