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Study on THz Wave Frequency Up-conversion by Flash Ionization

フラッシュ電離を用いたTHz波の周波数上昇に関する研究

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A frequency up-shifted from a source THz pulse is experimentally generated by the over-dense plasma that is rapidly created by ultra-intense femtosecond pulse laser. The center frequency of the source pulse is 0.35 THz is propagating a ZnSe crystal which is irradiated by short pulse laser. The magnitude of the upshifting frequency was controlled by laser intensity. We observed frequency up-conversion from 0.35 THz to 3.3 THz by the irradiance of the Ti:sapphire laser in ZnSe crystal.

1. Introduction

Over-dense plasma can be easily created by ultra-short intense pulse laser. Electromagnetic (EM) wave generated from such plasmas has a broad range of frequency which includes terahertz (THz) whose frequency is between traditional photonics and microwave frequency. THz region has many applications i.e, imaging, security, information-communication [1, 2].

Until now, high power tunable THz radiation source is using free electron laser [3]. But the system size is inconvenient for use in general applications [4, 5]. Development of compact and tunable THz source has been an open problem which we believe can be realized by using flash ionization. It is a physical phenomenon arising out of interaction between electromagnetic (EM) wave and over-dense plasma [6]. If an electromagnetic wave propagates in a homogeneous plasma, the wave suffers frequency up-shifting. The dispersion relation for angular frequency of up-shifting plasma ω_f is given by

$$\omega_f^2 = k^2c^2 + \omega_P^2 = \omega_0^2 + \omega_P^2, \qquad (1)$$

where k_0 is the wave number, c is the speed of light, ω_p is plasma angular frequency and ω_0 is angular frequency of the source electromagnetic wave. Therefore, the magnitude of up-conversion frequency is represented by

$$\Delta\omega = \sqrt{\omega_0^2 + \omega_P^2} - \omega_0, \qquad (2)$$

The up-shift frequency is controllable by changing the flash plasma density. Until now, the several experiments had done in microwave region [7-9]. In this letter we performed the frequency up-conversion with a ZnSe crystal irradiated by ultra-short pulse laser. We confirmed dependency of frequency up-conversion with laser intensity.

2. Experimental Setup

Fig.1 schematically illustrates the experimental setup of a pump and probe system. The Ti:sapphire chirped-pulse amplification laser system delivered an maximum energy 1mJ at a center wavelength of 800nm, and 1kHz repetition rate. The laser beam was split into three pulses. One is a pumping pulse to create electron carrier in a ZnSe crystal. Second is the chopped pump beam that was passed through the half wave plate and focused on ZnTe crystal to generate source THz pulse that is placed at center of two lenses. The angle of incidence pump laser to the ZnSe is 68° (Brewster's angle). Third is for detecting up-shifted THz wave by photoconductive (PC) antenna. The source THz pulse is focused in the ZnSe crystal by the off-axis parabola (OAP) mirror and lens pair which effective focal length is 76.2 mm and 150 mm, respectively. The output THz pulse is collected by another OAP and lens pair, and finally focused the PC antenna to detect the THz signal. We measured this small current by chopping the 0.5 kHz optical pulse train that triggers the emitter and using a lock-in-amplifier. The THz spectrum in the range to 4THz was obtained by applying a first Fourier transform.

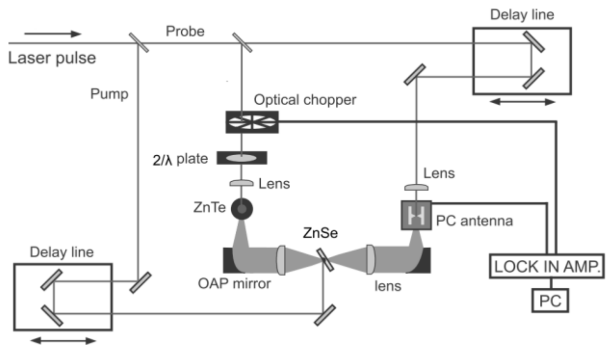

Fig.1. Experimental setup

3. Experimental Results

Fig. 2 shows the spectrum of the source THz wave and its up-shift. A solid line indicates the upshifted experimental data and dashed line is the original spectrum without the pump laser irradiation. The central frequency of source wave is 0.35 THz with a frequency broadening of 0.4 THz (FWHM). The upshifted spectrum is observed at 3.4 THz, when the laser intensity is 4.2 GW/cm^2.

Fig. 3 shows the dependency of amount of frequency up-conversion on laser intensity. We obtain frequency up-conversion from 0 THz to 3.0 THz.

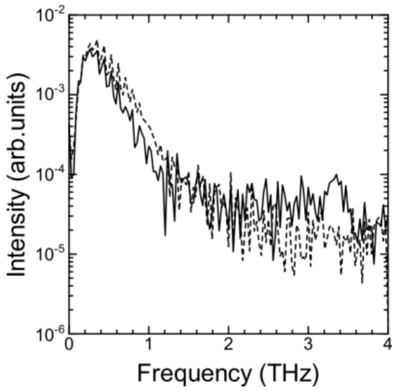

Fig.2. Observed spectrum at the laser intensity I_0 = 4.2 GW/cm^2.

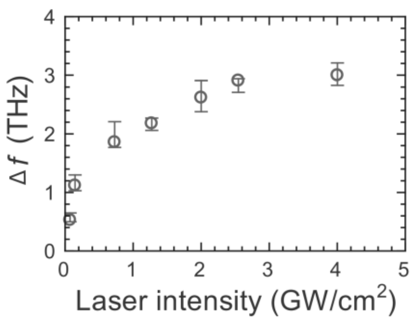

Fig.3. Dependency of amount of frequency up-conversion on laser intensity.

4. Conclusion

In conclusion, we performed the proof and principle experiment of the flash ionization with the semiconductor crystal of ZnSe. The plasma creation time is much shorter than the period of the source electromagnetic wave and plasma size is much larger than THz wave. We have demonstrated frequency up-shift up to 3.5 THz. Various frequencies can be observed by changing pumping laser intensity irradiated on the ZnSe crystal. We confirmed relationship between electric field strength of up-shifted THz pulse and intensity of it. This result has possibilities of tunable high power radiation source in THz region.

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