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Dynamics of Plasma Filament Generated by Sub-TW Laser Pulse in N_2 Gas

サブテラワットレーザーにより生成されたプラズマフィラメントの特性解析に関する研究

Takeharu Hommyo[1], Yusuke Hyuga[1], Kazuki Oguri[1], Koki Maruyama[1], Takamitsu Otsuka[1], Yasuhiko Sentoku[2] and Noboru. Yugami[1]

本明竹晴, 日向佑介, 大栗一樹, 丸山昂貴, 大塚崇光, 千徳靖彦, 湯上登

[1]*Department of Electrical and Electronic Engineering, Utsunomiya University, Yoto 7-1-2, Utsunomiya, Tochigi, 321-8585, Japan*

[2]*University of Nevada, Reno, 5625 Fox Avenue, Reno, Nevada 89506, USA*

[1]宇都宮大学大学 電気電子工学科 〒321-8585 栃木県宇都宮市陽東7-1-2

[2]ネバダ大学 リノ校 89506 アメリカ合衆国 ネバダ州 リノ フォックス・アベニュー 5625

Ultra short laser pulse propagation in gases undergoing the ionization generates the plasma filament due to the balance of the effects of diffraction, Kerr self-focusing and plasma defocus. We report the result of a proof-of-principle experiment in sub THz region from a DC to AC Radiation Converter (DARC) using the laser-produced plasma filament. The observed frequency from the DARC is in the sub THz region and increases with the plasma density increase as the theory predicted and the power was proportional to the square of the voltage applied to capacitors.

1. Introduction

The static electric field is converted into the electromagnetic wave, when the relativistic ionization front is propagating through the static electric field exited by the capacitor array. This is called a DC to AC Radiation Converter (DARC), which is an interesting source of the electromagnetic radiation having a broadband frequency range and high power. Figure 1(a) shows the schematic of the DARC. The theory of the DARC has proposed by W. B. Mori *et al.*, in 1995 [1]. The radiation frequency from the DARC is given by,

$$\omega_0 \approx \frac{k_0 v_f}{2} + \frac{\omega_p^2}{2 k_0 v_f} \quad , \qquad (1)$$

where k_0 is the wave number of the static electric field, $v_f \approx c$ is the velocity of the ionization front, and ω_p is the plasma frequency. Eq. (1) represents that the radiation frequency depends on the wave number of the static electric field and the electron plasma density of the ionization front. Spectral broadening is given by,

$$\Delta\omega \approx \frac{\omega_0}{N}, \qquad (2)$$

where N is the number of period of the static electric field. Furthermore, the DARC is expected to be efficient radiation source, since the electric field of radiation electromagnetic wave is directly converted from the electric field of the capacitor array. In this research, we have demonstrated the DARC operation in sub-THz region.

2. Experimental setup

The experimental setup is shown in figure 1(b). We demonstrated the DARC scheme using a relativistic ionization front creating by an ultra short intense laser pulse and the capacitor array placed in a chamber filled with N_2 gas. A Ti:sapphire laser system operated at 790 nm and could deliver up to 30 mJ in a pulse with a duration of 120 fs (FWHM). The capacitor array consist of 5 capacitors with a period d = 2 mm. The capacitor plates are separated by b = 1 mm. Pulsed high voltage (200 ns (FWHM), up to 4.7 kV) is applied alternatively to the top or bottom plate. The electron density was controlled

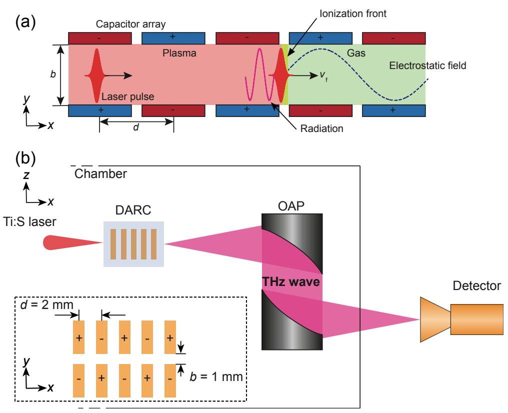

Fig. 1. (a) Schematic of the DARC. (b) Schematic of the experimental setup.

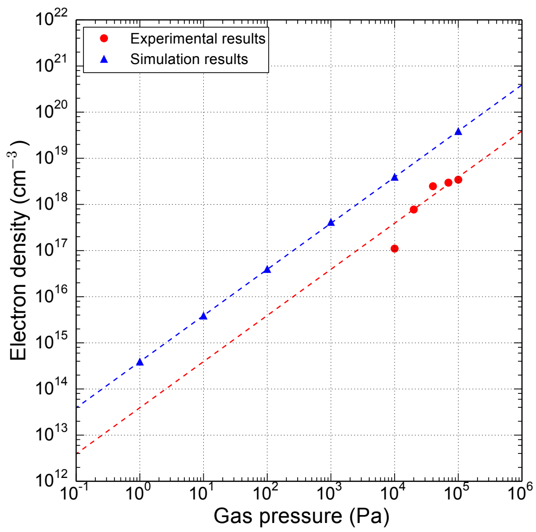

Fig. 2. Electron density as a function of gas pressure.

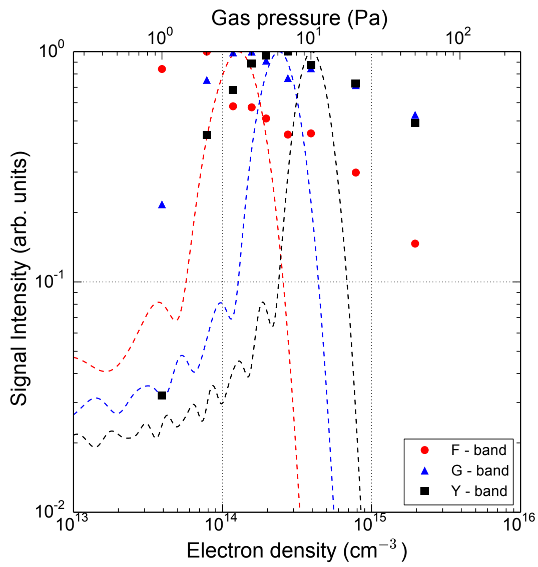

Fig. 3. Signal intensity as a function of electron density.

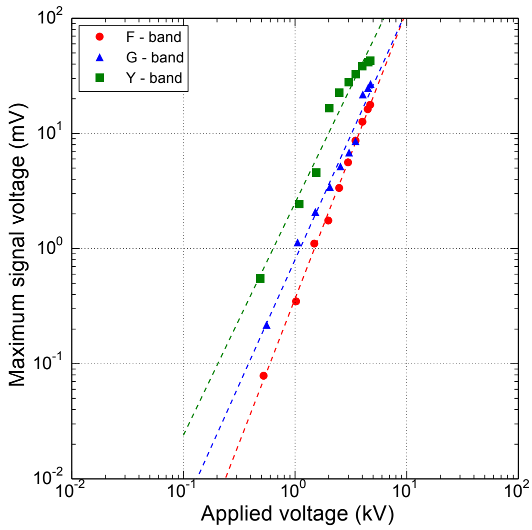

Fig. 4. Maximum signal voltage as a function of applied voltage.

by varying the gas pressure and measured by the laser interferometer. The emission from the DARC was detected with F-band (90 – 140 GHz), G-band (140 – 220 GHz) and Y-band (220 – 320 GHz) detectors.

3. Experimental results and discussion

Figure 2 shows the electron density as a function of the gas pressure obtained from the experiment results using the interferometer method. Due to the detection limit, the electron densities under gas pressure of 10^4 Pa were not measured. The calculation results using a 2D-PIC simulation code are also shown in figure 2. The dashed lines indicate the fitting data by the least-square method. The experimental and simulation results differed almost a order of magnitude.

Figure 3 shows the signal intensity of radiation as a function of the electron density for three detectors. The electron density was calibrated by using the experimental results shown in figure 2. The signal intensities observed by each detector have the peak at the different electron density. As the theory predicted, the frequency of electromagnetic waves radiated by the DARC is proportional to the electron density [1]. Dashed three lines indicate that the detected intensity for each detector which take the detectable ranges into consideration. Because the emitted radiation has the frequency broadening which is written as $(\sin[(\omega_0\text{-}\omega)T]/(\omega_0\text{-}\omega))^2$, the detection signal is evaluated by the integration over the specific frequency range.

Figure 4 shows the maximum signal intensity of the radiation as a function of the applied voltage. The signal intensity was proportional to the square of the voltage applied to the capacitors as the theory predicted [1-2].

4. Conclusion

We observed the THz wave from the DARC using the laser-produced plasma filament. The observed frequency is in the sub THz region and increases with the plasma density increase as the theory predicted and the power was proportional to the square of the voltage applied to capacitors. To our knowledge, this is the highest observed frequency ever by the DARC. The DARC is expected as high-power and broadband THz source.

References

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