# Preliminary Experiments on Interactions between Microwave and Plasma

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## 1. Introduction

Global warming caused primary by increases carbon dioxide ($CO_2$) is one of our global issues. Furthermore, nonrenewable energy such as fossil fuel and coal producing $CO_2$ will be completely consumed within 100- 150 years. The solutions is increasingly required and the most realistic solution is the solar power satellites (SPS) that converts the sun's energy into electrical energy on an orbit and transmits it to the ground by high-intensity microwave. The promotion of SPS is also mentioned in "Basic Plan for Space Policy" published by cabinet office in Japan.

The SPS was first proposed by Peter Glaser in 1968 [1] and had been researched in many countries. Fig. 1 shows the conceptual configuration of the basic microwave-type SPS called tethered SPS proposed in Japan [2]. The tethered model consists of 2.5km $\times$ 2.45km sized large transmission antennas and transmits high-intensity microwave beam of approximately $1\ \mathrm{kW/m^2}$ in the center power density toward the rectenna site that is the power receiving facility on the ground. It is a big gap between the power density of communication system in conventional space environment and that of high-intensity microwave beam. In the early phase of space experiments toward the practical SPS, it is necessary to fully verify some effects of space environment on direction finding, direction control, and efficiency of power transmission for wireless power transmission (WPT) of SPS. Especially, the serious concerns about microwave power transmission in space are interactions between microwave and ionosphere. There are mainly four concerns: refraction effects, Faraday effects, scintillation, and nonlinear interaction. The mechanism about interaction between high-intensity microwave and plasma in ionosphere are summarized in Table 1. Moreover, the pioneer experiments of nonlinear interaction were conducted by ISAS, Kyoto University and Kobe University using sounding rockets. The wave excitation in plasma was observed. However, quantitative evaluation has not been completed yet [3].

Our purpose is to verify effects on nonlinear interaction between high-intensity microwave and plasma on the laboratory experiments and, in this paper, we aim to confirm the fluctuations of plasma parameters using Langmuir and triple probe methods while high-intensity microwave is passing into plasma.

**Table 1.** ***Summary of interaction between high-intensity microwave and ionosphere [3].***

| Effects | Mechanism |
|---|---|
| **Refraction effects** | Refraction by plasma |
| **Faraday effects** | Rotation of the polarization of the microwave occurs in conjunction with magnetic field of the earth |
| **Scintillation** | Fluctuation in the phase path length of plasma density disordered structure |
| **Nonlinear interaction** | Self – contraction of thermal, microwave with steep density, and gradient. Three – wave resonance. |

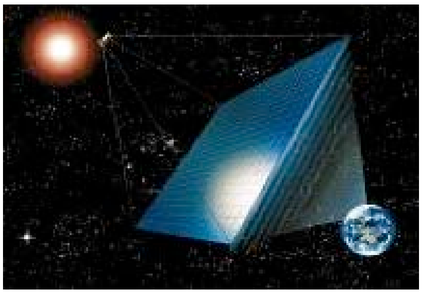


**Fig. 1.** ***Basic microwave-type Model [2].***

## 2. Methods

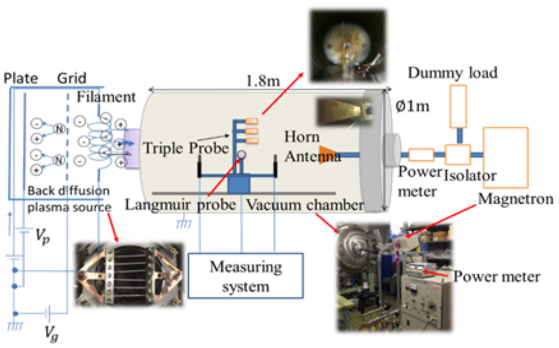
A schematic diagram in middle chamber is shown in Fig. 2. The chamber is pumped down to base pressure ($\sim 10^{-4} Pa$), and then filled with argon gas to a pressure of approximately $7.0 \times 10^{-3} Pa$. The plasma is produced by emitting electron from a set of tungsten filaments that are biased to a current of 44A and then applying plate voltage 220V and grid voltage 100V to accelerate it. The maximum output and pulse width of the magnetron are 2030W and 50ms in 5.8GHz, respectively. The magnetron is connected to an isolator, a dummy load, a power meter and a horn antenna thorough a flexible coaxial tube.

On the other hand, the electron temperature and density are measured by using probe methods as shown in Fig. 3 and Fig. 4. Fig. 3 shows a disk single probe with diameter of 3mm and how to obtain the relative $T_e$ and Ne. First of all, the values of current $I_{ps}$ are obtained when bias voltage ($V_{bs} = 4, 5, 40,$ and 45V) changes per a shot of microwave on the condition that plasma condition is stable. The waveforms in Fig. 3 show the one of the results. Then, we define the interval between -20 to 0ms as "Before radiation" and the other interval between 0 to 50ms while radiating high-intensity microwave as "During radiation." In accordance with the Fig. 3, each $T_e$ and $N_e$ referred to $T_{e\_}$ before, $T_{e\_}$ during, $N_{e\_}$ before, and $N_{e\_}$ during ($T_e$/ $N_{e\_}$ before/ during) can be obtained by giving the average values of "Before radiation" and "During radiation." At last, the relative $T_e$ and Ne subtract $T_e$/ $N_{e\_}$ before from $T_e$/ $N_{e\_}$ during. Fig. 4 shows a cylindrical triple probe ($d$=6mm, $L$=10mm, and $D$=5cm) and how to calculate $T_e$ and $N_e$ First of all, the values of current $I_{ps}$ from the resistance $R$ and voltage $V_{open}$ are obtained. Then, we calculate $T_e$ and $N_e$ and define them as the same way of single probe. At last, the relative $T_e$ and Ne subtract $T_e$/ $N_{e\_}$ before from $T_e$/ $N_{e\_}$ during.

## 3. Results

### 3.1 The results of single probe method

We can obtain electron temperature $T_e$ and density $N_e$ by using the average values. When the high-intensity microwave is changing at 140, 320, 700, 1250 and 2030W, fluctuations of $T_e$ and $N_e$ are obtained. Fig. 5 indicates fluctuations of relative electron temperature $T_e$ and electron density $N_e$ with an increase of amount of power in single probe. The electron temperature tends to decrease. On the other hand, the electron density is stable up to 1250W, but a significant increase at 2030W.



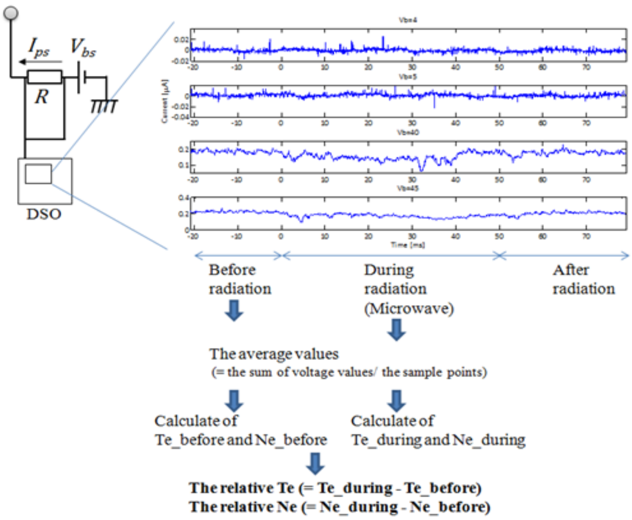




**Fig. 2.** ***The experimental setup.***

**Fig. 3.** ***The measuring system of single probe method.***

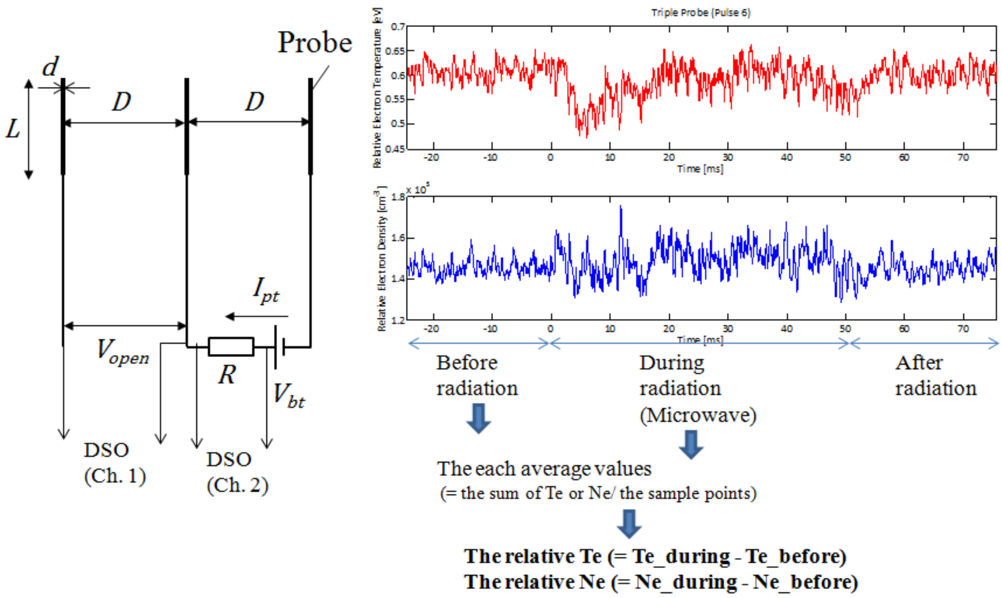



**Fig. 4.** ***The measuring system of triple probe method.***

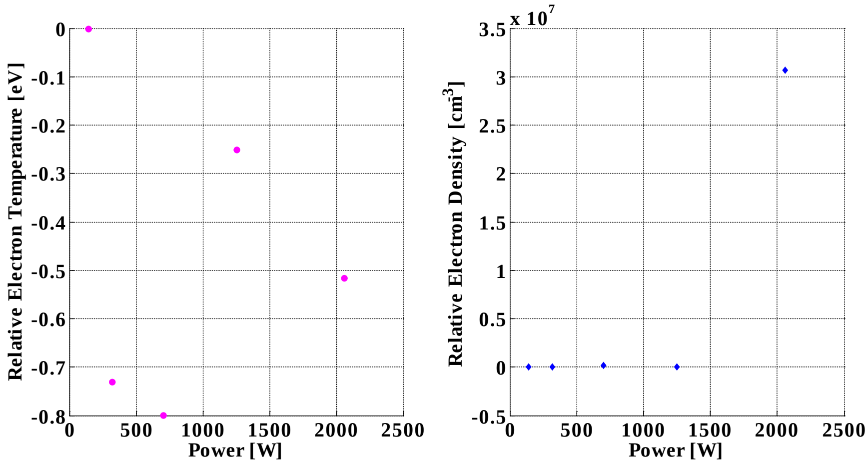



**Fig. 5.** ***The results of Langmuir probe method.***

## 3.2 The results of triple probe method

Fig. 6 shows the fluctuations of $T_e$ and $N_e$ while radiating the high-intensity microwave. At the beginning of microwave radiation, $T_e$ increases and $N_e$ decreases.

Fig. 7 indicates the fluctuations of $T_e$ and $N_e$ with an increase of power in triple probe. The electron temperature $T_e$ also tends to decrease. On the other hand, $N_e$ increases below 700 W, but decreases beyond then.

The fluctuations of $T_e$ are decreasing with an increase of power from both Fig.5 and Fig.6. On the other hand, the fluctuations of $N_e$ from both figures do not match due to the error in the third power between relative electron density of Fig. 5 and that of Fig. 7. We should investigate energy distributions and conditions about thermodynamic equilibrium while radiating the microwave, and increase the number of sample points in order to diagnosis more precisely in single probe method.

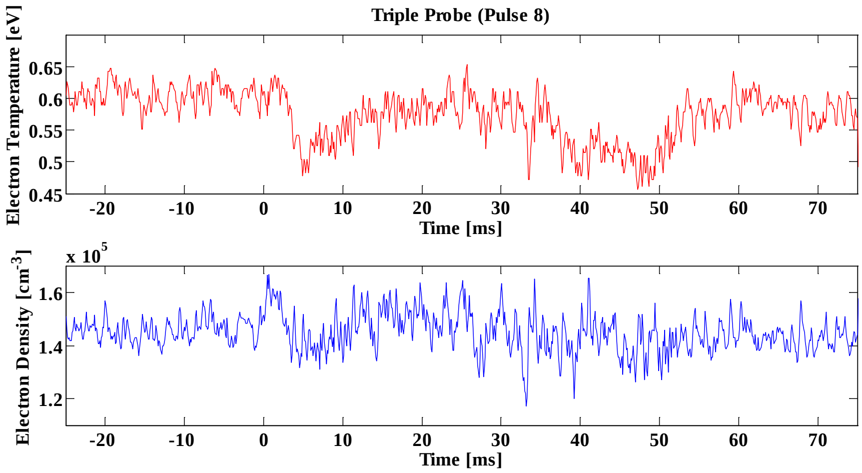



Fig. 6. ***The fluctuations of $T_e$ and $N_e$ in 1250W.***

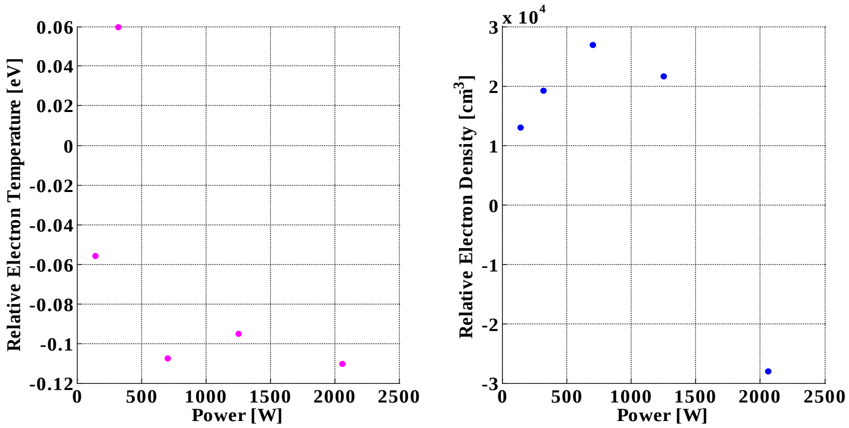



Fig. 7. ***The results of triple probe method.***

## 4. Conclusion

We confirmed fluctuations of voltage while radiating an intensity microwave. Based on this experiment, the following conclusions can be obtained:

(a) Fluctuations of plasma parameters were obtained while radiating the high-intensity microwave in the middle chamber;

(b) Rapid electron temperature drop in an initial stage was observed;

(c) Electron temperature drop with an increase in microwave intensity was observed.

In the future work, we need to measure more sample points in single probe method and microwave intensity. Moreover, we will challenge to evaluate energy distribution and observe wave excitation.


### Acknowledgments

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### References


[1] P. E. Glaser, “Power from the sun: Its future,” *Science*, vol. 162, pp.867-886, 1968.

[2] S. Sasaki, K. Tanaka, and K. Maki, “Microwave Power Transmission Technologies for Solar Power Satellites,” *Proceeding of the IEEE*, Vol. 101, No. 6, June 2013.

[3] K. Tanaka, N. Takaura, and S. Katano, “Preliminary experiments related to interactions between high-intensity microwave and plasma,” *Symposium of Space related Laboratory experiments*, Feb. 2015. (in Japanese)