Spectroscopic diagnostics of weakly-ionized argon surface wave plasma based on CR model

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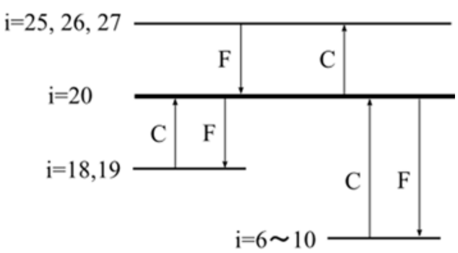
1. Introduction

Surface wave plasma of argon gas (Ar-SWP) has been utilized in such the material surface processing as etching, the plasma characteristics and the atomic elementary process although has not cleared up. Therefore, appropriate control of Ar-SWP is not achived. In the study an easy collisional-radiative model (CR model) was tried for analysing Ar-SWP characteristics. It has the virtue of non-intrusive diagnostics and has the potential of application to a low temperature and non-equilibrium plasma.

2. CR(Collisional-Radiative) model

It is necessary to know the elementary process of Ar-SWP for the establishment of a CR model. An elementary process will be modelled by estimating the sensitivity of electronic transition as indicated in Ref. [1]. However, this procedure cannot be adopted in the research, because there is no applicable model for the low-ionized and low temperature argon plasma of the research.

Therefore, we have tried to make a CR model by referring to such the forgoing research as Kano et al. for an argon atom[1], Fujimoto for a hydrogen atom [2], and so on[3][4]. As the results, we selected the level of $(4d+6s)^*$ to be a key. It means that the dominant effective quantum numbers become 5p* and >4f*. A CR model can decide both of electron temperature and electronic number density. The standard energy levels i=20 was selected for the electron



Level i=3, 5, 12- 17 were eliminated by the reason of no-account spectra in the experiment.

Fig.1 Atomic model of electronic transition for i=20 temperature of the Ar-SWP because this level has many electron transitions for sampling spectra. The schematic drawing of electronic transition is illustrated in Fig.1. Electron temperature was decided under the assumption of local equilibrium.

3. Experiments

A double probe and a plasma absorption probe (PAP) were made to measure electron temperature and electronic number density respectively. The spectroscope with an iced CCD camera was utilized for the analysis of spectra and for the development of a CR model The cylindrical chamber for the Ar-SWP generation is shown in Fig.2. The experimental conditions are the electric power supply of 0.4kW, the working gaseous pressure of 32Pa and the microwave frequency of 2.45GHz.

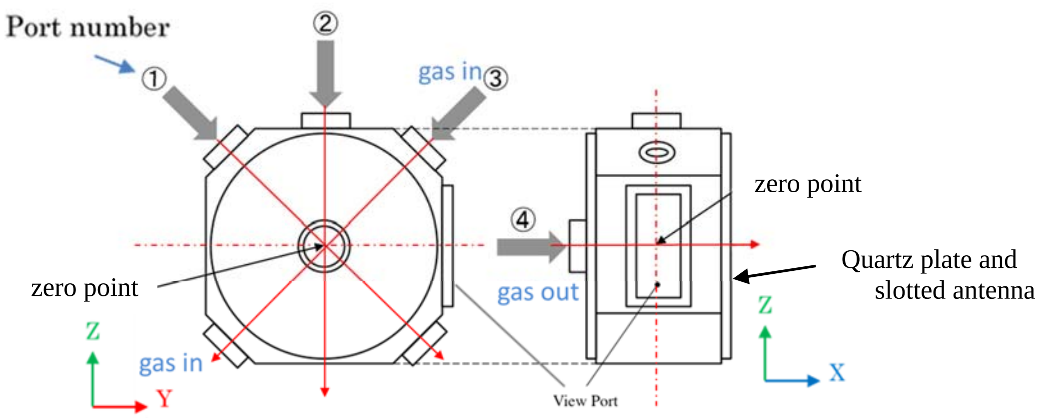


Fig.2 Details of the SWP chamber arrangement

4. Results and discussions

Figure 3 shows one of the spectra measured by the spectroscope for the CR model and it was applied to the equation (1), which represents the difference between the inflow and the outflow of the populations.

$$F(T_e) = [C_{6.20}N_6 + \dots + C_{10.20}N_{10} + C_{18.20}N_{18} + C_{19.20}N_{19} + F_{25.20}N_{25} + F_{26.20}N_{26} + F_{27.20}N_{27}] \\ -[(C_{20.25} + C_{20.26} + C_{20.27} + F_{20.19} + F_{20.18} + F_{20.10} + \dots + F_{20.6})N_{20}] \qquad \dots(1)$$

The relation between $F(T_e)$ and T_e in the result of Fig.3 is indicated in Fig.4. As assuming local equilibrium condition for the Ar-SWP, that is $F(T_e) = 0$, electron temperature becomes 2.3eV (about 27,000K) from Fig.4.

The electron number density measured by the double probe is shown in Fig.5, where the horizontal axis is the x-axis in Fig.2. The electron density is about 10^{10}-10^{12} counts/cm^3 and

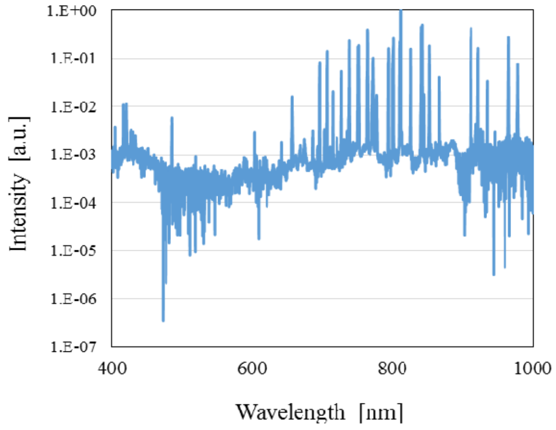


Fig.3 Spectra from the Ar-SWP

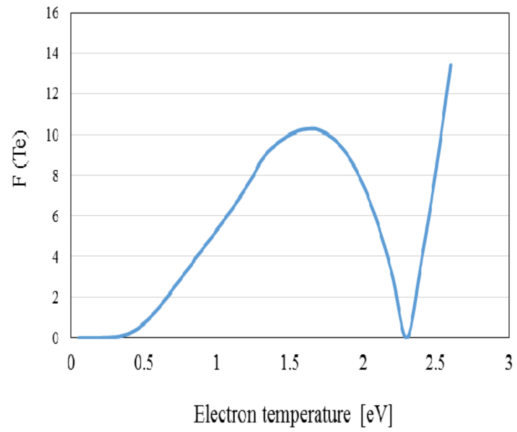


Fig.4 $F(T_e)$ with T_e of the eq.1

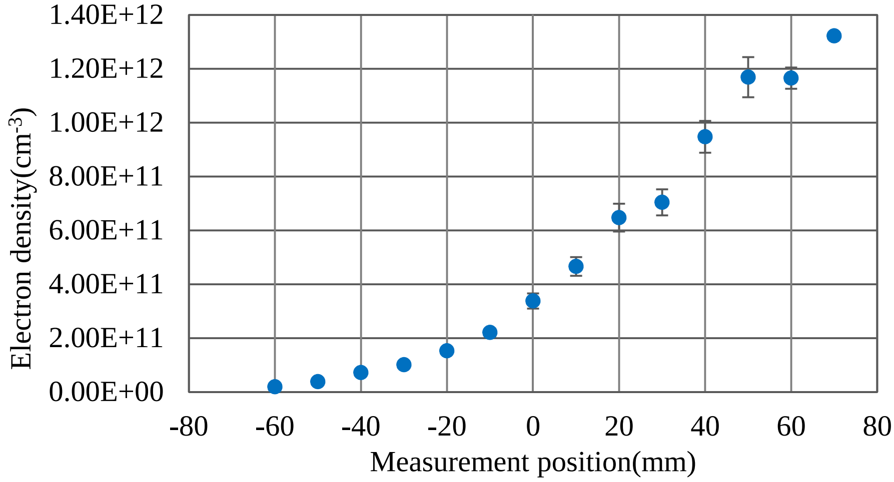


Fig.5 Electron number density along the cylindrical chamber axis measured through the port #4 in Fig.2

increases towards the quartz plate, from which a micro wave passes. The electron density on the yz-plane becomes maximum at the middle of the cylinder chamber, x=0.

Electron temperature measured by the double probe is the temperature of 2.44eV (about 28,000K), which is very close to that by the developed CR method. It was found that the CR model based on the energy level of i=20 is sure to involve the dominant elementary process of the Ar-SWP.

On the other hand, electrical excitation temperature of the plasma was about 4,500K as shown in Fig.6. These were derived on the basis of the Boltzmann plots. It is 23,000K lower than the results of the CR model and the PAP methods. The reason is considered that the electrical excitation temperature was estimated using the energy transition between 4s and 5p and it should not be dominant.

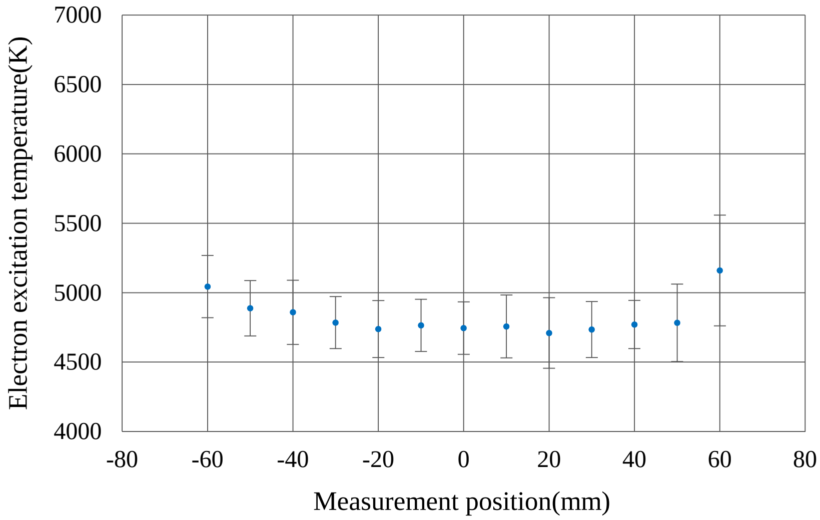


Fig.6 Electron excitation temperature, through the port #1

5. Conclusions

Collisional-radiative model has been developed to investigate the characteristics of argon surface wave plasma with low electron temperature and low electrical number density. It was applied to estimate the electron temperature and the obtained temperature is very close to the experimental one by the double probe method. It shows that the CR model involves the dominant elementary process of the argon surface wave plasma.

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