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Evaluation of electron temperature and electron density in a plasma treatment device for circuit board by using collisional-radiative model

衝突輻射モデルを用いたプラズマ基板処理装置の電子温度・電子密度評価

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Evaluations of electron temperature and density are important for plasma applications. In this study, we have observed plasmas in a surface treatment device for circuit boards by optical emission spectroscopy. Based on a collisional-radiative model, we have attempted to evaluate electron temperature and density using emission spectrum. As a result, the electron temperature evaluated about 1-2 eV which is close to the results of probe measurements, Moreover we confirmed discharge power dependence of electron temperature and density.

1. Introduction

It is important to measure plasma parameters such as electron temperature (T_e) and electron density (n_e) in plasma applications. So far, we have measured a plasma surface treatment device for circuit boards using probe method. In this study, we have measured the plasma using optical emission spectroscopy (OES) as passive measurement. Observed results are analyzed using a collisional-radiative (CR) model for evaluating T_e and n_e.

2. Experimental Setup

The experimental setup is shown in Fig.1. Experiments are performed by using a plasma surface treatment device for circuit boards (Advanced Plasma Systems, PWB-24). The device has a chamber with the dimension 1585 × 1300 × 1080 mm. 40 kHz AC power voltages are applied to 14 electrodes at regular intervals in a vacuum chamber. The output power is up to 10 kW. Though operational neutral gas pressure is typically 100-300 mmTorr for process gases such as He, H_2, O_2, N_2, Ar, etc, we use He for comparing with analysis model in this study.

A sapphire window is attached to the side port of the device for observing visible light emission from the plasma. The light through the window is focused to an optical fiber and the light is guided to a spectrometer (Ocean Optics Inc., HR2000). The wavelength range is 300-730 nm and the resolution is about 0.3nm. A partition board is placed on the position as shown in Fig.1 for defining the observed volume.

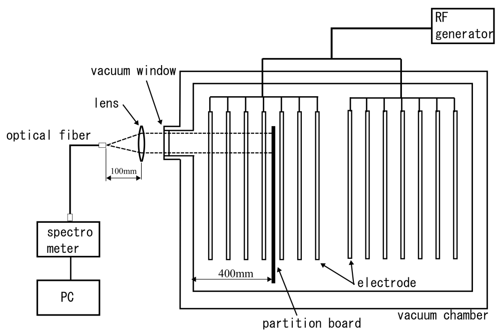

Fig. 1 Experimental Set up

3. Collisional-Radiative model

In order to evaluate T_e and n_e, we attempt to use a CR model for He [1-3]. According to CR model, the temporal variation of the population density of an excited state p, $dn(p)/dt$ can be described by a rate equation as follows,

$$dn(p)/dt = \sum_{q<p} C(q,p) n_e n(q) + \sum_{q>p} \{F(q,p) n_e + A(q,p)\} n(q) - \left\{ \left(S(p) + \sum_{q>p} C(p,q) + \sum_{q<p} F(p,q) \right) n_e + \sum_{q<p} A(p,q) \right\} n(p), \quad (1)$$

where $C(p,q)$ is the excitation rate coefficient for electorn collisions from state p to q and $F(q,p)$ is the inverse de-excitation rate coefficient. $A(p,q)$ is the spontaneous transition probability from p to q, and $S(p)$ is the ionization rate coefficient for state p. Eq.(1) is approximated to 0 for all the states except the ground state and metastable states. Solving the rate equations of each excited states with considered photo-excitation from the ground state, *n(p)* can be described the as follows [3],

$$n(p) = r_1(p)n(1^1S)n_e + r_2(p)n(2^1S)n_e + r_3(p)n(2^3S)n_e + r_4(p)n(1^1S)I_{3^1P} + r_5(p)n(1^1S)I_{5^1P} \ , \qquad (2)$$

where $r_1(p)$, $r_2(p)$, $r_3(p)$, $r_4(p)$, and $r_5(p)$ are the population coefficients, each of which is a function of T_e and n_e.

4. Results and discussion

Figure 2 shows observed spectra for He plasma with 8 kW in 250 mTorr. The averaged optical emission intensities have been obtained by the absolutely calibrated optical system. This result shows that typical He emission spectra with Hα line as contamination described below.

Figure 3 shows the comparison of experimentally obtained population density and calculated one using the CR model with lines intensity in Fig.2. In this result, the calculated population reproduced the observed one. Most of the population of 3^1P and 5^1P are produced by photo excitation from the ground states. For other states, the populations are produced mainly electron impact from the 2^1S state, and from 1^1S state is seems lower.

Figure 4 shows the T_e and n_e evaluated by CR model for each discharge power. The T_e is about 1.5 eV which is consistent with the temperature measured by probe method [4]. The n_e tend to increases with discharge power. In the case of 2 kW, the n_e is higher than other power conditions, A possible reason is that some error of observed emission intensities is large because of emission intensities is low in 2kW.

As mentioned above, Fig.2 shows emission lines of hydrogen especially at 656nm. The hydrogen line considered to be caused by moisture in vacuum chamber. This contamination would also cause the error in analysis using the CR model.

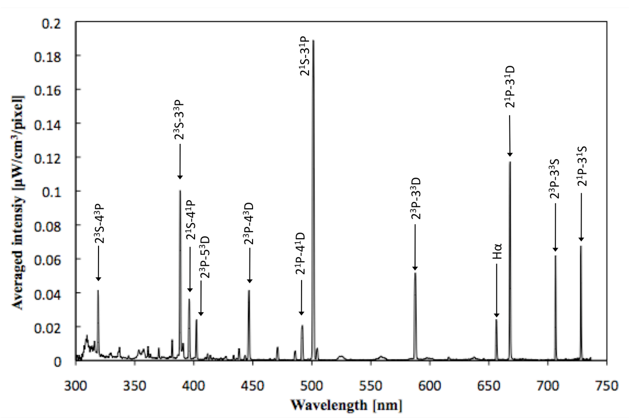

Fig.2 Observed spectra of He discharge

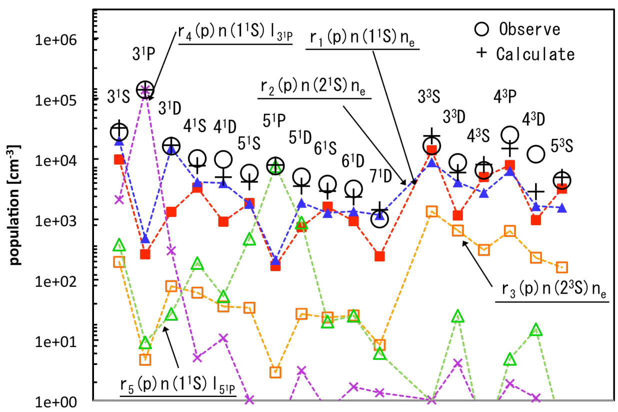

Fig.3 Comparison of population distribution between spectroscopic measurement and CR model analysis.

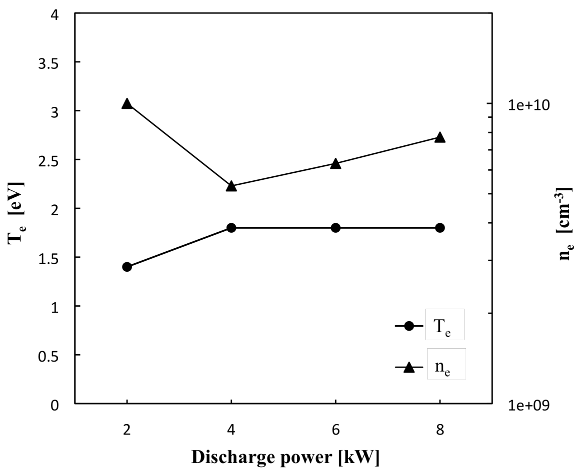

Fig.4 Evaluated T_e and n_e using observed spectra based on CR model for several discharge power.

5. Summary

We have observed plasmas in a surface treatment device by OES and have attempted to evaluate T_e and n_e using CR model. As a result, the T_e evaluated about 1-2 eV which is consistent with the results of probe measurements. And we confirmed discharge power dependence of T_e and n_e. Moreover we confirmed hydrogen lines. It is important result for accuracy of the evaluation using the CR model.

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