Report on Visit to University of Texas at Dallas by International Training Program

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As a long-term placement program of ITP (International Training Program), I had studied in the Prof. Goeckner- Prof. Overzet research group in UTD (University of Texas at Dallas) of United States for two months, from January 7, 2010 up to March 11, 2010. This is report of my stay.

Research

(a) Research theme

The research theme during my master course is “Study on basic process of photoresist surface reactions in plasma etching”, and I have studied surface reactions between fluorocarbon plasma ant photoresist as a part of the master thesis. The Prof. Goeckner- Prof. Overzet research group established measurement of absolute radical density in plasma with Fourier transform infrared spectrophotometer (FT-IR), which is one of the characteristics of the research group. Therefore, I set "Observation of the changes in the active species in the fluorocarbon plasma by the oxygen addition" as the research theme in the Prof. Goeckner- Prof. Overzet research group. Well-understanding of how many active species there are in the plasma helps me investigate the detailed reaction between photoresist and plasma.

(b) Experiment

In the first two weeks, the beginning of research in the UTD, I read some doctoral dissertations written by alumnus, who analyzed gas-phase reaction of fluorocarbon plasma, to figure out previous work of the group.

The experimental setup I could use in UTD is called GEC (Gaseous Electronics Conference) reference cell. Figure 1 shows the diagrammatic of experimental setup. It can make the inductively coupled plasma with applying the RF (Radio Frequency) 13.56 MHz power to upper electrode, and include not only the FT-IR system for measurement of absolute radical density, but also Langmuir probe for measurement of electron temperature and electron density.

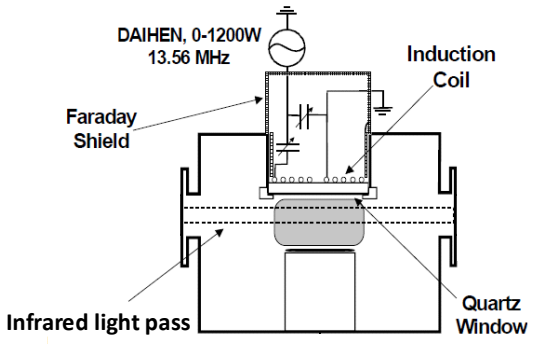

図 1. GEC reference cell 概略図

Firstly, I learned how to use the experimental setup from Ms. Cristina, who is one of main user of the experimental setup, with her experiment as an example. We discussed the behavior of electron density, so I think I could help her like she could help me.

The measurement of absolute radical density in plasma with FT-IR can be applied to only low pressure region, in which the absorbance of Infrared light is promotional to non-plasma CF_4 gas pressure. The principle is called Beer’s law.

In the third week, I checked the pressure region where Beer’s law can be applied and learned how to use the FT-IR system. The absorption length (diameter of chamber) is 64 cm, CF_4 gas flow rate is 1 sccm, and the pressure is changed from 3 mTorr to 60 mTorr. The relation between the absorbance of infrared light and pressure of CF_4 is shown in Fig.2. I find that the Beer’s law can be applied to the pressure region from 0 mTorr to 15 mTorr with this experimental setup from Fig.2. I could also find the absorption constant of infrared light for CF_4 gas, which enables us to calculate the absolute density.

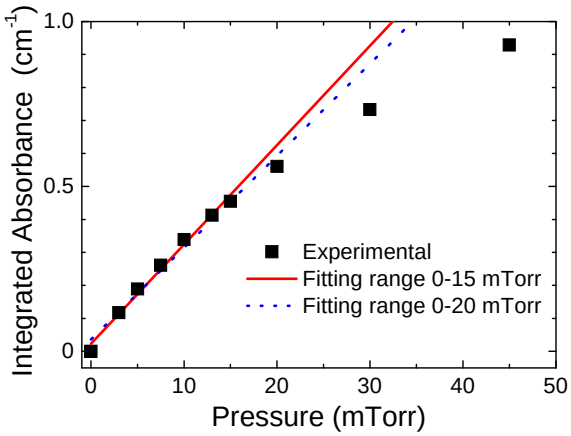

Fig.2 Relation between pressure and absorbance of CF_4

Then, I made the CF_4 plasma, and tried to measure the radical density and compare the IR spectrum of plasma-on with that of plasma-off. The experimental conditions are following; RF power 100 W, pressure 10 mTorr, and CF_4 flow rate 20 sccm. The result is shown in Fig.3. We can see the absorption of CF_4 with plasma is smaller than that without plasma, which means CF_4 gas is dissociated. However, the absorptions of radicals such as CF_3, CF_2 could not be seen.

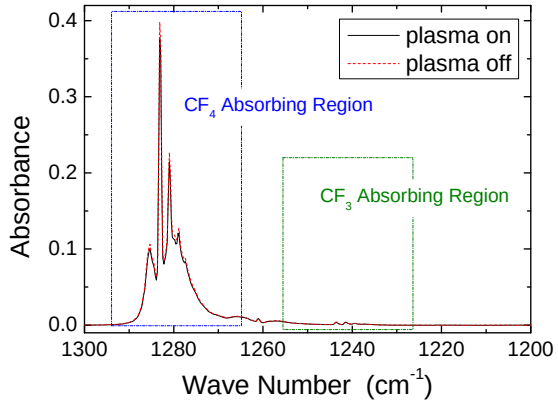

Fig.3 Comparison of IR spectrum with/without plasma

I discussed how I could measure radicals with Prof. Goeckner, and he taught me I should produce the plasma of H mode, which has a high density characteristic, with higher RF power. However, the CF_4/O_2 plasma of H mode is very unstable; I couldn't measure the radical density, but also produce the stable plasma especially with lower pressure region where Beer's law could be applied even if I applied higher power. Then I adjusted electric matching with Mr. Gabriel, who is Ph.D. candidate being familiar to this experimental equipment and could produce the stable plasma with such higher pressure region as 60 mTorr. The main cause of the plasma instability with lower pressure is thought that the electron density decrease due to fluorine atom which has high electronegativity and is easy to become negative ion.

I decided to do experiment with higher pressure region where we could produce stable plasma, and the plasma has a higher electron density characteristic from the fifth week. I tried to measure the products in the plasma and compare products of H mode (500 W) with that of E mode (100 W).

The following is experimental conditions; RF power is 500 W or 100 W, pressure is 60 mTorr, total flow rate of CF_4/O_2 is 20 sccm, and flow ratio of oxygen is 5 %. The IR spectra of each mode are shown in Fig.4. We could not see the COF_2 absorption with E mode of CF_4/O_2 plasma, but with H mode of that.

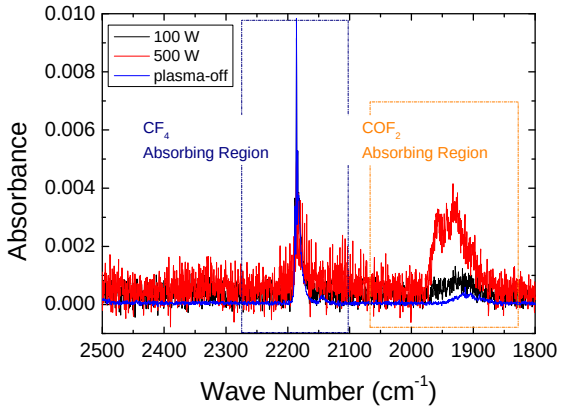

Fig.4 Comparison of IR spectrum with 100 W and 500 W

There is a period in which I couldn't use the experimental equipment because other student uses that. I calculated the distributions of electric field to understand how the charged particles are accelerated to substrate in the sheath and react with substrate materials for other student research. I referred "Principles of plasma discharges and materials processing" written by M. A. Lieberman, and "Analytical Solution for Capacitive RF Sheath" (IEEE TRANSACTIONS ON PLASMA SCIENCE, VOL. 16, NO. 6, DECEMBER 1988), and calculated the distributions of electric field in the

non-collision sheath of Ar CCP produced by RF power. I assumed the amplitude of sheath thickness is non-linear, and used the following equations for calculation of electric field,

$$E(x,t) = \frac{\tilde{J}_0}{\epsilon_0 \omega}(\cos\omega t - \cos\phi), \qquad s(t) < x$$

$$= 0, \qquad s(t) > x.$$

where J_0 is current density from the plasma to electrode, ε_0 is electric permittivity of the space, ω is the angle frequency of RF, and ϕ is the value which has the following relation with x [cm], which is the distance from the plasma-sheath edge, and average-amplitude of sheath thickness S_0 [cm].

$$\frac{x}{\tilde{s}_0} = (1 - \cos\phi) + \frac{H}{8}\left[\frac{3}{2}\sin\phi + \frac{11}{18}\sin 3\phi - 3\phi\cos\phi - \frac{1}{3}\phi\cos 3\phi\right]$$

$$\tilde{s}_0 = \tilde{J}_0/(e\omega n_0), \qquad H = \frac{\tilde{J}_0^2}{\pi e\epsilon_0 T_e \omega^2 n_0} = \frac{1}{\pi}\frac{\tilde{s}_0^2}{\lambda_D^2}$$

Figure 5 shows the time-fixed position dependence of electric field with distance from the plasma-sheath edge for abscissa axis. The assumptions of calculation were following; the electron density was 1.0 x 10^{10} cm^{-3}, the plasma potential was 62 V, current density J0 was 66.2 A/m^2, and the electron temperature was changed from 1 eV to 3 eV. From the Fig.5, it is suggested that the sheath thickness became thinner as the electron temperature became bigger.

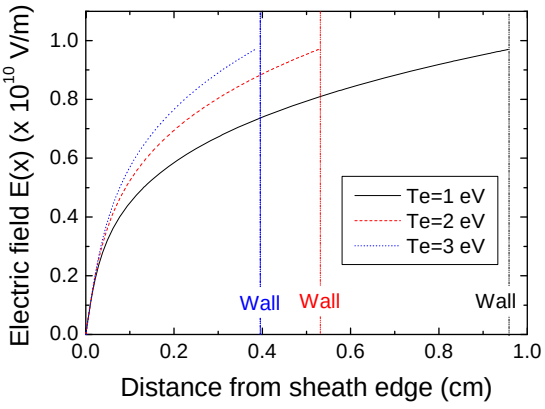

Fig.5 Position dependence of electric field in sheath

This calculation of electric field is not related to the research theme directly, but it is good opportunity for me to get better understanding of the plasma physics.

I introduced Mr. Gabriel to my research in Japan during the experiment with him, and he was interested in my research topic, investigation of the reaction between photoresist and fluorocarbon plasma. He was eager to cooperate with us, and the proposal of Mr. Gabriel was the measurement of the by-products from the photoresist by comparison between the measurements of particles in the plasma with photoresist and those without photoresist.

I couldn't try to measure the by-products because I didn't bring the photoresist which I have studied in Japan unfortunately. Then, we tried to measure the by-products from the 1813 photoresist, which is used in UTD instead of the photoresist I used in Japan. The experimental conditions were following; RF power was 400 W, the pressure was 60 mTorr, and CF_4 flow tate was 20 sccm. The comparison of between IR spectra with photoresist and that without photoresist is shown in Fig.6. Compared with IR spectrum without photoresist, there was absorption for CF_3, CF_2 in gas-phase IR spectrum with photoresist, that means there were many CF_3, and CF_2 in the plasma as the by-products from the photoresist. In the future, we will try to measure the by-products from the photoresist I use in Japan.

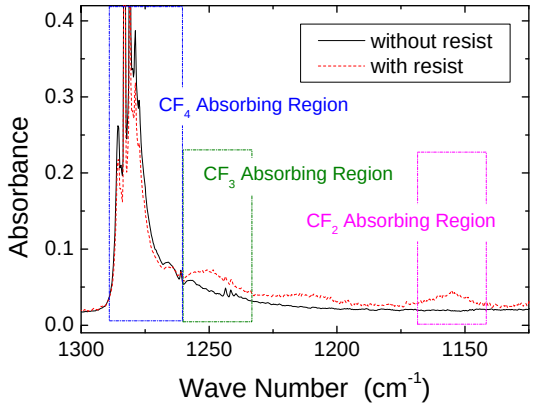

Fig.6 Comparison of IR spectrum with/without photoresist

(c) Others

I attended the weekly meeting held on every Wednesday, in which the duty person introduces a paper related his study and gives explanations for the paper. In the meeting, the robust discussions were conducted within not only professors, but also students. They students were so

assiduous that I was motivated by their enthusiasm about research.

College life in UTD

Prof. Goeckner picked me up at the Dallas-Fort Worth International Airport when I arrived at the airport. It takes 40 minutes from the airport to the UTD by car. However, it takes about two and a half hours by train. It is inconvenient to live without the car in Texas. After arrival at the UTD, Prof. Goeckner showed me their laboratory. I got the key of my room at the apartment office and went to my room, finally I took a rest on the first day. I could have a comfortable stay with the apartment in the university because there was all of what I need in the apartment such as eating utensils, cooking device, washing machine, and towel except consumable goods.

I heard it was warm in Texas but I felt that it was colder in Texas than in Japan because a serious cold wave hit Texas. I applied my identity card I need for staying in UTD. There was a Japanese student who is Ph.D. candidate in the Prof. Goeckner and Prof. Overzet research group fortunately, so he took care of my life in UTD including the application for ID card, taking me to supermarket located near the university teaching me how to ride the bus and train.

I almost cooked my own meals during my stay. I always went to supermarket in weekend by bus. There is the dining hall in the UTD but it has all-you-can eat buffet style for $8, so it was unsuitable for me to use daily. However, it was very good place because they had such a various foods and these were so delicious that I ate in the dining hall five time.

As mentioned above, every experience that I've had in this program such as study of the diagnostics of fluorocarbon plasma with FT-IR, discussion with students or professor in English, and life in a foreign country, will help me to promote my study in Japan and international understanding between United States and Japan. This stay in the United States gave me an irreplaceable two months.

Finally, I deeply appropriate professors in Nagoya University and University of Texas at Dallas, and all of person who assisted this program.