Report on Visit to Sungkyunkwan University by International Training Program

Nagoya University Electrical Engineering and Computer Science
Toshiya Suzuki

1. First of all

The tie-up of Toshiba and Samsung in the System LSI area was announced on the newspaper, ”Nippon Keizai Shinbun”, and surprised the industry on December 24, 2010. This imply that Semiconductor industry is facing the problem of NRE (Non-Recurring Engineering), which cannot earn the production cost, and it is assumed that world wise industry restructuring will be conducted. In the research industry, cost of equipment is getting more and more complicated and increasing. So before the industry, corporation and roll allotment beyond board is preceded.

In this internationalization, Japan seems to be late compared to the others countries. In spite of most of the cutting edge conference and paper are written with English, English level of Japan is still low. The number of students who study abroad is low, too. Japan have to take a view on abroad and focus on the other countries movement and the position of Japan in international world to lead the industry with the stock of money and skills until now. To see the affairs of the oversea, I thought that to feel it there would be the best way, that’s why I desired this training program.

2. About the University which I stayed

Sungkyunkwan University is one of the oldest private university which has a history for more than 600 years from its establishment as a school for Confucianism. It has two campus one is in Seoul for department of humanitie, art and gymnastic cource and the other is in Swan, located in around 35 km south form Seoul city, for science cource respectively.

In the program I joined Professor Han’s laboratory in CAPST(Center for Advanced Plasma Surface Technology) in Swan campus. At there we could see the cutting-edge experiment of plasma application and experiment directly those experiment.

3. Experiment

In the SKKU, I researched about “Measurement of H radical density in the H_2 plasma with Vacuum Ultra Violet Absorption Spectroscopy (VUVAS).

(1) Background

Hydrogen (H) atoms play important roles in many fields of materials processing. For example, hydrogenated amorphous silicon (*a*-Si:H) and polycrystalline silicon (poly-Si) thin films have been fabricated by reactive plasmas employing silane (SiH4) gas diluted with H2 gas. Hydrogen atoms are generated from dissociation of feed gases such as SiH4, and H2 and react with radicals and feed gases in the plasmas to produce important precursors for thin-film formation. Furthermore, H atoms and precursors contribute to surface reactions on the substrate. In these thin-film processes, it is well known that the control of H atoms is a key factor for synthesizing functional films of high quality. However, the behavior of H atoms has been not clarified enough in the processes because the information of absolute densities of H atoms is insufficient.

(2) VUV measurement system

VUVAS is the calculation method for absolute density of the particle in the plasma calculated with absorption rate of the intensity between transmitted light and emitting light. Theory of VUVAS is mentioned below.

If the parallel light from a source passes through as absorption cell, such as plasma, the intensity of the transmitted light is given as follows [1],

$$I(\nu) = I_0(\nu)\exp[-k(\nu)L], \qquad (1)$$

where ν is the frequency, $I(\nu)$ and $I_0(\nu)$ are the intensities of the transmitting light and the incident light, respectively. L is the absorption path length, and $k(\nu)$ is the absorption coefficient as a function of frequency ν.

The broadening of the absorption coefficient, that is, the broadening of the absorption line-profile is due to the causes as follows,

(a) Natural broadening due to the finite lifetime of the exited state.
(b) Doppler effect broadening due to the motions of the atoms.
(c) Lorentz broadening due to collisions with foreign gases.
(d) Holtsmark broadening due to collisions with other absorption atoms of the same kind.
(e) Stark effect broadening due to collisions with electrons and ions.

However, in this study the Doppler broadening and Lorentz broadening should be taken into account, because the density of the electron and absorbing atoms of the same kind should be low.

Here, we consider that a parallel beam of the light of frequency ν passed through a layer of atoms bounded by the planes at the length of dL. Suppose there are N_l normal atoms per cm^3 of which dN_l are capable of absorbing the frequency range between ν and $\nu+d\nu$, and N_u excited atoms of which dN_u are capable of emitting this frequency range. Neglecting the effect of spontaneous re-emission in view of the fact that it takes place in all direction, the decrease in energy of the beam is given by

$$-[I(\nu)]d\nu = dN_l dL\rho(\nu)B_{lu}h\nu - dN_u dL\rho(\nu)B_{ul}h\nu, \qquad (2)$$

where B_{lu} and B_{ul} are Einstein B coefficient from ground state l to excited state u and from l to u, respectively. h is Planck's constant, and $\rho(\nu)$ is the radiation energy density given by $I(\nu)=c\rho(\nu)$, (c: light velocity). Rewriting Eq. (2), we obtain

$$-\frac{1}{I(\nu)}\frac{d[I(\nu)]}{dL}d\nu = \frac{h\nu}{c}(B_{lu}dN_l - B_{ul}dN_u), \qquad (3)$$

Recognizing that the left-hand term is $k(\nu)d\nu$ as defined by Eq. (1), Eq. (3) becomes

$$k(\nu)d\nu = \frac{h\nu}{c}(B_{lu}dN_l - B_{ul}dN_u) \qquad (4)$$

And integrating over the whole absorption line, neglecting the slight variation in ν throughout the line,

$$\int k(\nu)d\nu = \frac{h\nu_0}{c}(B_{lu}N_l - B_{ul}N_u), \qquad (5)$$

where ν_0 is the frequency at the center of the line. Here we use the Einstein A coefficient.

$$\int k(\nu)d\nu = \frac{c^2}{8\pi\nu_0^2}\frac{g_u}{g_l}AN_l(1-\frac{g_l N_u}{g_u N_l})$$
$$\cong \frac{c^2}{8\pi\nu_0^2}\frac{g_u}{g_l}AN_l \quad (N_u << N_l), \qquad (6)$$

where g_l and g_u are the statical weights of the lower and upper level, respectively. Therefore, by measuring $I_0(\nu)$ and $I(\nu)$, $k(\nu)$ is decided and we can estimate the density N_l.

When the light source is incoherent light such as lamp, the intensity of measured light is the integrated value over the frequency

$$I_0 = \int e_0 f_0(\nu)d\nu,$$

$$I_a = \int e_0 f_0(\nu)\{1-\exp[-k_0 f_a(\nu)L]\}d\nu, \qquad (7)$$

where I_0 and I_a are the intensities of the incident light and the absorption, respectively, $f_0(\nu)$ is the emission line-profile function for the light source, e_0 is the emission intensity of the light source at a center frequency of $f_0(\nu)$, $f_a(\nu)$ is the absorption line-profile function, and k_0 is the absorption coefficient at the center frequency of $f_a(\nu)$. The absorption intensity $A(k_0L)$ is given by the following formula.

$$A(k_0L) = 1 - \frac{I_a}{I_0} = \frac{\int f_0(\nu)\{1-\exp[-k_0 f_a(\nu)L]\}d\nu}{\int f_0(\nu)d\nu} . \quad (8)$$

From *A(k₀L)* obtained by measurement, k_0 is determined by assuming the line-profile function $f_0(\nu)$ and $f_a(\nu)$. Then, the number density of state l, N_l, is estimated by using Eq. (6) as

$$N_l = \frac{8\pi\nu_0^2}{c^2}\frac{g_l}{g_u}\frac{1}{A}k_0\int f_a(\nu)d\nu \cdot \quad (9)$$

Side view of the fabricated VUVAS system is indicated in Figure 1. Absorption length is 40 mm, and light get thorough the MgF_2 lens, microscope, photo multi-plier and digital oscilloscope, and processed in PC as data.

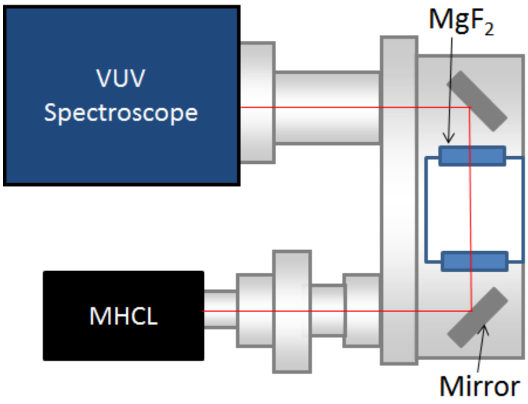

Fig.1 Side view of Vacuum Ultra Violet Absorption System

(3) MHCL

Recently, our research group has developed the measurement system of absolute densities of atomic H [2], N [3] and O [4] radicals in the ground state using the VUVAS with micro-discharge hollow cathode lamp (MHCL) as a light source. Transition lines used for measuring the absolute densities of H, N and O radicals are Lyman α at 121.6 nm, $^4P_{5/2}$-$^4S^0_{3/2}$, $^4P_{3/2}$-$^4S^0_{3/2}$ and $^4P_{1/2}$-$^4S^0_{3/2}$ at 120.0 nm and $^3S^0$-$2p^4$ $^3P_2$ at 130.217 nm, 3s $^3S^0$-$2p^4$ $^3P_1$ 130.487 nm and 3s $^3S^0$-$2p^4$ $^3P_0$ 130.604 nm, respectively. Each emission of these transition lines can be obtained by the H_2, N_2 and O_2 plasma, respectively. However, these emissions are caused by two major processes [5-7]. One is the direct excitation of ground state atomic radicals by the electron impact.

$$X + e \rightarrow X^* + e \rightarrow X + h\nu + e \quad (10)$$

, where X is the atomic radical of interest, X^* is X atoms in the excited state. The other is the dissociative excitation of ground state of X_2 by the electron impact.

$$X_2 + e \rightarrow X^* + X + e \rightarrow X + X + h\nu + e \; (11)$$

Reaction (10) is responsible for the production of slow excited X^* atoms. Reaction (11) can produce fast excited X atoms which produce a large Doppler broadening. Therefore, the structure of the atomic radical emission line profile consists of a two-component velocity distribution arising from two different excitation processes as shown in Eqs. (10) and (11). It is difficult to estimate the emission line profile, which involves a two-component velocity distribution. In the view of problem above in the measurement of absolute atomic radical density, we have developed a high pressure MHCL as a light source for VUVAS. The specific merits of the MHCL we expect are as follows,

(a) The emission line profile will not involve a large Doppler shift due to the fast excited atomic radical arising from dissociative excitation of molecules, since they should be thermalized before they emit light.

(b) The size of the hollow cathode is a small as 0.1 mm diameter, resulting in a high current density in the cathode, which is favorable for attaining a high dissociation degree of molecules and obtaining spectrally pure atomic radical emission.

(c) A point-source-like emission from a micro-hollow can be efficiently coupled to the entrance slit of a monochromator using an appropriate lens system.

(d) The lamp is compact and is operated with an inexpensive dc power source.

The cathode and anode consist of a plate with 0.5 mm thickness with a through-hole hollow of 0.1 mm in diameter. Helium (250 sccm) and helium gas containing a small amount of H_2, N_2 or O_2 gas (5 sccm) were used. The MHCL was operated at a total pressure of 0.1 MPa. Figure 2 shows the image view of MHCL.

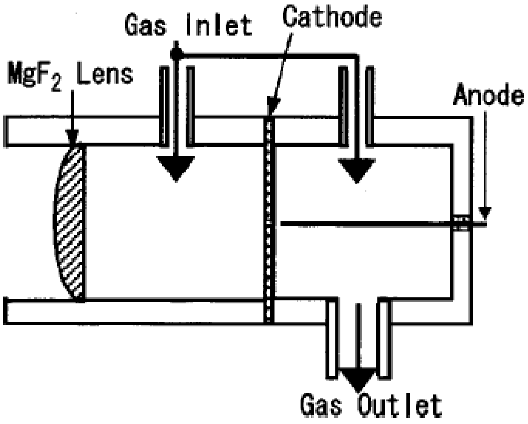

Fig. 2 Side view of MHCL

(4) Experiment results

During this program, I started from the fabrication of the measurement equipment and set up of the gas line and so on based on my knowledge and experience from my own laboratory in Japan.

During fabrication, I experienced hardships on the difference between the environment like absent of alternative components and the long duration from order to delivery and so on. So, I couldn't prepare of the measurement smoothly, and I often went to the market of the experimental components to the neighboring town with my coworker. I did introspection on confirming the absence of the components. Especially the absence of the small unexpected components delayed experimental schedule, so I felt it is important to think it is natural in spite of there is usual to be in Japan.

The measurement experiment after fabrication was preceded very smoothly. I discussed with coworker more than 30 minutes about daily experimental problem and questions every day. I also enjoyed each other's company at the laboratory every 2 hours every day with everybody to smoke at the balcony because at the laboratory most of all member smokes. At the conversation, we talked about our thinking about experiments and private think.

4. Through the life in the laboratory in Korea

I had impressed to their diligence through the life in the laboratory in Korea. I guess it depends on the laboratory, but Ph.D candidate degree duration increased without pity to 5 or 6 years if you couldn't get the experiment results because graduation degree of Ph. D candidate is much difficult. So, there was a good atmosphere like self-responsibility and students in Korea seemed to study harder compared to Japanese ones. It is also impressive much more students select to goes to Ph.D candidate because academic CV effect of their income in Korea. Japanese students have to study from their attitude to go to language school after their work in the university.

Through this experiment life for two months in Korea I could improve my motivation as a researcher and broad my sight. Especially I was so surprised for high motivation of Korean students. In Korea more students study not only Master course but also doctor course compare to Japan. And they had night motivation to study English and Japanese.

I communicated with Korean in English, but at the first time I asked to speak again and again. They have Korean accent in their English. But I got to use it through daily communication. I felt English is used around the world but every country has their own dialect. Like getting used to Japanese dialect we can get to use English dialect. I felt we have to have experiment in real life.

5. Finally

I would like to say a word thanks to Prof. Hori, Prof. Sekine and ITP affiliate to give me a chance like this. And appreciate to Prof. Overzet, Prof. Goeckner and ICAMP affiliate who support me both of research and daily life.

Reference

[1] S. Takashima, M. Hori, T. Goto, A. Kono, M. Ito and K. Yoneda, Appl. Phys. Lett. 75, 3929 (1999).

[2] A. C. G. Mitchell and M. W. Zemansky, Resonance Radiation and Exited Atoms (Cambridge, London 1961).

[3] R. S. Freund, J. A. Schiavone, and D. F. Brader, J. Chem. Phys. 64, 1122 (1976).

[4] K. Ito, N. Oda, Y, Hatano, and T. Tsuoi, Chem. Phys. 21, 203 (1977).

[5] S. Djurovic and J. R. Roberts, J. Appl. Phys. 74, 6558 (1993).