Report on Visit to Sungkyunkwan University by International Training Program

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Since I participated in the long-term placement program of International Training Program (ITP), I would like to report on research activities in Center for Advance Plasma Surface Technology (CAPST) of Sungkyunkwan University.

Low temperature plasma is a very important technology for many processing fields, such as microfabrication, thin film synthesis, surface modification, etc. In the process, high reactive species such as ions and radicals generated in the plasma is very important because they play roles to determine the process performance. Therefore, in order to develop the technology, the behaviors of these species have attracted very much. However, for measuring and analyzing the behaviors of these species, it is required expertness and know-how. Therefore, the developments of plasma process technology are frequently carried out on the basis of the process results only. In our research group, the equipment for measuring the absolute density of atomic radicals in processing plasmas has been developed. [1-4]

In order to measure the atomic radicals, absorption spectroscopy using vacuum ultraviolet (VUV) light with wavelength under 200 nm is used. The optical passes of vacuum ultraviolet light are maintained in the vacuum or inert gas ambience, because the vacuum ultraviolet lights are absorbed by atmospheric gas. Moreover, the absorption profiles of atomic radicals are very narrow under several pm, therefore, it is necessary to use the special light source for obtaining the correct absorption intensity of probe light due to atomic radical. Conventionally, large laser and vacuum systems are required for the measurement of atomic radicals. Therefore, in case of the technique with large laser system, it is not easy to apply the measurement to normal plasma processing equipments. In our group, we focused on the development of compact light source for the VUV absorption spectroscopy (VUVAS) and have successfully realized by employing a micro hollow cathode discharge in atmospheric pressure condition. By using an atmospheric pressure He plasma discharge with amount N_2, H_2, O_2 mixtures, the palm-sized light source has been realized and we can used the atomic spectra of N, H, O atoms which are emitted from the light source as a probe light for VUVAS. Therefore, it is easy to setup the measurement and tune the wavelength of probe light. In this time, the VUVAS system with the micro hollow cathode discharge lamp (MHCL) and VUV monochromator have been applied to a plasma process equipment in CAPST of Sunkyunkwan University. And then, the measurement of absolute density of atomic hydrogen radical in H_2 plasma has been carried out.

Figure 1 shows the experimental setup for measuring absolute density of atomic radicals in the plasma equipment of CAPST. The plasma equipment has RF antenna and sample stage. By supplying RF (13.56 MHz) power, a

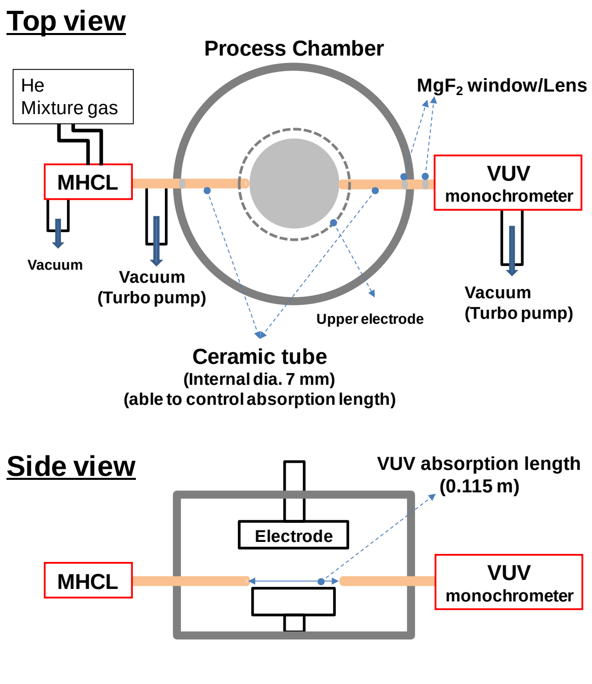

Fig.1 (a) Schematic diagram of experimental setup.

Fig.1(b) Photo of experimental setup.

capacitively coupled plasma is generated between the antenna and sample stage. As shown in Fig.1, a MHCL and VUV monochromator were installed to the process chamber. Moreover, the absorption length was 0.115 m which is same size of the diameter of sample stage. Firstly, we tried to measure the absolute density of H atom in H_2 plasma using VUVAS.

When the probe light is incoherent such as MHCL or the linewidth of frequency can not be neglected in comparison with the broadening of absorption coefficient of observed species, we must consider the linewidth of probe light to obtain the correct absorption intensity. The intensity of measured light is the integrated value over the frequency. Therefore, the absorption intensity a is given by the following formula,

$$a = 1 - \frac{\mathrm{I_{out}}}{\mathrm{I_{in}}} = 1 - \frac{\int f_1(v)\exp[-k_0 f_2(v) L] dv}{\int f_1(v) dv} \qquad (1)$$

where $\mathrm{I_{in}}$ and $\mathrm{I_{out}}$ are the intensities of the incident light and the absorption, $f_1(v)$ and $f_2(v)$ are line-profile functions of light source emission and absorption of atomic radical, respectively, and k_0 is the absorption coefficient at the center frequency of $f_2(v)$. In Eq.(1), k_0 is determined from a obtained by the measurement. In order to obtain a correct value of k_0, the line-profile function $f_1(v)$ and $f_2(v)$ are very important. In previous study, the emission-line profile $f_1(v)$ was assumed to be a Voigt profile because the total pressure in the MHCL is near 1 atm and the Lorentz broadening is large. On the other hand, the $f_2(v)$ is assumed to be a Gaussian profile because the discharge condition of measurement plasma is enough to be the low pressure and Lorentz broadening is low. The number density N is estimated by using Eq. (2) as

$$N = \frac{8\pi v_0}{c^2} \frac{g_1}{g_2} \frac{1}{A} \int k_0 f(v) dv \qquad (2)$$

where g_1 and g_2 are the statical weights of the lower and upper level, respectively. v_0 is the frequency at the center of the line and A is the Einstein A coefficient.

In order to obtain the atomic spectra of N, H, O atoms, He gas containing a small amount of H_2, N_2 and O_2 gas is introduced to the MHCL as a discharge gas. The mixing ratio of H_2, N_2 and O_2 gas is extremely low around 10^{-5}. If the mixing ratio is too large or there is an influence of contamination such as H_2O in gas lines, the densities of N, H, O atoms generated in the MHCL increase. The increase in the atom density in MHCL would bring on a change in the magnitude of the self-absorption in the MHCL and affect to the emission profile of the atomic radical and thereby the absorption intensity can not be obtained. In this study, we used gas supply and vacuum systems in CAPST for the MHCL. Moreover, we have focused on measurement of absolute density of H atom in H_2 plasma at the first. Therefore, we have optimized the mixing ratio of H_2 gas to He base gas. In order to estimate the self-absorption on a Lyman α (L_α, 121.56 nm) line in the MHCL, absorption measurements for RF excited capacitively coupled H_2 plasma were carried out for various H_2 mixing ratio in the MHCL. The discharge condition of H_2 plasma was fixed at a pressure of 0.97 Torr, a RF power of 180 W. The result shows in Fig.2. The absorption intensity increased with decreasing H_2 mixing ratio in the MHCL, but at H_2 mixing ratio below 1.0×10^{-3}% the absorption intensity became almost constant. Change in the magnitude of the self-absorption in the MHCL would cause the shape change of emission profile of the L_α line and thereby affect the absorption intensity. Therefore, the results in Fig. 2 indicate that the distortion of the L_α emission profile due to self-absorption in the MHCL is negligible for H_2 mixing ratio below 1.0×10^{-3}%. And the L_α line emission from the MHCL at the condition of a H_2 mixing ratio 1.0×10^{-3}% had a sufficient intensity level for carrying out absorption measurements.

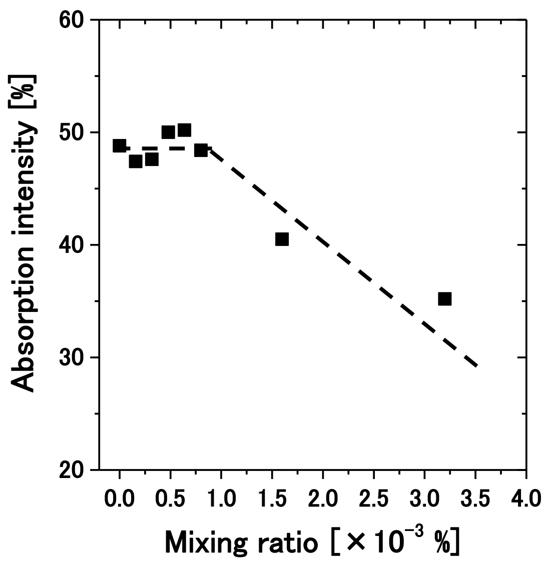

Fig.2 Dependence of the absorption intensity for the L_α line by H_2 plasma on the H_2 mixing ratio in the MHCL.

Figure 3 shows the measurement result of absolute H atom density in RF excited capacitively coupled H_2 plasma. The gas pressure in process chamber was fixed at 0.97 Torr. And RF power input to the antenna was changed from 60 to 300 W. As shown in Fig.3, the H atom density increased from 9.2×10^{11} to 2.6×10^{12} cm^{-3} with increasing the RF power. In this time, we could not carry out the measurement of plasma parameter (electron density and temperature) because there is no enough time to measure them. However, it is considered that the electron density increased linearly with increasing the discharge power although the electron temperature is almost constant. Therefore, it is supposed that the generation of H atom due to electron collision with H_2 molecule increased. From measurement result as shown in Fig.3, it was confirmed that we could measure the absolute density of H atom in the CAPST's plasma equipment with the VUVAS system with MHCL.

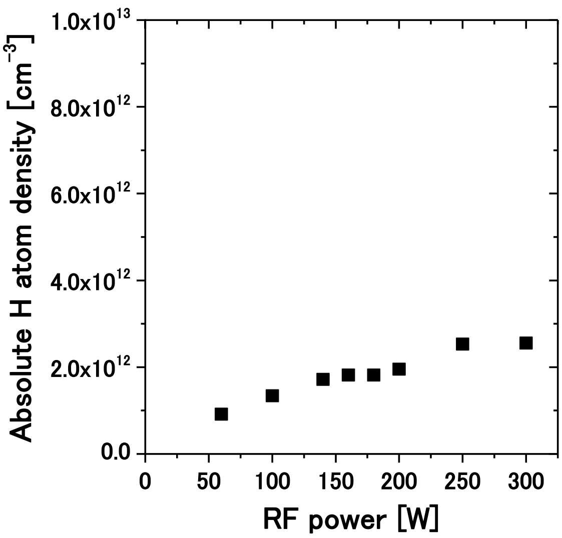

Fig.3 Absolute density of H atom in capacitively coupled H_2 plasma as a function of RF power.

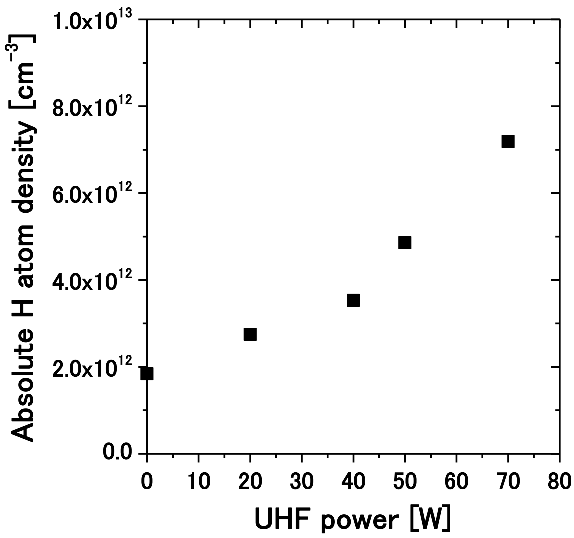

Fig.4 Absolute density of H atom in the double-frequency (RF and UHF) excited H_2 plasma as a function of UHF power (@ RF power of 180 W)

In order to realize the high performance of plasma process, the more high density of atomic radical is frequently required. It is well-known that the high density is realized by using the discharge power with higher excitation frequency.

Therefore, the electrodes supplied the UHF power was installed between the RF antenna and sample stage of the equipment shown in Fig.1, and then, we tried to investigate the effect of UHF power on absolute density of H atom in plasma. The discharge condition of H_2 plasma was a chamber pressure of 0.97 Torr and a RF power of 180 W. And UHF power was changed from 0 to 70 W. The measurement result was shown in Fig.4. As shown in Fig.4, it was confirmed that the absolute density of H atom increased up to 7.2×10^{12} cm^{-3} with increasing UHF power.

In this time, we have focused on the measurement of H atom density in pure H_2 plasma in ordered to check the VUVAS system with MHCL installed to CAPST's equipment. However, we could also confirm the possibility of H atom measurement in SiH_4/H_2 plasma using same VUVAS setup. Therefore, we will investigate the behaviors of H atom in the plasma CVD process with SiH_4/H_2 mixture.

During my staying in CAPST of Sungkyunkwan University for two month, I could discuss about the behaviors of activated species in plasma with many researchers. It was very meaningful for me to develop the breadth of knowledge for approach to plasma process research.

I am deeply grateful to Professor Jeon G. Han for the opportunity to study in his Lab. And I would like to thank Professor Toyoda, and Ms. Era for supporting this program and my visit to Ruhr University Bochum. Finally, I would like to thank Professor Hori, Professor Sekine, Professor Ishikawa, and Professor Kondo for assisting my study in CAPST of Sungkyunkwan University.

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