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Development of self-absorbing plasma light source for vacuum ultraviolet absorption spectroscopy

Keigo Takeda[1], Takayoshi Tsutsumi[2], Mineo Hiramatsu[1], Masaru Hori[2]
[1] Faculty of Science and Technology, Meijo University, [2] Center for Low-temperature Plasma Sciences, Nagoya University
e-mail: ktakeda@meijo-u.ac.jp

1. Introduction

Atomic radicals in process plasmas are important species to determine the features of process reactions, therefore, the quantitative investigations of atomic radicals are required to understand the mechanisms of plasma processes. Absorption spectroscopy is one of optical methods for estimating the absolute density of atomic radical in the process plasmas. The absorption spectroscopy of atomic radicals is carried out using the resonance lines in the vacuum ultraviolet region (λ: 0.2~200 nm). In our group, micro-discharge hollow cathode lamp (MHCL) has been developed [1] as a specialized VUV light source and the vacuum ultraviolet absorption spectroscopy (VUVAS) with the MHCL have been applied for the measurements of quantitative behaviors of atomic radicals in several process plasmas. In the absorption spectroscopy with a plasma light source, the density of atomic radical is estimated from the absorption intensity of incident light with a wavelength at an absorption line of the atomic radical. In the plasma process with several gas chemistry, many kinds of molecular species would exist and be generated in the plasma gas phase, and the absorption caused by them frequently occur in the absorption spectroscopy of process plasma. The background absorption is a crucial issue for the density estimation of atomic species because it disturbs the precise measurement of light absorption intensity due to the atomic radicals.

In this study, a self-absorbing VUV light source for the measurement of background absorption has been developed using a micro-discharge hollow cathode plasma. In a plasma light source, ground state atoms exist in not only the discharge region but also the outside of plasma although excited atoms localize in the discharge region. The lights emitted from the excited atoms should be absorbed by the ground state atoms in the plasma light source. The phenomenon is called as self-absorption. In the self-absorption, the absorption in the center of the emission line profile is greater than the edge because of the larger absorption coefficient. As the density of ground state atom in the plasma light source becomes higher, the center intensity of emission profile becomes lower due to the self-absorption. The self-absorbing plasma light source has a potential to use as a VUV light source for the measurement of background absorption near the edge of absorption line of target atomic species.

2. Experimental

The MHCL used in this study has a cathode electrode consisting of a cupper plate with a through-hole hollow of 0.1 mm in diameter and a pin type cupper anode electrode. He gas containing small amounts of H_2 gas was introduced into the MHCL. The MHCL was operated at a total pressure of 1 atm. In the condition, emission profile of H atom in MHCL without self-absorption effect was estimated to be a Voigt profile including Lorentz and Gaussian (Doppler) broadenings and the ratio of Lorentz ($\Delta\nu_L$) and Doppler width ($\Delta\nu_D$) was estimated to be $\Delta\nu_L/\Delta\nu_D = 1.5$ and H atom temperature is about 300 K. Tradition line used for measuring the absorption intensity of H atom was Lyman α line of H atom at 121.56 nm. The inductively-coupled H_2 plasma (H_2-ICP) was used as a measurement target for the VUVAS with self-absorption MHCL. The discharge condition of ICP was a pressure of 4.4 Pa, a H_2 gas flow rate of 190 sccm, and a RF input power of 200 W. The density of H atom in the H_2-ICP was estimated to be 1.7×10^{12} cm^{-3} by VUVAS. The VUV light emitted from the MHCL went through the ICP. An absorption length of incident light was set to 34 mm. The absorption intensity of incident light due to H atom in the H_2 ICP was measured as a function of H_2 partial pressure in the MHCL.

3. Results

Figure 1 shows the experimental and calculated results about the change in light absorption intensity due to H atom in the H_2 ICP as a function of the estimated H atom density in the MHCL. The absorption intensity decreased with the increase in the H atom density in MHCL. This behavior indicates that the self-absorption effect in the MHCL increased with the increase in H atom density in the MHCL. The absorption intensity was lower than 1% at the H atom density of about 5.5×10^{13} cm^{-3} (H_2 partial pressure: 486.4 Pa) in MHCL. From the result, it is found that the background absorption in process plasma with H atom density under 1.7×10^{12} cm^{-3} can be measured by using the self-absorption MHCL.

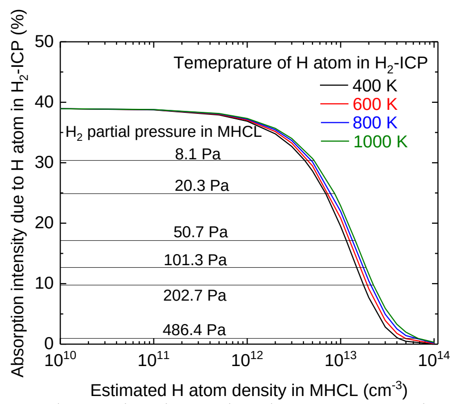

Figure 1 Absorption intensity due to H atom in H_2-ICP as a function of estimated H atom density in MHCL.

References

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