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Highly-Sensitive Monitoring of Electron Density with Surface Wave Probes
表面波プローブによる高感度電子密度モニタリング

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This paper reports on monitoring of electron density with surface wave probes. In order to achieve this, the probe head was modified so as to enhance electrostatic coupling between the probe antenna and plasma. The modification improved the sensitivity of the probe, and made the density monitoring possible even in low-density and high-pressure plasmas where electron densities could not be measured with the previously-used probe. The improvement of the sensitivity extended application range of the probe to actual process conditions. In the present study, density measurements in low-density and high-pressure CVD plasmas and detection of gas components for endpoint detection in fluorocarbon etching plasmas were examined.

1. Introduction

Electron density is one of essential factors to govern reactive plasmas for materials processing since a source gas is mainly dissociated by electron impact process. Therefore development of accurate simple monitoring techniques of the electron density is important to control and stabilize the plasma processing.

As a novel tool for the issue, surface wave (SW) probes have been developed[1], and validity of the probe has been demonstrated for measurements of electron densities in various reactive processing plasmas. However, there are still remain problems, especially for sensitivity. In the probe, an electron density is determined from peak frequency of obtained absorption spectra. The absorption peak intensity decreases with a decrease in electron density n_e as well as a indrease in operating pressure p. Under conditions for n_e>~10^{10} cm^{-3} and p>~1 Torr, the decrease in the absorption intensity becomes serious to make the density measurement difficult.

To date, the improvement of sensitivity by removal of glass tube cover has been reported, and the improved probe has been applied to the plasma sensor for the discharge pressure up to ~1 Torr [2]. However, in actual plasma process, the glass cover is inevitable in order to avoid metal contamination.

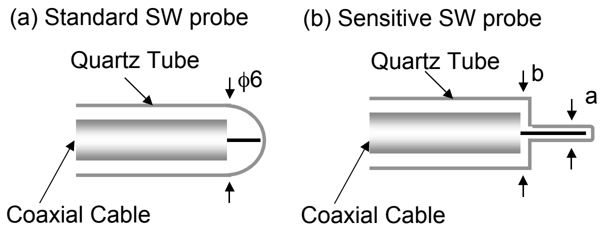
(a) Standard SW probe
(b) Sensitive SW probe

Fig. 1 Structure of surface wave probe

In this report, the improvement of the sensitivity of the glass-covered SW probe is carried out by modifying the probe head structure. The probe is used for density measurements in actual CVD plasma sources under low-density and high-pressure conditions. Furthermore, the probe is also applied to detection of slight change in gas component in fluorocarbon etching plasma for end-point detection.

2. Experimentals

In the present study, two kinds of plasma sources are used. One is an inductively-coupled plasma (ICP) source. The ICP is produced in a stainless-steel cylindrical vacuum vessel by supplying 13.56 MHz RF powers through one-turn loop antenna. Argon is fed into the vessel with a constant flow, and the discharge pressure is adjusted between 10 and 1000 mTorr by controlling residence time of the discharge gas. The other is a capacitively-coupled plasma (CCP) of an actual CVD source for formation of low-k films. The CCP is produced by supplying RF powers between two parallel electrodes in BCB-containing helium at a discharge pressure of 1 - 4 Torr.

Here two types of SW probes shown in Fig. 1 are used: one is a previously-used *standard* PAP. As shown in Fig. 1(a), a 50 Ω coaxial cable with a 0.28-mm-diam. and 5-mm-long tiny rod antenna is inserted into a 6-mm-diam. and 1-mm-thick cylindrical quartz glass tube. One end of the tube is closed with a semi-spherical shape at the head. The other is a *sensitive* SW probe shown in Fig. 1(b). Basically, the sensitive PAP has the same structure as the standard PAP, however the shape of the glass tube at the head is modified. The diameter of the glass tube is reduced at the rod antenna, and the gap between the rod antenna and the outer surface of the glass tube decreases. This modification of the sensor head enhances the absorption sensitivity of the probe due to the stronger antenna-plasma coupling. In this study, the diameter a of the glass tube at the probe head is 0.5~1.7 mm.

3. Experimental Results and Discussions

3.1 *Improvement of sensitivity and detection of slight density variation*

At first, a comparison of the sensitivity between the two types of SW probes was made. In the standard SW probe, several absorption peaks were observed, however the absorption intensities of the all peaks were as low as ~1 dB. However, the sensitive SW probes had peak intensities much higher than the standard probe. A pressure dependence of the absorption intensity was obtained as shown in Fig. 2. As the pressure increased with the discharge power almost constant, the absorption intensity decreased for the standard and the sensitive probes. However, regardless of the pressure, the sensitive probe B had the higher intensity than the standard probe by a factor of ~10. Thus the reduction of the distance between the plasma and the probe antenna is useful for improvement of the sensitivity. The SW probes allowed us to detect 1% variation of electron density artificially induced by changing ~1 % the discharge power. In the sensitive probe, the detection of the slight density variation was possible even for high pressure condition of ~500 mTorr.

3.2 *Density measurements in CVD plasmas*

A plasma source for CVD processes is typically operated under low-density (n_e<~10^{10} cm^{-3}) and high-pressure (>~1 Torr) conditions. Therefore the standard SW probe is difficult to be applicable to measurements of the electron densities due to insufficient sensitivity. Here the sensitive probe with the sensitivity improved is applied for the density measurements in a CVD plasma source. In the experiment, the discharge pressure is 3 Torr. Even in such a high pressure condition, absorption spectra was clearly obtained, and the radial distribution and the power. dependence of the electron density was successfully measured.

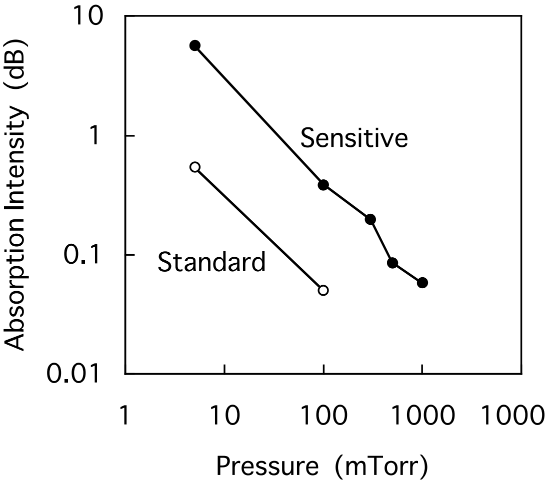

Fig. 2 Pressure dependence of absorption intensity for standard sensitive SW probe.

3.3 *Detection of slight change in gas component*

Simulating end-point detection in an etching process, a small amount of CO_2 gas were introduced into the Ar plasma as a etch product, and the electron density variation induced by the CO_2 injection were examined. The SW probe was located near the inner surface of the vessel so as to realize an actual situation in an commercial etching device for mass production. Even for the CO_2 fraction as low as ~0.3 %, the sensitive SW probe was able to detect the density variation. In comparison with optical emission spectroscopy, the CO_2 injection was precisely detected with the SW probe, suggesting that the SW probe will be applicable to precise end-point detection.

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