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# Properties of inductively coupled rf $Ne/N_2$ plasmas
# 誘導性結合型Ne/$N_2$プラズマの特性

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The measurements with a floating probe method and optical emission spectroscopy are carried out in inductively coupled rf (13.56 MHz) $Ne/N_2$ discharges in the total pressure range from 5mTorr to 50mTorr, changing the Ne fraction from 50% to 90%. The measured electron density is around $10^{17}m^{-3}$ and the measured electron temperature is in the range of 3-6eV. Both the density and the temperature gradually increase with the Ne fraction. $N_2$ dissociation rate, which corresponds to the density ratio of N to $N_2$, can be estimated by actinometry. The dissociation rate reaches more than 10% when the Ne fraction is larger than about 80%.

## 1. Introduction

Inductively coupled plasmas (ICPs) at low pressures have been widely used in the material processing, because the high densities and spatially homogeneous profiles of reactive species, such as atoms, free radicals and ions, can be produced and the ion bombarding energy at the surface can be independently controlled [1]. The inductively coupled plasmas are typically operated at pressures lower than 50-100 mTorr in typical electron density range of $10^{16}$ - $10^{18}$ $m^{-3}$. Such high-density plasmas containing nitrogen are useful sources of active species, such as nitrogen atoms, metastable nitrogen molecules, and nitrogen ions, and have been applied to semiconductor surface nitridation and etching of dielectrics. The dissociation degree of molecular nitrogen, which should be a significant parameter for the improvement of the nitridation processes, has been reported to be low in low temperature $N_2$ and Ar/ $N_2$ plasmas [2]. However, Akatsuka et al [3] investigated the dissociation degree of microwave discharge nitrogen plasma diluted with one of rare gases, and showed the marked increase in the nitrogen dissociation degree with increasing the mixture ratio of Ne.

In this study, measurements with a floating probe method and optical emission spectroscopy are carried out in inductively coupled rf (13.56 MHz) $Ne/N_2$ discharges in the total pressure range from 5mTorr to 50mTorr, changing the Ne fraction from 5% to 50%.

## 2. Experiments

A schematic diagram of the experimental apparatus is shown in Fig.1. A stainless steel chamber is cylindrical, 160 mm in inner diameter

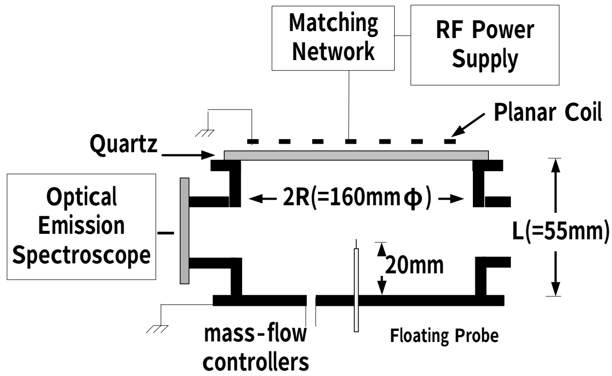


Fig 1 Experimental apparatus

and 55 mm in length, with a quartz plate of 10 mm thickness placed at the upper end of the chamber. Discharges are sustained by an azimuthal electric field induced by a rf coil current supplied to a planar three-turn coil from a power source connected to an L-type capacitive matching network. The planar coil mounted about 5mm above the quartz plate is concentric in the center of the chamber to maintain the discharge symmetry. An electrostatic shield can practically eliminate the capacitive coupling between the coil and the plasma, resulting in suppression of any rf plasma potential fluctuation. A planar probe is installed at the chamber center in order to measure the electron density and the electron temperature［4］. The power $P_{abs}$ injected into the plasma, which is estimated by subtracting the transmitted power without plasma from that with plasma at the same current, is kept at 170 W in our experiment. The flow rates of Ne and $N_2$ are controlled using two mass-flow controllers, and the total flow rate corresponding to the sum of two flow rates is maintained at 20SCCM.

The atomic nitrogen density in the plasmas is estimated from the optical emission intensities at 746.8 nm and 750.4 nm (the excited Ar), where a small amount of Ar (below 3%) is mixed as a actinometer [5].

## 3. Results and Discussions

Figures 2 and 3 show the electron density and its temperature measured as a function of $X_{Ne}$, where $X_{Ne}$ corresponds to the Ne fraction. As shown in Figs. 2 and 3, the measured electron density does not strongly depend on $X_{Ne}$ below $X_{Ne}$ lower than 80%, beyond which the increase in the density with $X_{Ne}$ is more prominent. On the other hand, the electron temperature gradually increases with increasing $X_{Ne}$. The measured electron density is around $10^{17}$ $m^{-3}$ at any condition, whereas the measured electron temperature decreases from 4.2eV to 6eV at 5mTorr, from 2.7eV to 4eV at 50mTorr. The electron temperature measured by the floating probe method should correspond to the slope of the high energy region in electron energy probability function (EEPF). Therefore, the temperature may be somewhat lower than the effective electron temperature corresponding to the slope of the bulk region in EEPF.

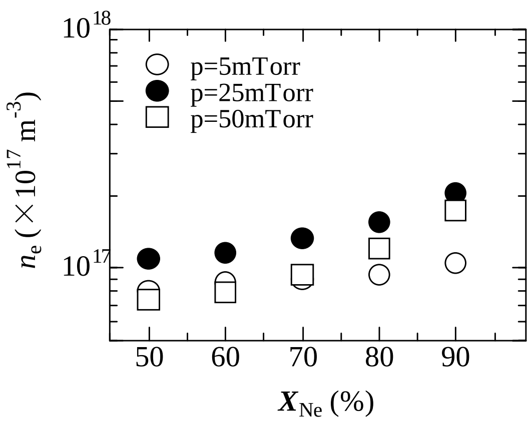


Fig.2 Electron density measured as a function of $X_{Ne}$

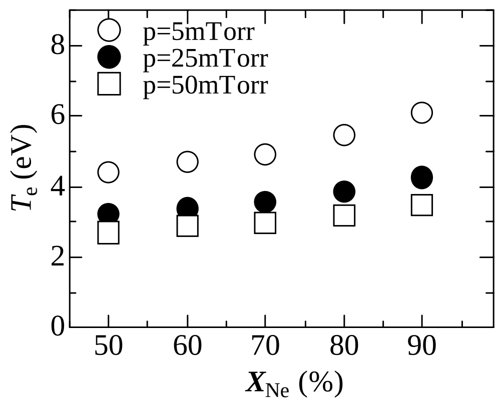


Fig.3 Electron temperature measured as a function of $X_{Ne}$

The dissociation rate (DR), which corresponds to the density ratio of N to $N_2$, can be estimated by actinometry. The DR estimated as a function of $X_{Ne}$ is shown in Fig. 4. As shown in Fig. 4, the DR abruptly increases with the increase in $X_{Ne}$ at any pressure. However, the dissociation rate does not strongly depend on the total pressure $p$, although the rate coefficient for dissociation of nitrogen molecules induced by electron impact strongly depend on $p$. The fractional rate of the energy loss due to the dissociation of nitrogen molecules to the total energy loss may be a significant parameter in order to explain the relationship between DR and $p$. Asides from the fractional rate of energy loss described above, the investigation on the influence of dissociation processes by the collisions between the metastable Ne and $N_2$ will be required.

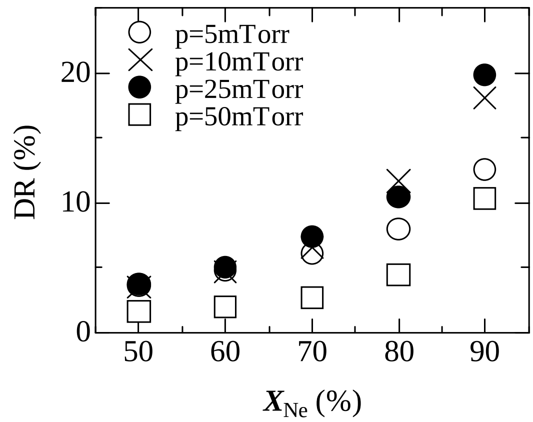


Fig.4 DR estimated as a function of $X_{Ne}$.

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