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Virtual OES of Hydrogen Emission and its Application to Process Control

H原子のバーチャルOESモニタリングと加工制御への応用

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Although SiN etch rate and uniformity strongly depend on a spatial distribution of H radical density which is affected by chamber wall conditions, it is difficult to measure it in actual process equipments. By using a numerical model to calculate an OES intensity of H with the plasma-wall reactions and comparing it with measured OES, we could quantitatively estimate the loss rates and the special distributions of the H radical on various wall conditions. Including time-dependent fluctuation, the prediction model will be useful to control the plasma process.

1. Introduction

The SiN etching is one of the most important processes in manufacturing CMOS devices, and its fluctuation caused by of the plasma instability must be minimized. A real-time monitoring of spatial distributions of reactive species is difficult to detect them in mass production equipments. To understand the space/time- dependent fluctuation of the plasma, we need to clarify the interactions between wall materials and reactive species. In our previous study, a statistical SiN etch rate model using data from an EES system became remarkably more accurate by adding the OES signal of H (656.3 nm) [1]. We also found that the SiN etch rate increased with the H_2 density in CF_4/H_2 plasma [1]. As a next step, we measured the SiN etch rate and the intensity of the H radical under various chamber wall conditions, and developed a numerical simulation of H_2 plasma

2. Experiments

A dual frequency CCP etching system with the OES system was used for the plasma measurement. We measured SiN etch rates using $CH_2F_2/Ar/O_2$ plasma and the optical emission intensity ratio of H (balmer line, 656.3 nm) over Ar (750.4 nm), in H_2/Ar plasma under three wall conditions: Si, SiO_2, and C-F polymer. The plasma density was about 1 x 10^{11} cm^3 with the surface wave probe.

3. Results

3.1 *Fluctuation of SiN etch rates*

When we changed the condition of the chamber wall, spatial distribution of SiN etch rates varied, as shown in Fig. 1(a). The etch rate was relatively low just after chamber parts were exchanged (the top plate surface was Si, and other walls were covered with quarts). After O_2 cleaning (Si top plate was oxidized), etch rates became higher. Then etch rates decreased again after C_4F_8 plasma discharge (all parts were covered with thin polymer).

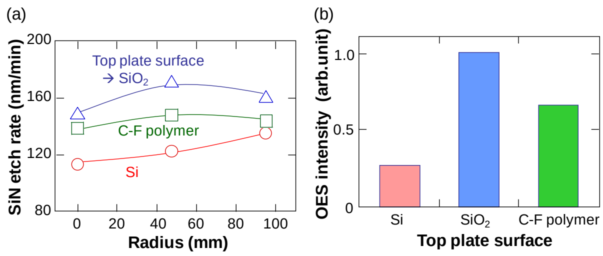

Fig.1. (a) SiN etch rate uniformity and (b) H intensity.

Figure 1(b) shows the optical emission intensity ratios of H/Ar under various wall conditions detected by the OES system. These intensities depended on the top plate surface conditions. These results are qualitatively consistent with changes in the SiN etch rate shown in Fig. 1(a).

3.2 *Virtual OES: Simulation of OES signal*

To describe the phenomena by numerical model, the spatial distribution of the H radical density and the virtual OES signal were calculated as shown in Fig. 2. First, we divided the chamber space into unit cell, and gave the initial density of H_2 molecule, electron density, and electron energy. Then, H densities in each cell were calculated from the balance equation between the H radical generation by electron impact dissociation of H_2 (G_{gas}), and losses by reactions with ions and electrons (L_{gas}), by pimping (L_{pump}), by sticking into chamber walls (L_{wall-n}), and by sticking into the wafer (L_{wafer}):

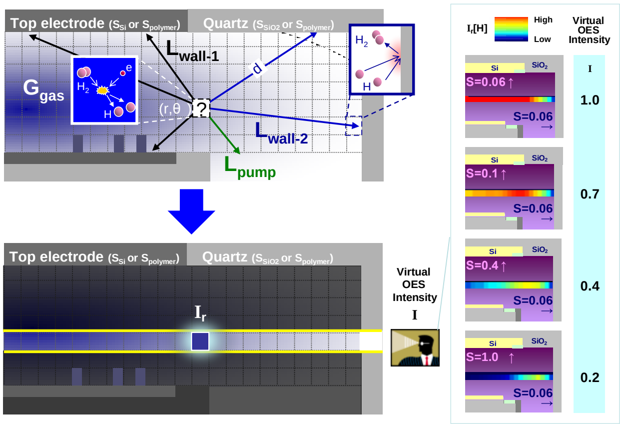

Fig.2. Schematic pictures of our model.

$$\frac{d[H]}{dt} = G_{gas} - L_{gas} - L_{pump} - L_{wall-1} - L_{wall-2} - L_{wafer} \quad (1)$$

The loss rate on the top plate (L_{wall-1}), the chamber side wall (L_{wall-2}), and the wafer (L_{wafer}) were functions of the surface loss probability *S* and of the distance from a cell to each wall. Chamber walls were made of Si or quarts and were sometimes oxidized and /or covered with the C-F polymer by the plasma treatment.

Using H radical density in each cell, a local intensity of the H radical, I_r[H], was also calculated. "Virtual OES signal" *I*[H] was calculated by the integration of I_r[H] along with the chamber radius as shown in Fig. 2, and its formula is given by

$$I[H] = \sum_r I_r[H] \quad (2)$$

More details of our model are described in Kuboi *et al*. [2].

4. Discussion

4.1 *Prediction of SiN etch rate uniformity*

In comparing measured OES data with virtual OES, the *S* values of the H radical under chamber wall conditions (Si, SiO_2, C-F polymer) were estimated to be 0.5, 0.06, and 0.1, respectively, which are consistent with experimental data and MD calculation. Adopting these values, we could calculate spatial distributions of H radicals, for example, at etching time of 30 s, as shown in Figs. 3(a)-3(c). The distributions were significantly varied with chamber wall conditions.

In Fig. 4, we can see a good relationship between the experimented SiN etch rate and the calculated H flux supplied to the substrate. The change in each rate caused by the wall surface conditions could be successfully predicted with this model.

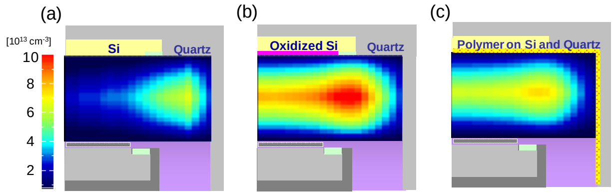

Fig.3. Spatial distribution of H radical.

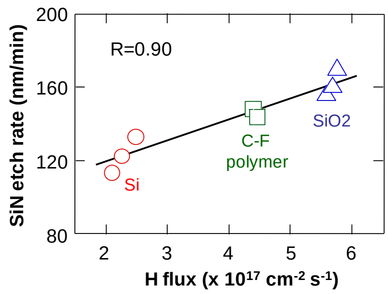

Fig.4. Relationship between SiN etch rate and H flux.

4.2 *Time-dependence of H intensity*

As shown in Fig. 5, our virtual OES could reproduce the behavior of measured OES data during the SiN etching after the deposition process where the loss probability *S* is time-dependent.

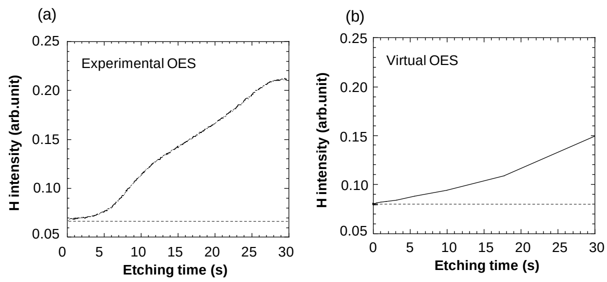

Fig.5. Time variation of H intensity.

5. Summary

We have studied the mechanism of the SiN etch rate fluctuation caused by the changes in plasma-wall reactions. Not only the spatial distribution but also the time variation of the chamber wall condition is important to control property of the SiN etching. As for film etching other than SiN etching, control of the above two elements seems to be essential and necessary for plasma process.

References

[1] M. Fukasawa, A. Kawashima, N. Kuboi, H. Takagi, Y. Tanaka, H. Sakayori, K. Oshima, K. Nagahata, and T. Tatsumi: Jpn. J. Appl. Phys. **48** (2009) 08HC01.

[2] N. Kuboi, M. Fukasawa, A. Kawashima, K. Oshima, K. Nagahata, and T. Tatsumi: Jpn. J. Appl. Phys. **49** (2010) 08JD01.