Estimation of HF gas temperature in low temperature plasma using infrared absorption spectroscopy

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Abstract: The insulating films etching process using HF gas as a plasma feed gas has gained attention. In this study, we estimate the HF gas temperature in both the gas and plasma phase using Fourier-Transform Infrared Spectroscopy (FTIR). The results indicate that HF gas temperature estimation was feasible at least under low HF partial pressure conditions.

1. Introduction

Dry etching using low temperature plasma is a key process and used widely for the manufacturing of semiconductor integrated circuits. As planar semiconductor miniaturization approaches its limits, 3D structures have been adopted, and improving their performance is now required. An example of this is 3D NAND flash memory, which requires the formation of further high aspect ratio (HAR) holes by plasma etching. Recently, the cryogenic etching process using plasma with HF as the main component has shown great results in HAR etching for 3D NAND flash memory [1]. However, the physical and chemical understanding of this process remains insufficient.

The gas temperature in plasma is an important parameter as it significantly influences plasma chemical reactions, and it is also important for plasma reaction modeling. Gas temperature in plasma is often measured using optical emission spectroscopy (OES) which targets electronically excited species. The vibration-rotation transitions of HF have been observed in the infrared region, and infrared emission studies of HF in flames have been conducted [2-3]. This study aims to estimate the HF gas temperature in low temperature plasma using FTIR.

2. Methods

Experiments were conducted using a dual-frequency capacitively coupled plasma reactor for etching, with FTIR equipment mounted for in-situ measurements. Gases were introduced through the showerhead of the upper electrode. The FTIR measurement range was fixed at approximately 3500 cm^{-1} to 4400 cm^{-1}, including the vibration-rotation line of HF molecules [4]. Background measurements were conducted in the absence of gas flow while sample measurements were performed at a certain pressure with gas flow. The temperature was estimated using the theoretical absorption [5] and the experimentally obtained absorption.

3. Results and Discussion

Figure 1 shows the absorbance in the FTIR measurement under the condition of a pressure of 3 Pa, HF flow of 10 sccm, and Ar flow of 40 sccm. The wavenumber region corresponding to the P branch is affected by H_2O in the optical path, whereas the R branch region is not. Therefore, the R branch was selected for gas temperature estimation.

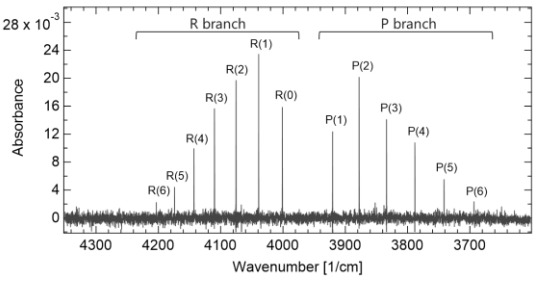

Fig. 1. Infrared absorption spectral profile of HF molecules

When the partial pressure of HF was low, the R branch mostly followed Boltzmann distribution. The calculation results showed that the temperature of HF molecules in the gas phase was approximately 300 K, which is likely attributed to the experiment being conducted at room temperature and the chamber walls maintaining at a similar temperature. On the other hand, the HF gas temperature in the plasma was 400 K. However, as the partial pressure of HF increased, the infrared absorption spectral profile of HF deviated from the Boltzmann distribution even in the gas phase. This may be related to the strong cohesive force of HF molecules.

4. Conclusion

An attempt was made to measure the gas temperature of HF molecules in the gas phase and plasma phase using FTIR. When the partial pressure of HF was low, the HF absorption spectral profile followed a Boltzmann distribution, resulting in a reasonable gas temperature estimation. However, at higher partial pressures, the profile deviated from Boltzmann distribution.

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