Analysis of Reaction Gases in a PECVD Chamber: Reaction Analysis Using a High-Resolution Mass Spectrometer

Introduction

Plasma-enhanced chemical vapor deposition (PECVD) is an evaporation technique that forms various thin films on a substrate using a material gas in a low-vacuum chamber. PECVD, which decomposes the material gas via plasma, is widely used to develop silicon, silicon oxide, and silicon nitride films in semiconductor device fabrication. As semiconductor devices feature increasingly smaller rules and require shorter turn-around times, a variety of material and reaction gases have come into use. The Si film development process is composed of two steps: deposition and cleaning (Fig. 1), and repetition of these steps to accomplish efficient operation.

<Cleaning step>

To remove the residual Si film in the reaction chamber, Ar plasma produces a fluorine gas from a NF_3 gas. The SiF_4 (gas) formed from the reaction of the fluorine gas with the Si film is discharged by a vacuum pump.

<Deposition>

In the reaction chamber, Ar plasma decomposes a SiH_4 gas into Si and $2H_2$, depositing Si on the substrate. During this step, Si is also deposited on the inner walls of the chamber.

Because complex physicochemical and minor reactions occur in plasmas, high-resolution mass spectrometry (HR–MS) is needed for detailed-reaction gas analysis to examine active species and residues. For this work, we connected the JEOL INFITOF HR–MS to a PECVD chamber to directly monitor the reaction gases in the chamber.

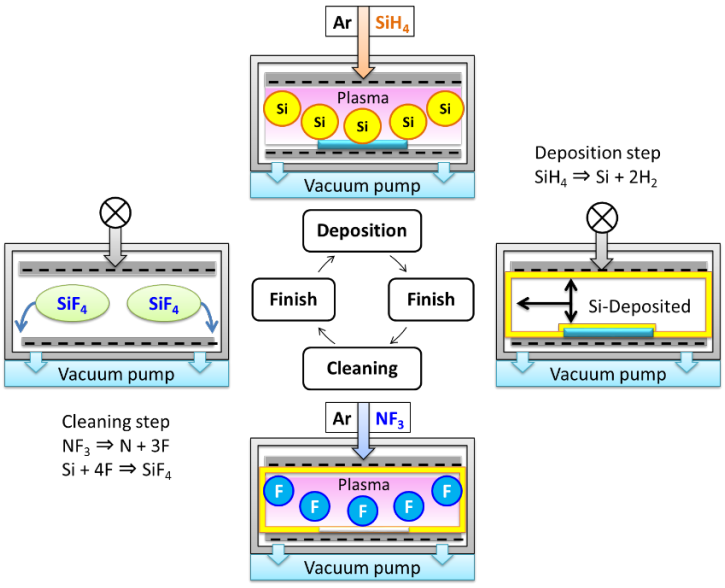


Figure 1. Principles of deposition and cleaning, using a PECVD system.

Experiment

Figure 2 shows a schematic diagram of a PECVD–HR–MS device. The interface connecting the PECVD device and the INFITOF was designed to select and control the gas volume according to the type and objective of the film deposition. HR–MS measurement conditions are shown in Table 1.

Figure 2. PECVD connection diagram.

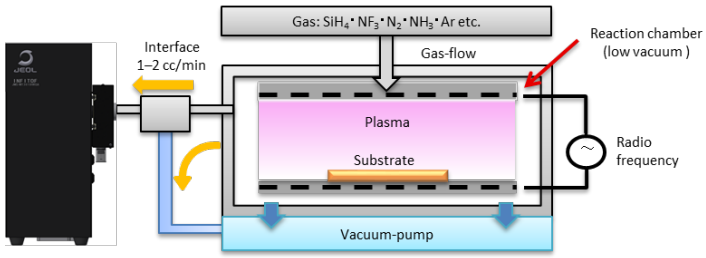


Table 1. Measurement Conditions.

HR-MS: JMS-MT3010HRGA (JEOL)	
Ion source temp.	250˚C
Interface temp.	250˚C
Collection gas flow rate	1–2 cc/min
Ionization mode	EI (70 eV, Yttrium coated filament)
Measurement mode	Extended
Resolution	R≒4300
Scan range	*m/z* 0.8 – 250
Repetition time	1000 msec

Results

[Reaction gas analysis during cleaning]

The cleaning step is important for maintaining deposition quality. Figure 3 shows the behavior of the gases detected during the NF_3 cleaning step. The mass spectrum of Scan No. 182 is shown in Figure 4. Reaction products such as SiF_4 and SiF_3 were clearly detected while the NF_3 gas was being supplied. As shown from these results., reaction monitoring during the cleaning process can be an effective tool for evaluating different aspects of the cleaning step such as cleaning time and gas phase reactant/product compositions.

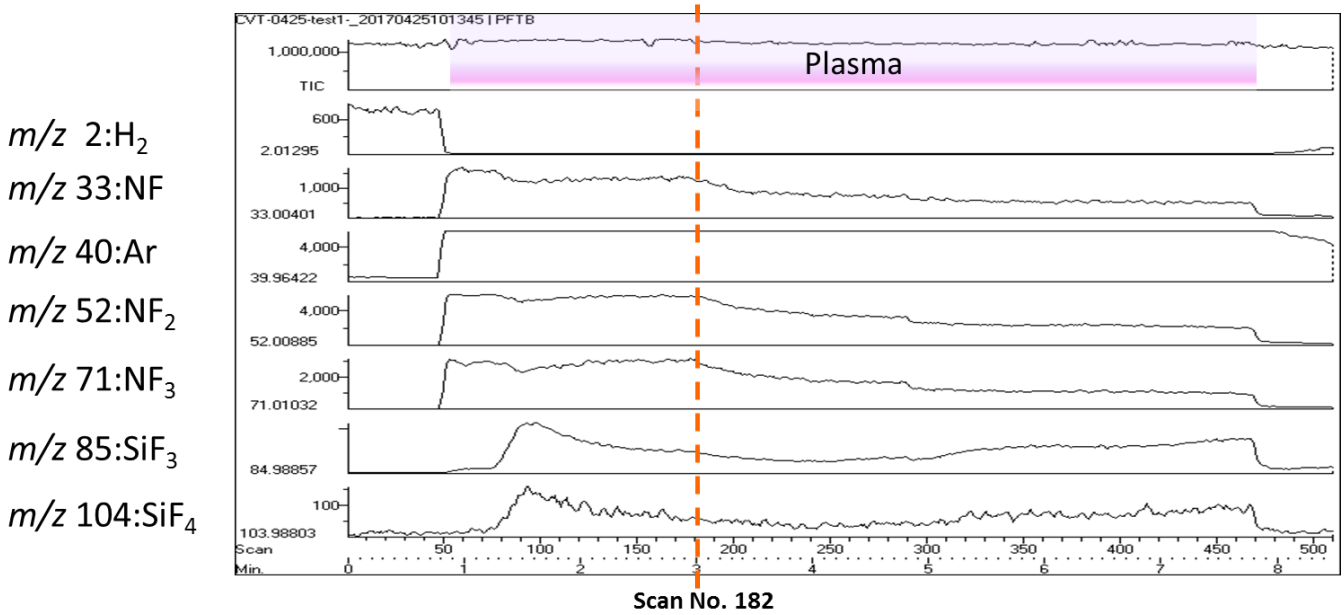


Figure 3. Monitoring results of the cleaning step.

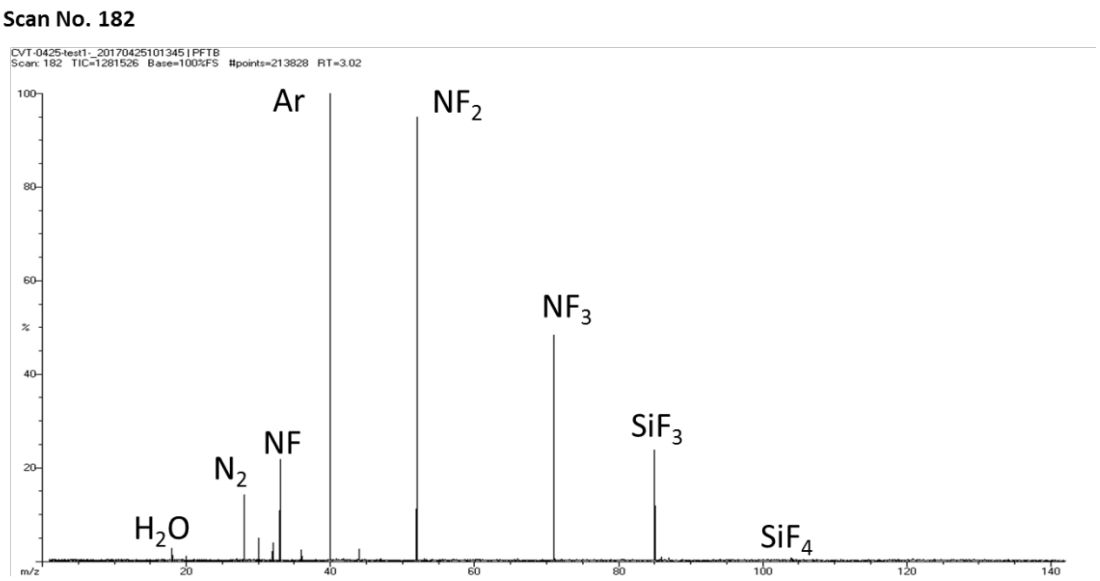


Figure 4. Mass spectrum of Scan No. 182 during cleaning.

[Reaction gas analysis during deposition]

Figure 5 shows the reaction behavior of the gases observed during the deposition step. Residues from the first cleaning step (HF, SiF_3, etc.) were detected before the multi-layer depositions of silicon films (SiN, SiO, Si), which was repeated three times. The mass spectrum of Scan No. 214 is shown in Figure 6. This mass spectrum shows minor components such as N_2O and SiF_2H, thus demonstrating how HR–MS can provide a detailed reaction analysis during the deposition steps.

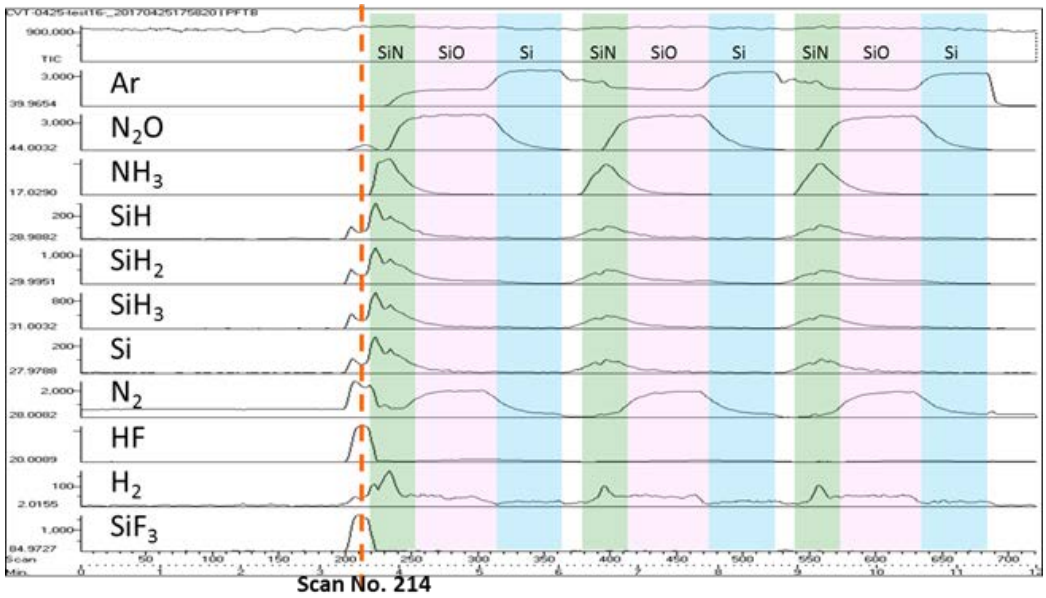
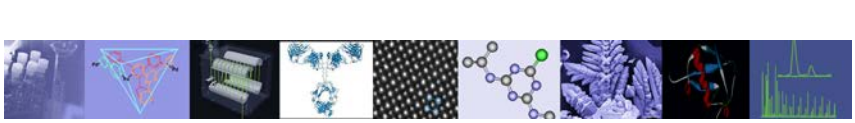


Figure 5. Monitoring results of the deposition step.



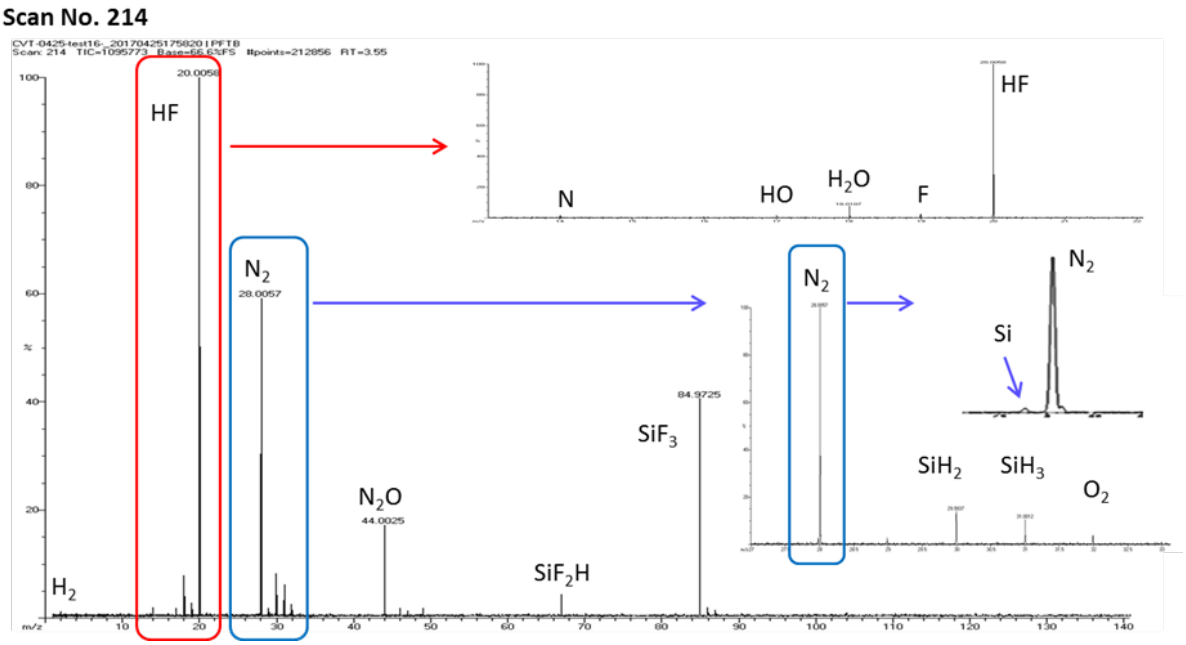


Figure 6. Mass spectrum of Scan No. 214 during deposition.

Conclusion

As semiconductor devices feature increasingly smaller rules and require shorter turn-around times, a variety of material and reaction gases have come into use. In this work, we showed that the JEOL INFITOF (JMS-MT3010HRGA) is a powerful tool for reaction gas monitoring during the cleaning and deposition process steps used in a PECVD device. The JEOL INFITOF is effective for a wide range of applications, including the physicochemical analysis of minor reactions of gases for process evaluation and R&D.

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