Two dimensional simulations of VHF plasmas for industrial applications

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論 文 名　:　Two dimensional simulations of VHF plasmas for industrial applications

（産業応用 VHF プラズマの２次元シミュレーション）

Title

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論 文 内 容 の 要 旨

Thesis Summary

This thesis deals with the topic of very high frequency (VHF) plasma simulations for industrial applications such as amorphous silicon thin film solar cells and the semiconductor fabrication. A VHF capacitively coupled plasma (CCP) source is widely used for plasma enhanced chemical vapor deposition (PECVD) and plasma etching. Industries require further cost reduction of solar cells and semiconductors. Larger area fabrication of films and fine etching are key technologies, but they have been mostly carried out by trial and error. Recently, there is a trend of a large area and narrow gap discharge in industries, so it is limited to diagnose the VHF-CCP characteristics inside the vacuum chamber. Therefore, plasma simulation has become a powerful tool to accomplish the goals. This thesis consists of five chapters, and the last chapter 5 provides a summary of two dimensional simulations of VHF plasmas for industrial applications.

In this work, the VHF-CPPs of a frequency of 60 MHz in the PECVD process with multi-hollow geometry and multi-rod electrodes were examined, where the substrate was placed behind the discharge electrodes. Triode VHF-CCP sources using the multi-hollow geometry and multi-rod electrodes were designed for achieving high deposition rate with high-quality films for amorphous silicon (a-Si) fabrication. As is well known, distribution of SiH_3 and SiH_2 radicals as well as the density and temperature of electrons are important parameters for deposition rates and higher-order silanes generation that is related to film quality of a-Si. In this thesis, it was focused to examine the VHF plasma characteristics and higher-order silanes generation using the plasma hybrid model, where 149 chemical reactions were considered.

In the first part, the multi-hollow geometry plasma was simulated for SiH_4/H_2 gas to prepare amorphous silicon. A typical character of the VHF plasma of a high electron density with a low electron temperature was obtained. The density ratio of SiH_3/SiH_2 that is a measure to judge film quality at the center and near the substrate was very large, indicating the fabrication of high-quality amorphous silicon. However, it was found that there were many higher-order silanes with high densities near the substrate. The density of Si_5H_{12} radicals that contribute to a dust formation was comparable to the SiH_3 density, suggesting generation of dust particles. Furthermore, the multi-hollow plasma effect was not found at the selected pressure.

In the following part of this thesis, the multi-rod electrode geometry was simulated for pure SiH_4 gas. It was found that the SiH_3 density was similar to that in the case of the multi-hollow plasma, however, high-order silanes densities near the substrate were significantly lower than the SiH_3 density. Therefore, the multi-rod electrodes can fabricate high-quality films. To optimize the process of VHF plasma discharges in the multi-rod geometry, the simulations were performed at different pressures. Increases in pressure were found to negatively affect the deposition rate in the simulated geometry.

The last part of the thesis was dedicated to the simulation of a VHF argon plasma (100 MHz) at 5.3 Pa for etching process in a CCP geometry using the Particle In-Cell with Monte Carlo Collision Module. Plasma uniformity along the discharge electrodes is a key subject in plasma etching and has been studied using simulations by many researchers. In this study, two-dimensional PIC simulation was performed under the assumption that the plasma is produced by electrostatic fields. It was found that the electron density peaked near the edge of the discharge electrode and at the center, which is the first result found without taking into account electromagnetic fields. The results obtained by this simulation will be useful for designing a VHF plasma source for large-area etching processes.