Correlation of Optical Emission Spectroscopy Line Ratios with Deposition Rate and Refractive Index of Silicon Nitride Films in Plasma Enhanced Chemical Vapor Deposition

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Optical emission spectroscopy (OES) is common non-invasive method for monitoring plasma in semiconductor manufacturing and analyzes emitted light without disturbing the plasma.[1] Quantitative understanding of plasma states from OES peak intensities is still challenging.[2] In this work, the deposition rate and refractive index of silicon nitride (SiN_x) deposited using trisilylamine (TSA), NH_3 and N_2 gas were predicted using OES analysis in plasma enhanced chemical vapor deposition (PECVD). The four dominant peaks of 337 nm (N_2 second positive system), 391.2 nm (N_2^+ first negative system), 656 nm (H_α Balmer line), and 486 nm (H_β Balmer line) were selected, and the correlation between the deposition rate and intensity ratios of I_{N2+}/I_{N2} and $I_{H\alpha}/I_{H\beta}$ was investigated. The I_{N2+}/I_{N2} was found to be strongly correlated with the deposition rate with coefficient of determination (R^2) of 0.85 and mean absolute percentage error (MAPE) of 3.66%. This strong correlation is attributed to the fact that the ratio represents the variation of electron temperature, which increases molecular dissociation and ionization in plasma. However, the refractive index was poorly correlated with the I_{N2+}/I_{N2} and $I_{H\alpha}/I_{H\beta}$ line ratios, and the intensity ratios of I_{NH}/I_{N2} and I_{SiH}/I_{N2} were suggested from 336 nm (NH), 414.2 nm (SiH), and 337 nm (N_2) peaks as indicators representing the relative radical density of NH and SiH radicals. These line ratios were derived because they have similar overlap of excitation cross sections with electron energy distribution function (EEDF) in typical inductively coupled plasmas (ICP). The derived I_{SiH}/I_{NH} ratio showed a strong correlation with the refractive index, as the atomic composition of N and Si in the film is directly influenced by NH and SiH radicals in plasmas. The refractive index with I_{NH}/I_{N2} and I_{SiH}/I_{N2} line ratios showed high accuracy with R^2 of 0.95 and MAPE of 0.27%. This work demonstrated that the OES intensity ratio proposed as I_{N2+}/I_{N2} and I_{SiH}/I_{NH} can effectively predict deposition rate and refractive index in SiN_x PECVD.

Reference

[1] I. J. Kim, I. Yun Robot. Comput. Integr. Manuf. 2018, 52, 17-23.
[2] J. Li, Y. Kim, S. Han, J. Niu, H. Chae Plasma Chem. and Plasma Process. 2022, 42, 989-1002.

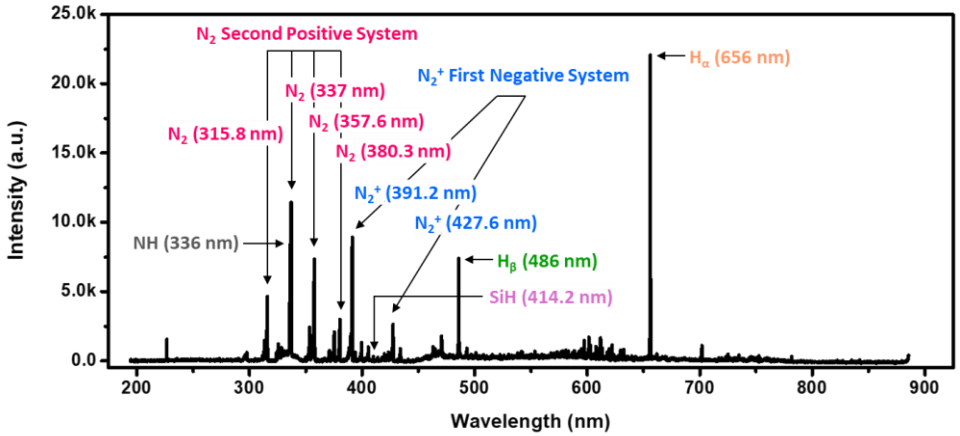

Figure 1. Plasma emission spectra monitored by OES at the reference condition.

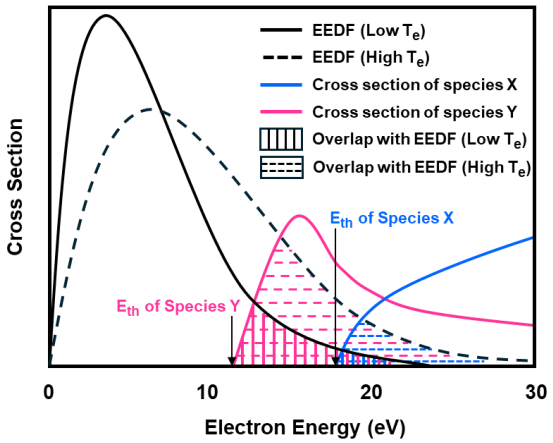

Figure 2. Comparison of excitation cross sections of chemical species overlapped with the EEDF at low and high T_e

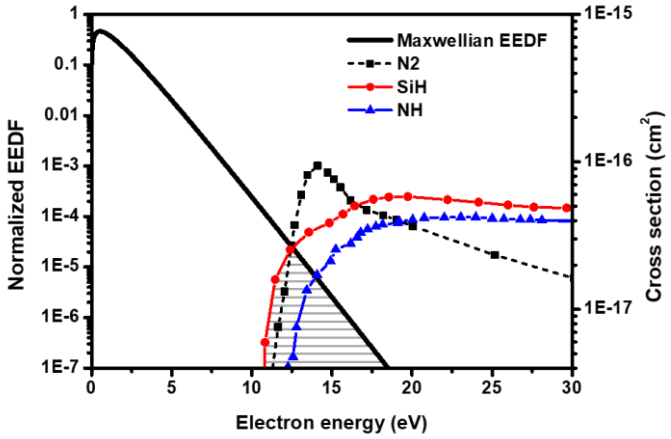

Figure 3. Overlap of EEDF and excitation cross section for NH, SiH, N_2.