Statistical Analysis of PECVD SiO_x Deposition Rate and Refractive Index Using Design of Experiments

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Abstract

Silicon dioxide is largely used in electronics, photonics, and surface engineering. Plasma-enhanced chemical vapor deposition (PECVD) enables the deposition of SiO_x at significantly lower temperatures than thermal oxidation or conventional CVD, making it particularly suitable for temperature-sensitive substrates. However, realizing the full benefits of PECVD SiO_x requires tight process control, as even small variations in deposition conditions can cause thickness nonuniformity, increased optical loss or mode mismatch, and inconsistent electrical performance, ultimately reducing yield.

In this work, we use a design of experiments (DOE) approach to quantify the effects of key PECVD parameters on the deposition rate and refractive index of SiO_x thin films. Particularly, we consider the N_2O:SiH_4 flow ratio, chamber pressure, RF power, and sample temperature as factors. We conducted a randomized 2^4 factorial design with three replicates, yielding 48 deposition runs. Film thickness and optical constants were characterized by spectroscopic ellipsometry and fitted using a Cauchy dispersion model, with the refractive index reported at 632.8 nm.

For the deposition rate, the dominant response driver is the N_2O:SiH_4 ratio, followed by chamber pressure and RF power, while substrate temperature showed no statistically significant effect within the 200–350°C window. Multiple two-way and higher-order interactions were significant, showing strong coupling between plasma conditions and reactant delivery that would be missed with one-factor-at-a-time process parameter tuning. A regression model including main effects and interactions effectively describes the deposition rate as a function of the DOE factors (R^2 of 0.996).

In contrast, the refractive index was most strongly influenced by the precursor flow ratio and substrate temperature. The corresponding regression model showed excellent agreement with the data (R^2 of 0.974), indicating a strong relationship between process conditions and film optical properties. By capturing both main effects and interaction-driven behavior, the DOE approach enables reliable process tuning of PECVD SiO_x films with respect to growth rate and refractive index across the investigated parameter ranges.