Practical issues in tomographic reconstruction of semiconductor processing plasmas

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Ensuring spatial uniformity in plasma processing has become increasingly crucial as both the number and complexity of semiconductor manufacturing steps continue to rise. Real-time, in-situ visualizing of such plasma has long been desired to monitor spatial parameters and to pre-emptively mitigate unexpected issues inside chambers. Although optical diagnostics in conjunction with tomographic reconstruction has been investigated [1,2], practical challenges inherent to real-world environments have limited its widespread application. Here, we propose an advanced tomographic reconstruction incorporating a line-of-sight (LoS) correction technique to enable robust and reliable plasma monitoring. Among the practical issues, we here focused on two systematic errors frequently compromise reconstruction accuracy: (i) refraction- and reflection-induced field-of-view (FoV) distortion at vacuum viewports and chamber walls, and (ii) geometric misplacement or tilt of multi-pixel detector arrays. While statistical noise can be reduced by longer exposure or advanced denoising techniques, geometric mis-calibration constitutes an irreversible systematic error. Once acquisition is complete, the true weights cannot be reconstructed from the projections alone; the attainable accuracy of any subsequent inversion is therefore bounded by the initial geometric uncertainty.

Phantom-based simulations demonstrated that neglecting the aforementioned factors can increase the reconstruction error by up to sixfold, quantitatively validating the necessity of compensation. Using COMSOL Multiphysics, the accurate LoS was simulated precisely accounting for the actual chamber geometry. The corresponding weight matrix was then derived for Philips–Tikhonov regularization [1,2] to reconstruct plasma emission profiles.

A capacitively coupled plasma (CCP) chamber, consisting of two parallel cylindrical electrodes with a diameter of 200 mm, was employed to validate our measurement methodology. The operating pressure was varied in the range of 100–500 mTorr with a constant argon flow rate of 15 sccm. Plasmas were generated by a 250-W sinusoidal power at 13.56 MHz. Line-integrated plasma emission was measured using six detector units, each equipped with a pinhole and a line-scanning camera. Our results clearly demonstrate that accurately modeling the FoV distortions—caused by reflection and refraction within the chamber—and incorporating them into the weight matrix can significantly enhance the accuracy of tomographic reconstruction.

References

[1] Jang, J. et al. Review of Scientific Instruments. **89**, 10E111 (2018).
[2] Park, S. et al. Plasma Sources Science and Technology. **28**, 035012 (2019).