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Development of Microwave Based Plasma Density Sensors for Process Monitoring and Feedback Control of Plasma Processing Tools

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Abstract:
Plasma based processing plays a crucial role in modern micro/nano manufacturing where high yield and high throughput processing is of primary importance. To improve process stability and reliability, it is desirable to monitor the plasma conditions during the process by plasma property sensors. The sensor's output can also be used for feedback control of the plasma processes. The most fundamental property of plasmas is the electron density. Microwave based measurements, as compared to electric probe based techniques, have the advantage of being non-intrusive and less perturbation to the plasmas, i.e., without extracting currents from the plasma.
Thus, a non-invasive sensor, e.g., microwave-based ones, for monitoring, or even feedback control of the plasma density of plasma tools is highly desirable. Two types of microwave diagnostics have been investigated for this purpose. The first one is based on a transmission line structure immersed in the plasmas. It is operated as an interferometer and thus does not need expensive microwave network analyzer based instruments. The plasma density is determined by the phase shift of a microwave going through the transmission line.
Several transmission line structures have been studied, including a coaxial line (Transmission-Line Microwave Interferometer, TLMI, see Fig. 1)[1], a ridged microstripe line (Ridged Microstrip Microwave Interferometer) [2] and an air-bridge microstrip line (ABMMI). The ABMMI has also been employed for feedback control of plasma density in etch process using an ICP etcher.[3] Numerical Simulation analysis and experimental results show that the air-bridge structure yields the highest sensitivity for plasma density measurements. Figur2 2 shows the experimental measurement results for these three types of sensors (ICP, Ar plasma). The second type of the microwave sensors is a probe employing a microwave resonant structure where the resonant frequency is determined by the density of the plasma surrounding the probes. We first focused on the plasma absorption probe (PAP), having a relative simple structure, i.e., the tip of a coaxial cable enclosed by a dielectric tube. A compact PAP with a diameter of 2 mm has been developed to minimize perturbation to the plasma. Both simulation and experimental results show good agreement with the regular 6 mm diameter. Moreover, approaches have been explored to improve the sensitivity of the PAPs, e.g., by loading the probe tip with dielectrics (DL-PAP) or using a disc shaped tip (D-PAP). Analysis showed that, for both DL-PAP and D-PAP, the microwave coupling of the probe can be shifted toward the critical coupling and thus giving rise to a higher sensitivity.

References
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[3]. C. Lin, et, al, J. Vac. Sci. Technol. A, 26, 1282-1286, 2008.

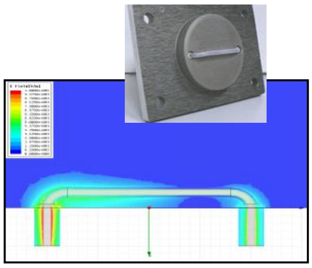

Fig. 1. TLMI and HFSS simulation results (electric field).

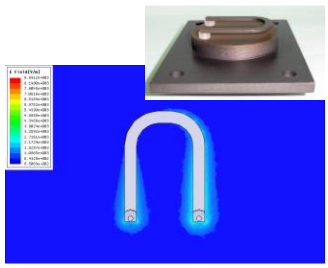

Fig. 2 ABMMI and HFSS simulation results (electric field)

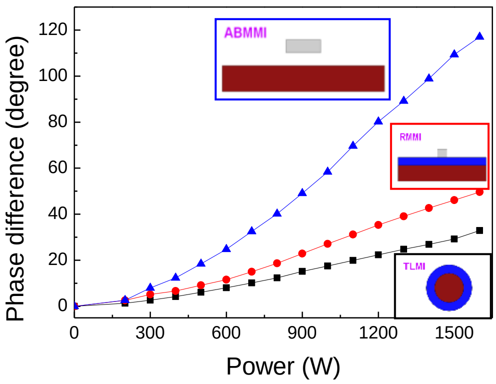

Fig. 3. Experimental results of TLMI, RMMI and ABMMI (ICP, Ar plasma).