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Plasma modeling for plasma processing

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This work is based on joint plasma research projects between Shibaura Mechatronics Corporation and Chubu University, focusing on applied plasma modeling. Shibaura Mechatronics designs large automated equipment for the manufacturing of various electronic and optical devices (semiconductor chips, flat-panel displays, lithography masks, magnetic and optical disks, dashboard displays, etc.), and the majority use low-temperature plasma at some stage for pattern etching, surface processing/activation and/or cleaning. This requires sound modeling with reasonable (not too long) computational times, preferably using commercially available simulation software. The broad range of process requirements call for a broad range of plasma sources: capacitively-coupled discharges for slow-rate etching of thin films, inductively coupled plasmas (ICP) with RF biased substrate for independent control of ion flux and ion energy, planar microwave surface plasma with and without additional substrate bias for high-speed photo resist removal, atmospheric pressure barrier discharges for substrate cleaning and bio activation, low-pressure DC and RF magnetron discharges for material sputtering/deposition, remote microwave plasma sources for ion-free chemical dry etching, etc.

While PIC or kinetic codes provide the best physical insight, they are too slow for practical design purposes, and PIC commercial packages are barely available. On the other hand, fluid modeling can be performed in a more or less standard multi-physics finite element simulation, coupling particle production, loss, and transport to electrostatic (Poisson) and/or electromagnetic solvers. One such environment is the COMSOL© package, and at Chubu University we have been applying it to the interpretation of various low-temperature plasmas. Here we use it as a tool to get insight into the important features of several types of processing plasmas.

Figure 1 is a demonstration of mode jumps in microwave plasma sustained by a surface wave (SW) travelling along the plasma-dielectric interface at the top plasma boundary in a chamber with dielectric (quartz) top wall. In order to make the model axially-symmetric, the SW is excited via a ring slot fed by coaxial line. At fixed RF frequency the wavelength depends on the electron density along the interface, and at some discrete densities strong standing-wave resonances occur [1].

In another application, the dependence of wavelength on electron frequency in slot line facing plasma is used for plasma monitoring by miniature resonating antennas [2].

Figure 2 shows an example of capacitive coupling in ICP. Traditional ICP modeling takes into account the electron heating by the inductive RF electric fields generated by the RF current in the ICP antenna, but neglects the RF potential oscillation of the antenna. Such RF potential oscillations are inevitable due to the large RF currents and the non-negligible antenna inductance. They give rise to a significant additional electric field, which, although oscillating at the RF frequency, is essentially electrostatic and causes additional capacitive coupling of RF power to the plasma. Unlike the inductive field, this field has a significant normal component at the plasma-dielectric interface below the antenna, which, at low plasma densities, can cause large sheath voltage oscillations. Ions get accelerated by the time-averaged sheath voltage, and wall abrasion by high-energy ion bombardment may become an issue. Here we account for the capacitive coupling by applying an oscillating RF potential to the ICP antenna in addition to the oscillating RF current.

Suppression of unwanted electrostatic coupling is achieved by either shielding the electrostatic fields by properly designed Faraday shields, or by antenna designs with lower antenna potential, to be discussed in the talk.

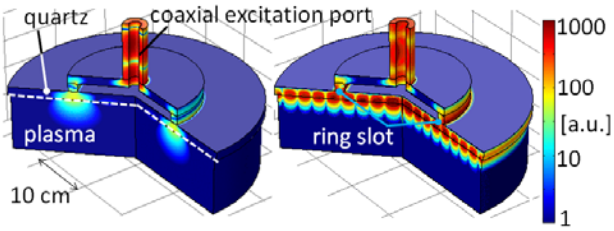

Figure 1. RF electric field profile in a planar 2.45 GHz cylindrical SWP with ring slot excitation at low plasma density (left, electron density $n_e = 1.5 \times 10^{11}$ cm^{-3}, which is below the surface wave resonance) and at a standing-wave resonance (right, $n_e = 8.8 \times 10^{11}$ cm^{-3})

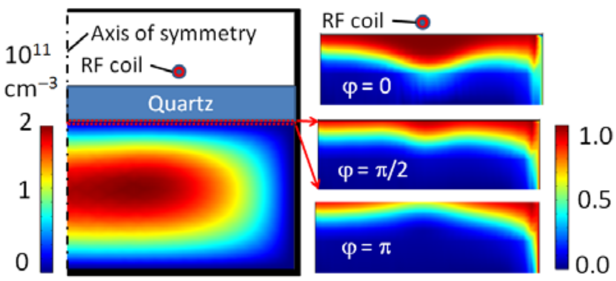

Figure 2. Left: ion density n_i in a cylindrical ICP plasma with one-turn coil antenna on the top. Right: relative ion density excess $(n_i - n_e) / n_i$ in the plasma sheath below the ICP antenna at different phases of the RF coil voltage, vertical scale zoomed out 18 times.

References

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