SELF-CONSISTENT MODELING OF CUTOFF-DENSITY RESONANCE IN SURFACE-WAVE PLASMAS

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Surface-wave plasmas are a type of wave-heated low-temperature plasmas sustained by an electromagnetic wave traveling along a plasma-dielectric interface [1]. To support surface wave propagation, the electron density n_e must be above the critical density n_c (7.4×10^{10} cm^{-3} for the 2.45 GHz plasmas widely used in industrial applications).

On the other hand, the electron density at the wall (on the outer side of the plasma sheath) is very low as in any sheath, definitely below n_c. Thus there is always a surface where $n_e = n_c$ somewhere in the bulk plasma or in the sheath. Along this surface the electron plasma frequency $\omega_p \propto n_e^{1/2}$ is equal to the wave frequency, resulting in an electron plasma resonance with strong locally enhanced electric fields. While the resonance has been observed both by measurements and modelling, there is little consensus about its "role". Can we do practical estimates forgetting about it, or do we get the particle and energy balance grossly wrong if we omit it?

The answer of this question is complicated by conflicting simultaneous trends when changing the pressure. For example, the general feeling is that the resonance should be more important at low pressures. The thinking is that at low pressure non-collisional transit-time electron heating at the sharp resonance is needed to compensate for the dearth of electron-neutral collisions. However, this is also when electron density at the sheath-presheath boundary goes up due to increased ion mobility, pushing an eventual resonance into the sheath, maybe too close to the wall for it to play any significant role on the particle and energy balance?

What happens actually depends on quantitative balance and cannot be predicted without self-consistent analysis, taking into account as much phenomena as possible. This requires adequate numerical modelling. Full 3d PIC modelling would be best, but is impractical at this point due to the vastly different time scales for ions and electrons, especially at higher pressures.

This contribution attempts to answer some of the questions above by means of self-consistent modelling using a commercially available finite-element multi-physics simulator, capable of multi-fluid plasma simulations. The local electron resonance occurred naturally in all cases tested (admittedly not many), as shown in the example in Fig. 1. The contribution of the resonance area to the particle and energy balance is analysed, to get insight into how important the resonance is. Admittedly this fluid model is not suitable for low pressures dominated by non-collisional heating, where further research is needed.

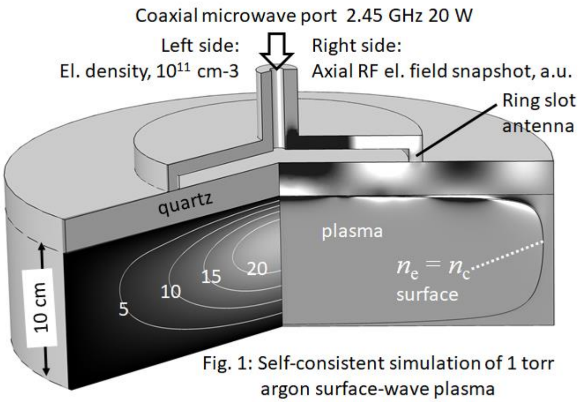

Fig. 1: Self-consistent simulation of 1 torr argon surface-wave plasma

Acknowledgment: Much of the author's experience with such modeling comes from collaboration with Prof. Keiji Nakamura from Chubu University.

Reference:

[1] I. P. Ganachev, H. Sugai: Plasma Sources Sci. Technol. **11** (2002) A178.