Control of heating dynamics and distribution functions in technological plasmas

Topic: Plasma self-organization

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The author cannot attend the Town Hall meeting.

Background

Low temperature plasmas are key tools for the manufacturing of a variety of high-tech products ranging from integrated circuits to biocompatible surfaces [1]. Our modern life would not be possible without plasma technology, since etching and deposition processes on microscopic scales could not be performed at low temperatures in a controlled way so that laptops, smartphones, and flat panel displays would not exist.

Most applications rely on capacitively and/or inductively coupled radio-frequency (RF) plasmas [2]. They have been optimized by empirical methods without a detailed understanding of the underlying plasma physics. While this approach has been successful in the past, this is no longer the case now, since applications are facing extreme challenges in terms of feature size reduction, atomic layer etching/deposition, and extreme uniformity control, that cannot be realized based on trial-and-error methods. In order to master these technological challenges a detailed scientific understanding of the particle (electrons, ions, neutrals) heating dynamics and the mechanisms of formation of process relevant energy distribution functions in the plasma and at boundary surfaces is required. Based on this understanding, concepts to control and customize heating dynamics and distribution functions must be developed.

Despite its extreme societal and economic relevance funding in this field is strongly limited in the US. Consequently the US is loosing its leading role in this field to Europe and Asia. Besides the scientific results, training of future low temperature plasma scientists and engineers is in great danger without adequate support of this kind of research by national funding agencies.

Approach to advancing the scientific frontier

A combination of state-of-the-art experimental diagnostics, kinetic simulations, and models is required. Particle heating dynamics must be studied with nanosecond resolution by non-intrusive diagnostics in combination with simulations/models. Energy distribution functions must be measured, simulated, modeled, and related to the heating dynamics. In RF plasmas, one promising concept to control and customize both the heating dynamics and distribution functions is voltage waveform tailoring (VWT) [3,4]. By driving a plasma with a voltage waveform that corresponds to a finite Fourier Series of N consecutive harmonics of a fundamental frequency the electron heating dynamics can be tailored by adjusting the harmonics' phases and amplitudes individually without modifying the reactor itself, but only its external circuit. Very little is known about this technology. Recent investigations in capacitive RF plasmas have shown that the electron heating dynamics can be controlled in this way, but works significantly differently compared to classical reactor concepts [5]. These investigations have also shown that our

current understanding of electron heating in capacitive RF plasmas is fundamentally incomplete [6]. It was demonstrated successfully that ion energy distributions can be customized and uniformity control across large substrates can be realized in this way. A variety of potential applications in inductive plasmas and for biomedical purposes exist.

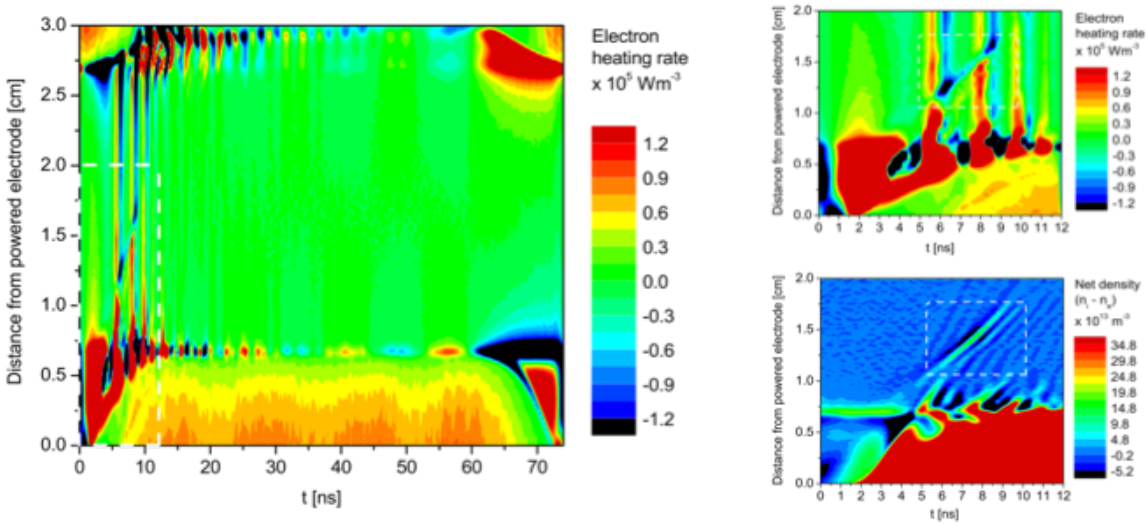

Fig. 1: Electron heating rate and net charge density space and time resolved within the RF period of the fundamental driving frequency in a capacitive RF discharge driven at 4 consecutive harmonics of 13.56 MHz (all harmonics' phases are 0 deg). PIC/MCC simulation results: Argon, 3 Pa, 800 V, 3 cm electrode gap. The results show complex heating dynamics far beyond the current level of understanding [5].

Impact of this research

The US can ensure its leading role in plasma technology and semiconductor manufacturing only by providing adequate funding to research in this field. The extreme societal relevance is obvious, since our modern life is heavily influenced by plasma technology via semiconductor products. This multi-billion dollar industry relies heavily on research in low temperature plasma technology. If adequate funding is not restored, next generation semiconductor devices will not be developed or will be created outside the US. This would correspond to an economic and societal dilemma. Collaboration between companies and academic research must be fostered.

References

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