Why Does Fresh Nucleation Occur in a Dusty Plasma Void?

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Dusty plasma voids are created by ion drag, which pushes relatively large negatively-charged particles out of the center of the plasma. In neutral aerosols, high particle surface area density typically quenches fresh nucleation, because nucleation and surface growth compete for the same species. However, in a dusty plasma, particle surface growth is dominated by neutral radicals, whereas nucleation occurs primarily via anion-molecule reactions. In an argon-silane plasma these anions are created mainly by electron dissociative attachment to silane. Hence high particle surface area does not quench nucleation. Rather, nulceation occurs in the void because anions are pushed by the electric field into the void, a positive potential maximum. The anions are trapped there, where they react with SiH_4 to grow successively larger clusters. This behavior is shown by a 1D, transient model of capacitively-coupled RF argon-silane plasmas which extends previous work [1] by adding chemical kinetics to predict particle nucleation and growth. Simulation results are shown for a 13.56 MHz plasma with a 4-cm electrode gap, pressure of 100 mTorr and RF voltage amplitude of 250 V. Gas flow is through a showerhead electrode. The particle size distribution (left) and density profiles of charge carriers (right) at 2.0 seconds following plasma turn-on are in Fig. 1. Ion drag pushes larger, more charged particles out of the center, creating a relative void 2.35 cm above the lower electrode. Neutral drag and gravity push particles towards the lower electrode, creating an asymmetric distribution of the particle cloud. A high concentration of very small (1- or 2-nm) particles is in the void created by fresh nucleation. These particles become negatively charged, perturbing the plasma potential profile. In turn, the profiles of all charge carriers have a local maximum at the same location. SiH_n anions, being much less mobile than electrons, show a particularly strong peak at that location, which drives fresh nucleation.

[1] P. Agarwal and S. L. Girshick, Plasma Sources Sci. Technol. **21**, 055023 (2012).

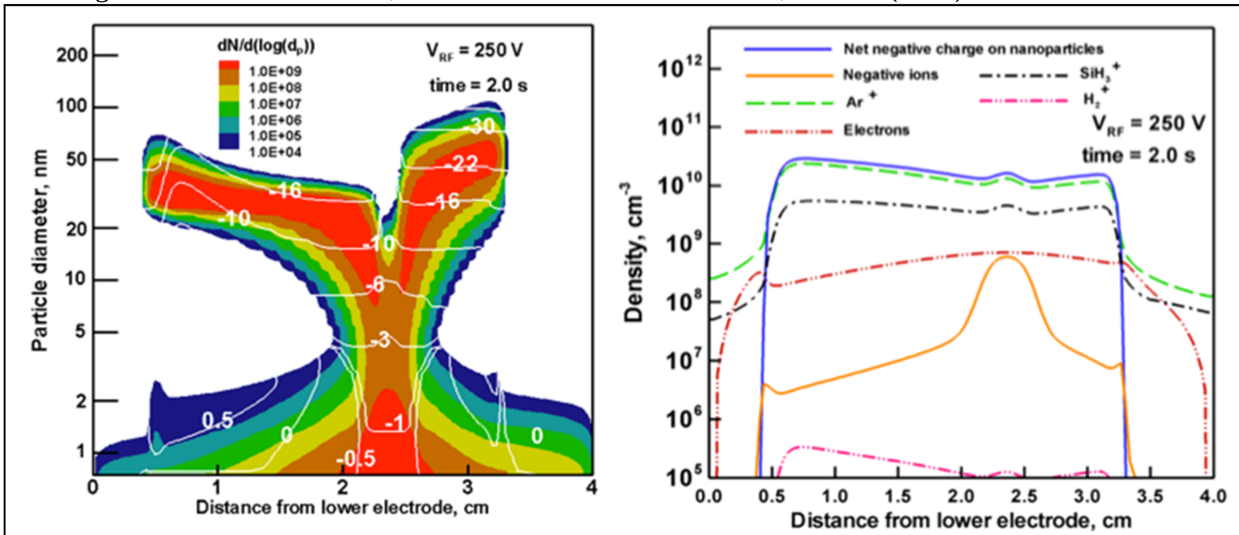

Figure 1 – Simulation results for an argon-silane 13.56-MHz RF plasma in which silicon nanoparticles nucleate and grow, 2.0 s after plasma initiation. Left: spatial profile of particle size distribution across 4-cm electrode gap. Right: corresponding density profiles of charge carriers.

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Highlight

Center for Predictive Control of Plasma Kinetics: Multi-Phase and Bounded Systems

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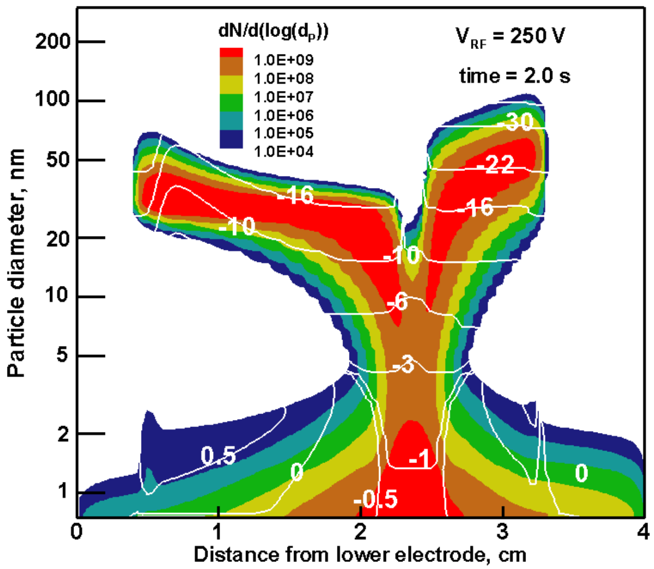
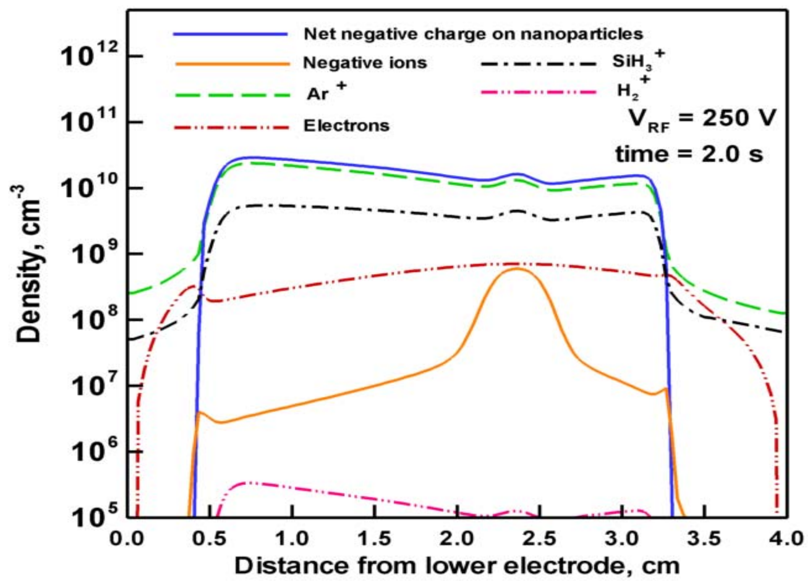
WHY DOES FRESH NUCLEATION OCCUR IN A DUSTY PLASMA VOID?

- **Numerical model self-consistently couples plasma, chemistry & aerosol for capacitively-coupled RF argon-silane plasma (13.56 MHz, 250 V, 100 mTorr)**
- **Ion drag pushes large particles out of center, creating void**
- **SiH_n anions are pushed to void, and trapped there, by negative potential well, created by profile of charge carried by nanoparticles**
- **These anions in turn drive fresh nucleation by successive rxns with SiH_4**



Particle size distribution & average particle charge



Charge carrier density profiles

Ferromagnetic Enhanced Inductive Plasma Sources

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An invited review on inductive plasma sources enhanced with ferromagnetic cores has recently been published (“Ferromagnetic enhanced inductive plasma sources”, J. Phys. D: Appl. Phys. **46**, 283001, 2013). Plasma devices based on inductively coupled plasma (ICP) sources enhanced with ferromagnetic cores (FMICP) are found in various applications, including plasma fusion, space propulsion, light sources, plasma chemistry and plasma processing of materials. The history of FMICP, early attempts for their realization, recent developments and examples of successful FMICP devices are given in this review. A comparative study of FMICPs with conventional ICPs demonstrates their advantages in power transfer efficiency, power factor and their ability to operate without large rf plasma potentials at low plasma densities in small dimensions. This can be accomplished while also effectively controlling the plasma density profile.

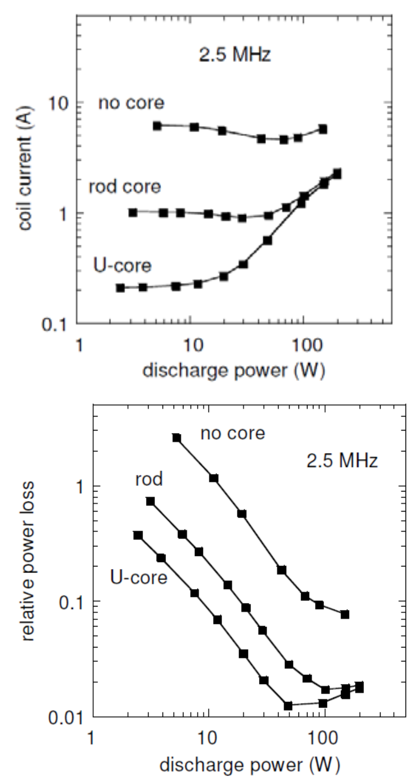


Fig. 1 – Effect of ferromagnetic core on the coupler current (A), and on the coupler power loss (B).

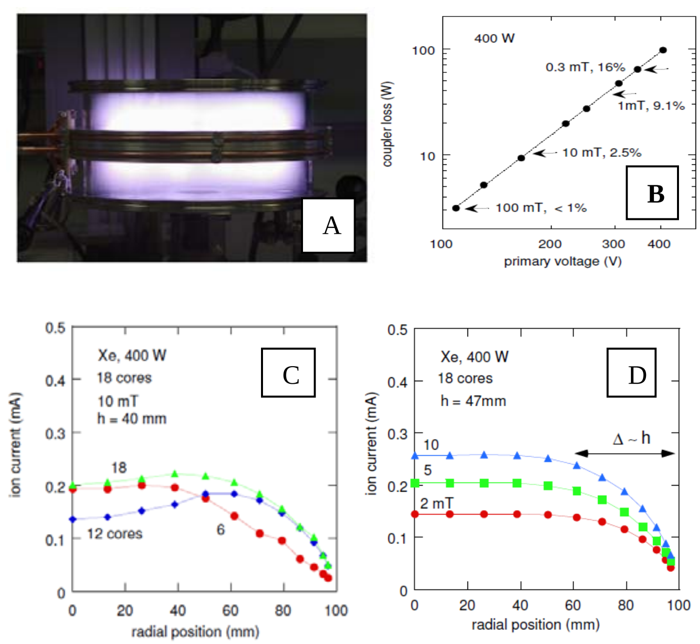
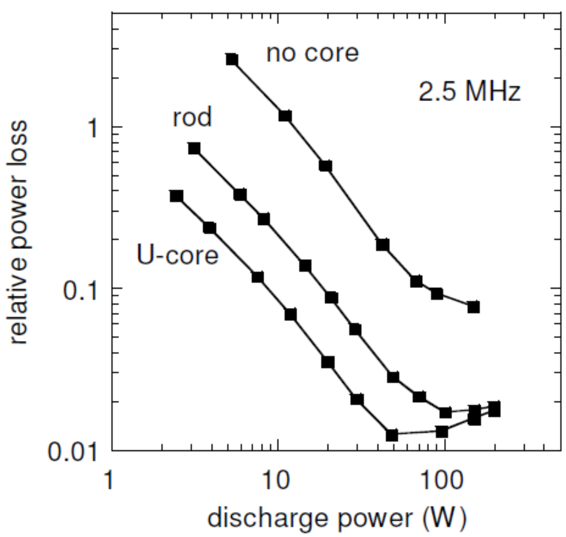


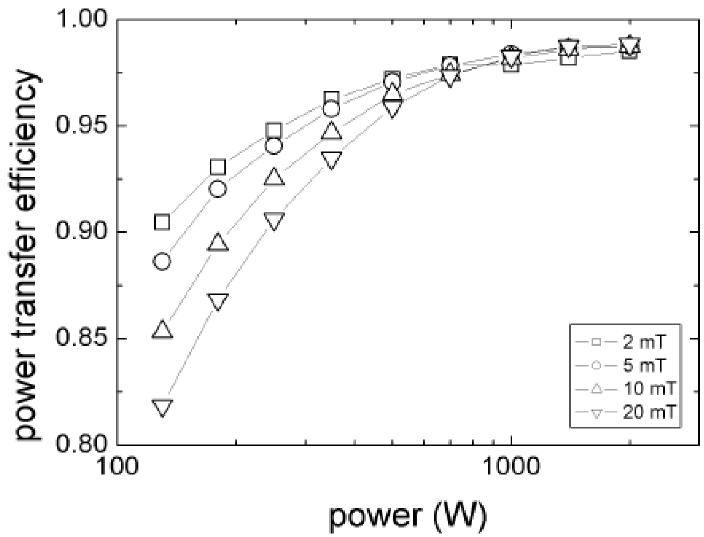
Fig. 2 – A distributed FMICP source with 18 couplers.
A – Side view; B - Coupler power loss and primary voltage at different Xe pressure; C – Control of the ion current distribution at the chamber bottom; D – Uniform distribution of the ion current at the chamber bottom.

FERROMAGNETIC ENHANCED INDUCTIVE PLASMA SOURCES

- An invited review on inductive plasma sources enhanced with ferromagnetic cores has recently been published (J. Phys. D: Appl. Phys. 46, 283001 (2013)).
- A variety of ferromagnetic enhanced inductively coupled plasmas (FMICP), from fusion devices and lighting sources to plasma processing reactors and plasma propulsion, are discussed.
- The use of FMICP leads to dramatic improvement in plasma source energy efficiency and in the ability to control the spatial distribution of the plasmas.



- Reduction of power loss



- Power transfer efficiency of FMICP

HIGHLIGHT

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