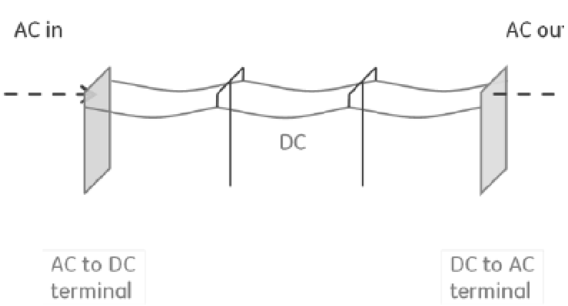
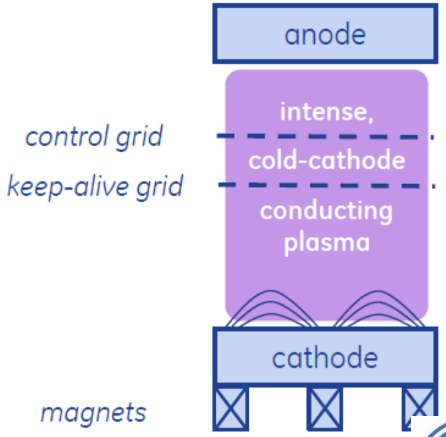
Helping General Electric Upgrade the U.S. Power Grid

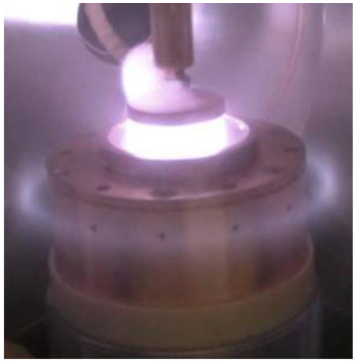
PPPL lends GE a hand in developing an advanced power-conversion.
General Electric Co. sought help at PPPL (Igor Kaganovich, Alex Khrabrov, Johan Carlsson) in designing a plasma-based power switch.

The advanced switch would consist of a plasma-filled tube that turns current on and off in systems that convert the direct current (DC) coming from long-distance power lines to the alternating current (AC) that lights homes and businesses; such systems convert AC to DC power as well. The tube would become a compact, less costly alternative to the bulky assemblies of semiconductor switches now installed in power-conversion systems throughout the U.S. electric grid.

Thanks to PPPL modeling, GE researchers identified a new contracted mode of operation of the switch.







Laboratory test of a liquid-metal cathode.
(Photo courtesy of General Electric)

GE imagination at work

PPPL

Riding an electron wave into the future of microchip

Plasma's ability to reproduce fine patterns on silicon has made plasma sources ubiquitous in microchip manufacturing.

A groundbreaking fabrication technique, based on what is called a DC-augmented capacitively coupled plasma source, affords chip makers unprecedented control of the plasma. In this process DC-electrode borne electron beam reaches and hardens the surface of the mask that is used for printing the microchip circuits.

A computer simulations by D. Sydorenko, A. Khrabrov and I. Kaganovich reveal that the beam generates intense plasma waves that move through the plasma like ripples in water and strongly affect plasma. Insights from both numerical simulations and experiments related to beam-plasma instabilities thus portend the development of new plasma sources and the increasingly advanced chips that they fabricate.

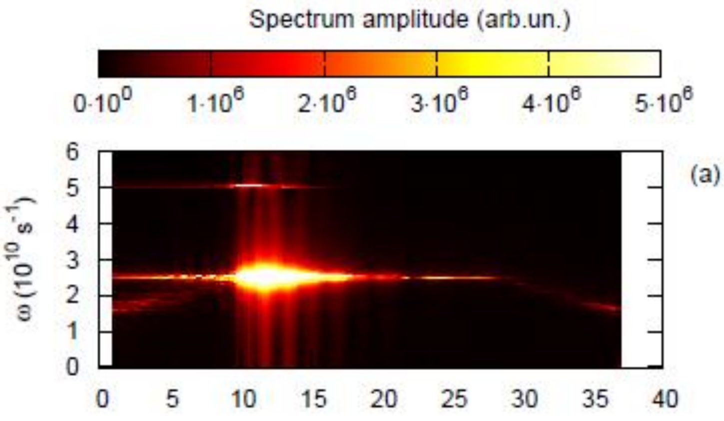
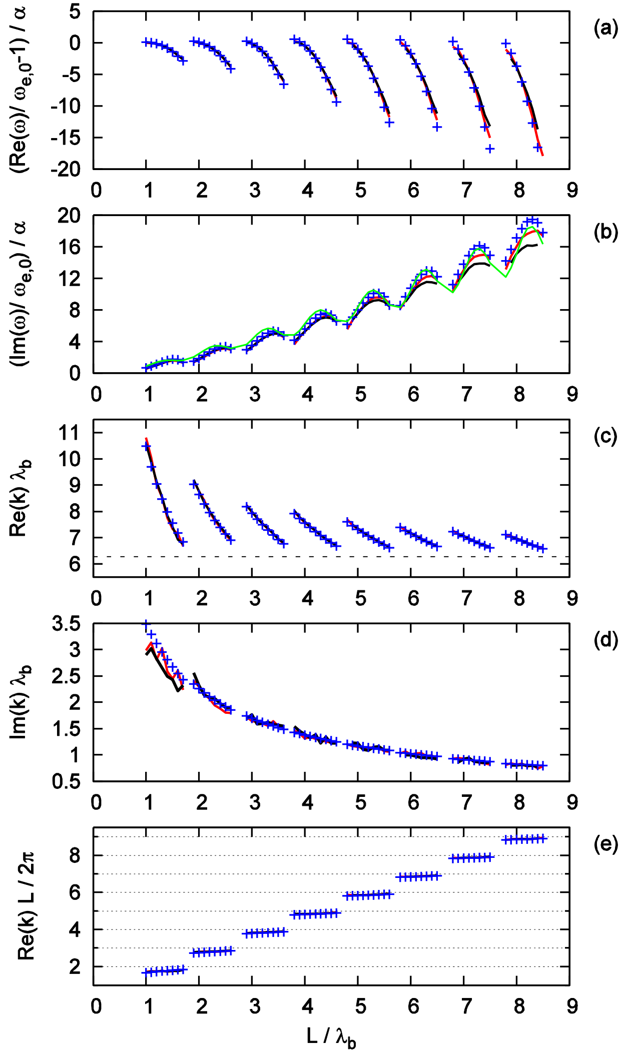


Image of a plasma wave spectrum in a DC-augmented capacitively coupled plasma source.

TWO-STREAM INSTABILITY OF AN ELECTRON BEAM PROPAGATING IN A BOUNDED PLASMA

- **Electron beam propagating in a bounded plasma excites a two-stream instability. An analytical model has been developed to predict growth rate of instability and was reported in invited talk at 2015 DPP APS meeting in Savanna, Georgia.**
- **Figure shows frequency (a), temporal growth rate (b), wavenumber (c), spatial growth rate (d), and the number of wave periods per system length (e) versus the length of the system. The blue crosses mark analytical solution. Solid red and black curves represent n_b/n_p= 0:00015 (red) and = 0:0006 (black). in (b), the solid green curve represents the fitting formula. In Fig. (c), the black dashed line marks the resonant wavenumber.**



PLSC_0512 **HIGHLIGHT**

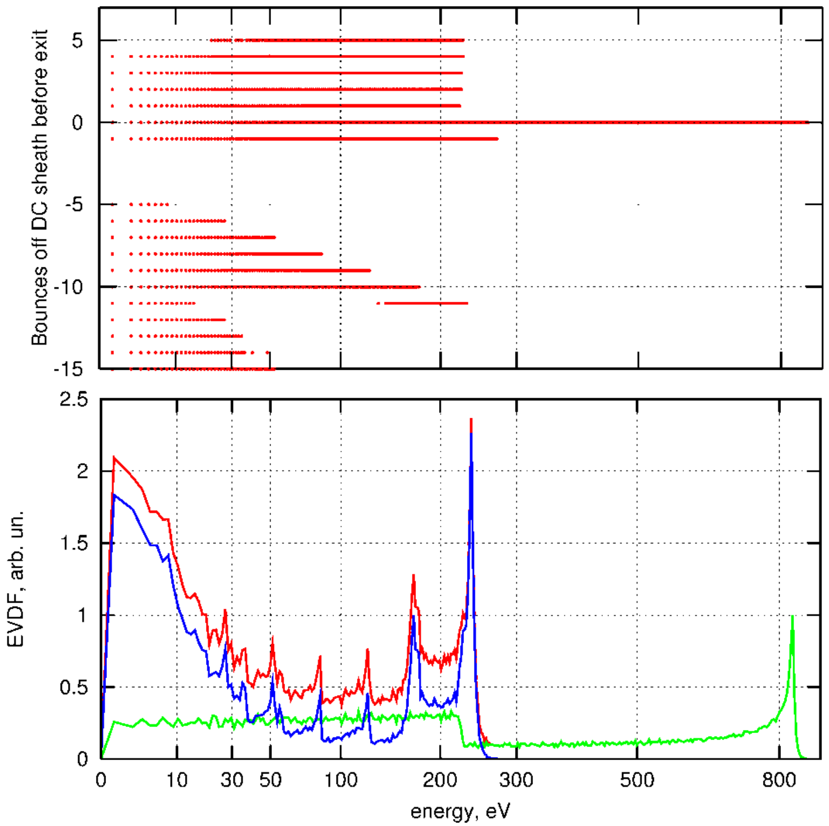
PPPL
PRINCETON PLASMA PHYSICS LABORATORY

Center for Predictive Control of Plasma Kinetics: Multi-Phase and Bounded Systems
PSC
Department of Energy Plasma Science Center

DOE Plasma Science Center
Control of Plasma Kinetics

Complex Electron Energy Distribution in Asymmetric RF-DC Discharge

- **Low-pressure capacitively-coupled discharges with additional DC bias applied to a separate electrode are important for plasma-assisted etching for semiconductor device manufacturing. Measurements of the electron energy distribution function (EEDF) impinging on the wafer and in the plasma bulk show complex structure of EEDF with multiple peaks and steps.**
- **An analytical model has been developed to predict existence of peaked and step-like structures in the EVDF. These features can be explained by analyzing the kinematics of electron trajectories in the discharge gap.**



- **Electron Energy Distribution Function showing correlation between number of bounces and energy peaks**

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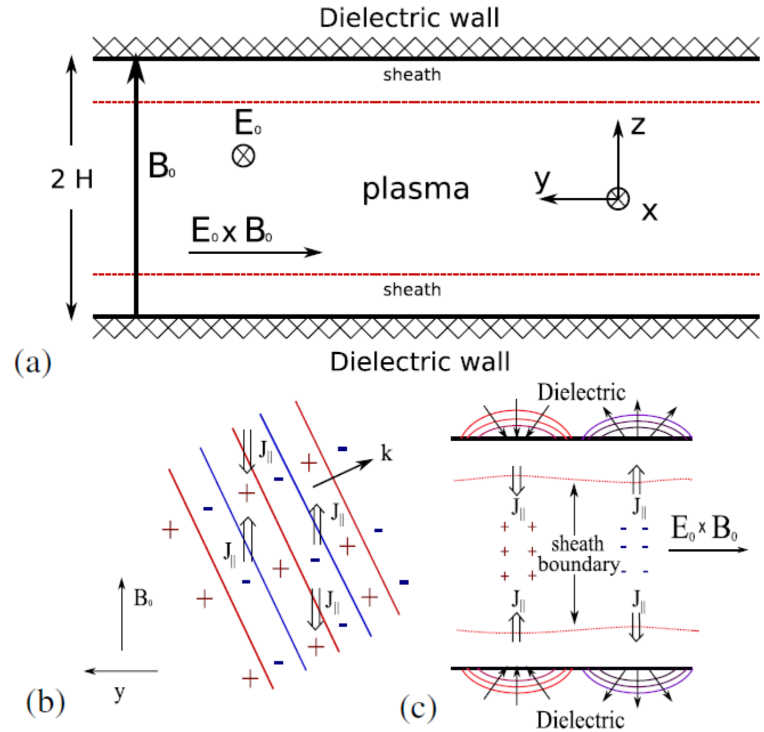
SHEATH-INDUCED INSTABILITIES IN MAGNETIZED PLASMAS

- **A new instability was identified that can explain possible mechanisms of anomalous transport in magnetized plasmas.**
- **Ion acoustic waves in plasmas of finite size with E×B electron drift become unstable due to the closure of plasma current in the chamber wall.**
- **The instability is sensitive to the wall material: a high value of the dielectric permittivity of the wall material reduces the mode growth rate by an order of magnitude. This theoretical study may explain previous experimental findings that wall material may strongly affect Hall thruster operation.**

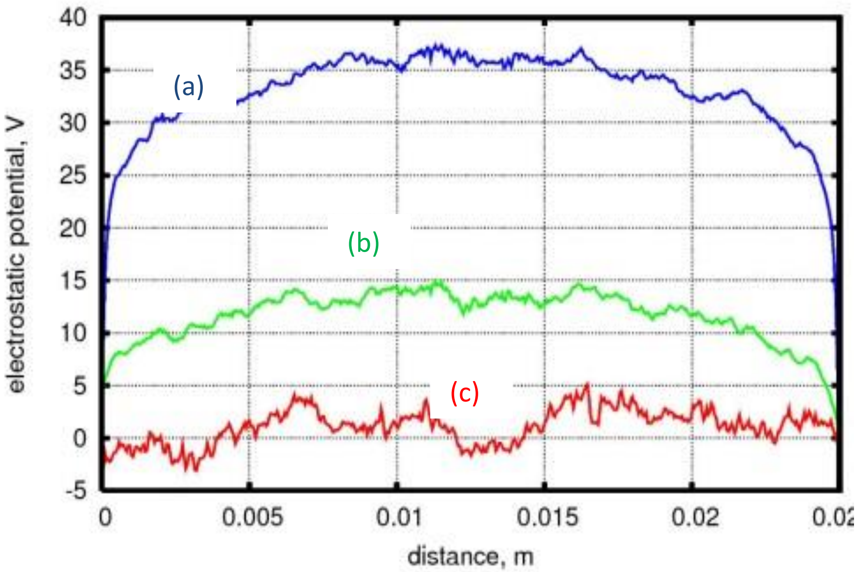


- **(a) Geometry of the plasma; (b) Perturbed parallel current in infinite plasma by an oblique wave with respect to the magnetic field; (c) Perturbed current in bound plasma.**

 HIGHLIGHT

CONTROLLING PLASMA PROPERTIES: ELECTRON INDUCED SECONDARY ELECTRON EMISSION

- Kinetic studies of bounded plasmas by walls having secondary electron emission (SEE) predict a strong dependence of wall potential on SEE [1-3].
- Sheath oscillations occur due to coupling of the sheath potential and non-Maxwellian electron energy distribution functions [2].



Potential profiles:
(a) E=200V/cm no emission
(b) E=200V/cm with SEE,
(c) E =250V/cm with SEE [1,3]

- When electrons impacting walls produce more than one secondary on average no classical sheath exists.
- Strong dependence of wall potential on SEE allows for active control of plasma properties by judicious choice of the wall material.

[1] Phys. Rev. Lett. 108, 255001 (2012)
[2] Phys. Rev. Lett. 108, 235001 (2012)
[3] Phys. Plasmas 19, 123513 (2012)