White Paper for *Frontiers of Plasma Science Panel*

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Indicate the primary area this white paper addresses by placing "P" in right column.
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	"P", "S"
• Plasma Atomic physics and the interface with chemistry and biology	
• Turbulence and transport	
• Interactions of plasmas and waves	P
• Plasma self-organization	
• Statistical mechanics of plasmas	

Indicate type of presentation desired at Town Hall Meeting.

	"X"
Oral	X
Poster	
Either Oral or Poster	
Will not attend	

Title:	**Ultrafast and nanoscale interfacial charge transport and its interaction with electromagnetic waves**
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Ultrafast and nanoscale interfacial charge transport and its interaction with electromagnetic waves

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Panel: Interactions of plasmas and waves
Topic: (2) Theory and Computation, (8) Intense charged particle beams

Charge carrier transport across interfaces of dissimilar materials (including vacuum) is the essence of all electronic devices. Ultrafast charge transport across a nanometer scale length is of fundamental importance in the miniaturization of vacuum and plasma electronics. With the combination of recent advances in electronics, photonics, and nanotechnology, these miniature devices may integrate with solid-state platforms, using nanoscale vacuum gap as the conducting channel [1]. With ballistic transport, vacuum is intrinsically a much better carrier transport medium compared to solid, in which the carriers suffer from optical and acoustic phonon scattering, causing degradation in both signal quality and the device itself. The vacuum-solid-state hybrid nano devices thus combine the advantages of ballistic transport through vacuum with the scalability, low cost and reliability of conventional silicon transistor technology [1]. This new generation of vacuum and plasma nano-devices naturally falls into the realm of *"Beams and Coherent Radiation"* in APS-DPP for the next decade.

A few research areas are envisioned.

a) Nanoscale charge transport. Despite intensive investigations, general scaling laws on charge transport in nanoscale remain to be found. The issues include: basic electron emission physics including field, thermal, and photo emission (and combination of them), effects of quantum tunneling, space charge, exchange-correlation, effects of surface morphology on work function, contaminants, scattering events, frequency response, etc. These studies are fundamental to vacuum-solid hybrid nanoelectronics [1].

Current crowding and contact resistance requires investigation. Making good contacts remains the major challenge for using electronic materials with exceptional mechanical, electrical, and thermal properties, such as carbon nanotubes and graphene. There are preliminary models of electrical contacts in the classical and ballistic/quantum regimes. The transition between these regimes remains unclear since this study is only at its infancy.

b) Ultrafast electron emission and transport. Ultrafast laser-induced electron emission from a metallic tip would generate ultrashort electron bunches whose creation would open up a wide range of applications. Many fundamental questions may be posted, including thermionic/field/multiphoton emission, charge redistribution, thermalization and Joule heating, and

Nottingham effect, all under ultrafast condition. The effects of space charge, of electric field enhancement, and of screening by neighboring tips under ultrafast condition, are likely to be very different from the DC condition. [If the laser pulselength is very short, light may not have sufficient time to travel from the base to the top of an emitter, or from one tip to its neighbor.]

c*) Beam interaction with plasmonics and meta-materials.* As the frequency increases and the circuit size shrinks, high frequency effects on the electrical conductivity, surface roughness, and surface plasmons, etc, will play important roles for beam-circuit interaction. Different radiation mechanisms, such as Smith-Purcell, Cherenkov, bremsstrahlung, etc., need to be investigated along with these effects. Radiation generated from novel structures such as metamaterials and photonic crystals requires significant improvement on the efficiency. Graphene is introduced for radiation generation, tentatively showing great promise in the THz regime.

These research areas are multidisciplinary, which benefit not only plasma science but also neighboring fields such as nano-optoelectronics and nonlinear optics, with applications far beyond: single-molecule sensing, transition voltage spectroscopy, molecule electronics, resistive switching, carbon nanotube and graphene based electronics.

[1] J.-W. Han and M. Meyyappan, "Introducing the Vacuum Transistor: A Device Made of Nothing", *IEEE Spectrum*, 23 Jun 2014.