White Paper for *Frontiers of Plasma Science Panel*

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	"P", "S"
• Plasma Atomic physics and the interface with chemistry and biology	P
• Turbulence and transport	S2
• Interactions of plasmas and waves	
• Plasma self-organization	S1
• 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:	**Electron Emission Effects in Bounded and Dusty Plasma**
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Research frontier and importance of the scientific challenge.

Photon, electron and ion bombardment of materials leads to the emission of electrons from the materials. This so-called secondary electron emission (SEE, see Fig.1) phenomenon is a common link between particle-surface interactions in plasmas, particle accelerators, light sources, and space environments [1]. The plasma-surface interaction in the presence of a strong electron emission is omnipresent in numerous plasma applications such as, for example, cathodes, emissive probes [2], divertor plasma [3], surface discharges, dusty plasma, plasma thrusters [4] and plasma processing [5]. In a plasma system, electron and ion fluxes to the wall are determined by particles velocity distribution functions and by the sheath potential, which are consistent with the wall properties. Electrons with sufficient energy to overcome the wall sheath potential and ions accelerated by the sheath potential can impact the wall and produce secondary electrons. The secondary electron emission can then reduce the sheath potential, leading to an increased loss of plasma electrons to the wall, increased wall heating, and increased cooling of the bulk plasma [3]. These secondary electron emission effects become even more pronounced for micro-scale plasmas as the plasma-facing surface to volume increases. For dusty plasmas with energetic particles impinging on micro- and nano-scale particles, particles charging and their interactions are also governed by secondary electron emission process [6]. In particle accelerators (e.g. with proton beams) and light sources, particle impact and cyclotron radiation on the walls can produce electrons which themselves can

interact with the wall and lead to secondary electron emission [7]. In the superconducting radio-frequency particle accelerators, secondary electron emission is competing with superconductivity to define power dissipation and accelerating field limits [7]. Electron emission from the walls leads to accumulation of stray electrons due to multipacting. Accumulated cloud of electrons may cause instabilities in the particle beams and overheating of facility components. This multipacting phenomenon can create a cloud of electrons that may lead to instabilities in the particle beams and overheating of facility components. A similar multipactor discharge is often initiated in high power microwave devices detuning these devices with detrimental consequences due to the formation of the plasma [8]. For space environments, secondary electron emission is a key factor in charging of spacecraft surfaces by electron, ion and photon fluxes (Fig.2), leading to a surface breakdown and arcing with a plasma formation. Important factors that influence the arc threshold are: electric field enhancement factor defined by surface quality and material, electron secondary emission caused by energetic ions hitting conductor, presence of triple junction and adsorbed gases in the area of triple junction, etc. [9]. Similar SEE-induced arcing initiated from triple junction regions are observed in various laboratory experiments and plasma processing as unipolar arcing (Fig. 3).

Although the role of the secondary electron emission in the above processes and applications has been acknowledged, its effects are neither well characterized nor well understood and therefore, cannot be reliably predicted. For example, electron emission significantly changes the space-charge distribution around emissive probes, adding uncertainty to plasma potential measurements [2]. This status quo is in a great part due to a complex synergistic nature of particle-surface interactions, which often involves a coupling between impinging particles and materials properties and surface geometry. This coupling is particularly strong for plasma-surface interactions. In this problem, plasma and materials sciences are not separable – the plasma and surface interact and evolve together. The plasma science challenges are i) to develop an understanding of SEE effects on plasma and plasma effects on SEE, including but not limited to heating and energy relaxation of emitted electrons in the plasma through collisions and collective effects, surface recombination, surface charging, and surface breakdown, ii) to characterize SEE properties and SEE effects directly in plasma rather than in vacuum as it is commonly done, and iii) to develop control of SEE effects. The materials and surfaces sciences challenges are to understand i) how surface evolves from interaction with plasma, ii) how these surface and materials modifications affect the SEE from these materials, and iii) how to control SEE properties of materials. For example, changing surface properties with various coatings or due to wall erosion, trapping of emitted particles in complex surfaces, nanoscale effects all can significantly alter the electron emission properties of plasma facing surfaces.

Approach to advancing the frontier, new research tools and capabilities required.

<u>a) Theory & simulation</u>

Description of SEE emission from the walls or dusty particles in plasma environment requires solving self-consistent system of equations for electron velocity distribution function, sheath, and plasma profiles. This can be performed using particle-in-cell codes or direct solution of the Boltzman equation for electrons in self-consistent electric field [10]. Electrons emitted from the walls can form beams that can excite two-stream or other instabilities. Theoretical description of SEE requires calculation of processes in materials. Effects of absorbed layer on the surface have to be taken into account. Detailed calculations of SEE requires quantum chemistry approaches or other many body calculations [11]. SEE can be function of nanoparticles' size and different for nanoparticles than for larger objects [12]. Modern simulation tools can handle both problems if given resources.

<u>b) Experiment</u>

In spite of many theoretical studies of SEE effects in plasma and extensive experimental data base of SEE properties measured in vacuum for various materials (see Fig.1) [1,13,14], there are practically no direct measurements of SEE properties in plasma or measurements which would track the emitted electrons and their interaction in the plasma [15]. These measurements would be particularly important for low pressure weakly ionized plasmas. In such plasmas, the electron mean-free-path is large compared with the characteristic size of the plasma, and therefore, the electron motion is almost collisionless. The absorption of energy may occur in a nonlocal manner, independently for different groups of electrons, and as a result, the electron velocity distribution function may deviate from Maxwellian that may substantially alter the sensitivity of the plasma to the electron emission. For measurements of kinetic properties of electrons and other charged particles various electrostatic probes and energy analyzers are typically used. More advanced non-invasive diagnostics such as laser Thomson Scattering, Laser-Induced Fluorescence, optical emission spectroscopy may have certain advantages over probes and analyzers, but their interpretation and resolution of kinetic properties require future development. Not less important for validation of modeling is to develop in situ measurements of effective secondary electron emission yield and energy distribution function of secondary electrons from the actual plasma-facing surface during the plasma. The difference between the SEE properties measured in plasma and SEE properties measured in vacuum using electron gun as the source of impinging electrons can be due to the sheath, collisions and evolving surface and coatings of the actual surface [16]. The insitu measurements of SEE in plasma can be conducted in a plasma with an electron energy distribution function having a population of nearly mono-energetic electrons energetically well resolved and separated from bulk cold electron population [16].

Impact of this research on plasma science and related disciplines, potential for societal benefit.

Development of validated predictive modeling capabilities on SEE effects will have a profound effect on many plasma technologies and applications which involve accelerated particles impinging the wall. For example, advanced plasma sources for atomic scale semiconductor processing relay on electron-induced SEE. Mitigation of electron cloud effects in particle accelerators requires reduction and control of SEE. Similarly, maximum gradient in accelerating structures, which is limited by breakdown and SEE, maybe increased if SEE can be controlled and reduced. Satellite charging in space is strongly affected by SEE as well. In summary, understanding and controlling of these processes will lead to superior technologies.

Figures

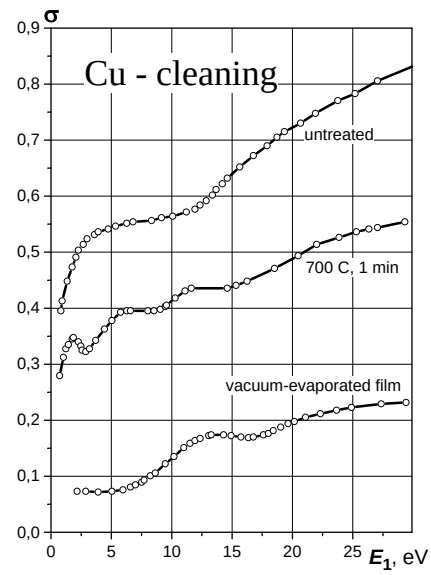

Fig.1 SEE as a function of energy of impinging electron in Cu as a function of surface condition [1].

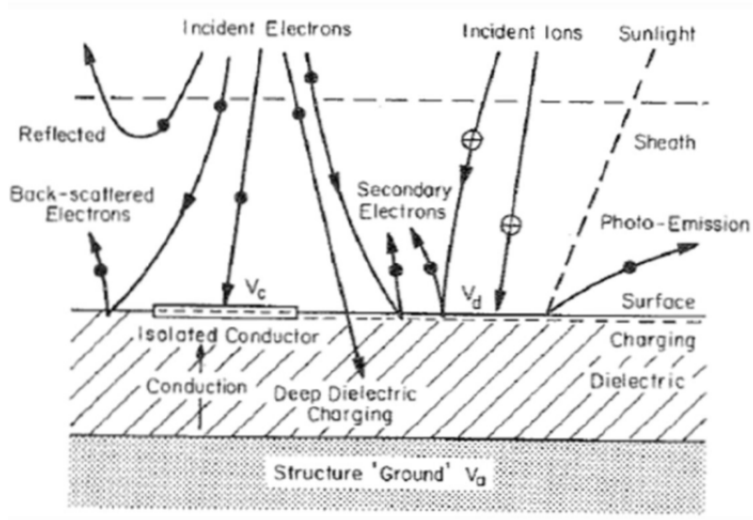

Fig. 2 Schematics of satellite surface charging from Ref. [9].

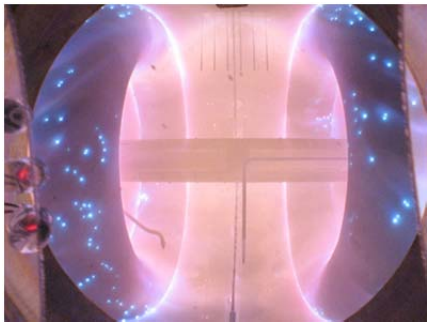

Fig. 3 Dielectric coating on metal wall promotes the formation nearly steady-state unipolar arcs seen as blue spots of light in the magnetic reconnection experiment at PPPL.

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