Plasma-Surface Interactions

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Motivation—Plasmas are used for a range of applications such as lighting, microelectronics material processing, surface treatment, cleaning, and arc-based ion sources. These diverse plasma systems all contact a surface. The boundary layer between the bulk plasma and the surface is a sheath layer characterized by large gradients in electric field and space charge. These fields energize charged particles influencing plasma excitation and ionization. Excited species extracted from the plasma subsequently moderate processes that occur on the surface. Byproducts of these surface-based reactions injected into the plasma influence both the distribution of species in the plasma as well as the distribution of electric fields in the sheath.

While there has long been a belief that surfaces can modify the plasma characteristics, a lack of flexible diagnostic tools capable of directly characterizing the interaction between the surface and the plasma impeded the development of a first principles understanding of the critical interaction parameters. Without such characterization, we cannot begin to understand or suggest engineering changes to the surfaces that result in the desired plasma properties.

Accomplishment—We have developed and applied a flexible, non-pertubative, laser-based technique to measure the spatial distribution and temporal evolution of the electrical field in an argon plasma sheath. Changes in sheath structure due to topology and composition of the bounding surface have been characterized for a range of technologically relevant conditions. Figure 1 contains snapshots of the measured field distribution above a metal-dielectric interface at several phases of the radio frequency drive voltage. As the electrode voltage evolves from the maximum [Fig. 1(a)] to the minimum, the sheath electric field decreases and the spatial distribution changes. This provides a measure of the dynamic behavior of the charge in the sheath. Temporal resolution of the technique is currently limited by the pulse width of the laser (~ 5 ns).

The role of surface topology and composition is shown in Figs. 1 and 2. In Fig. 1, the field above the metallic surface is greater than above the dielectric (Teflon) surface, partially due to surface charging of the dielectric material. In Fig. 2a, the step junction shows a complicated sheath structure with field enhancements and depletions depending on location. These field gradients will lead to changes in the ion energy and direction, which can modify ion-surface interactions. Figure 2b shows the impact of two different metals on the sheath structure, likely due to material dependent secondary electron emission coefficients.

Significance—Our *in-situ* measurements are the first to characterize the dependence of the sheath properties on surface topology and composition and will lead to an improved understanding of the significant role that surfaces play in determining the desired plasma and surface properties. In addition, the measurements of spatial and temporal electric field distributions in the plasma can be used to test the validity of assumptions employed in various plasma models. Calibration of field induce Stark shifts in other atomic and molecular species can be made to extend this technique beyond argon.

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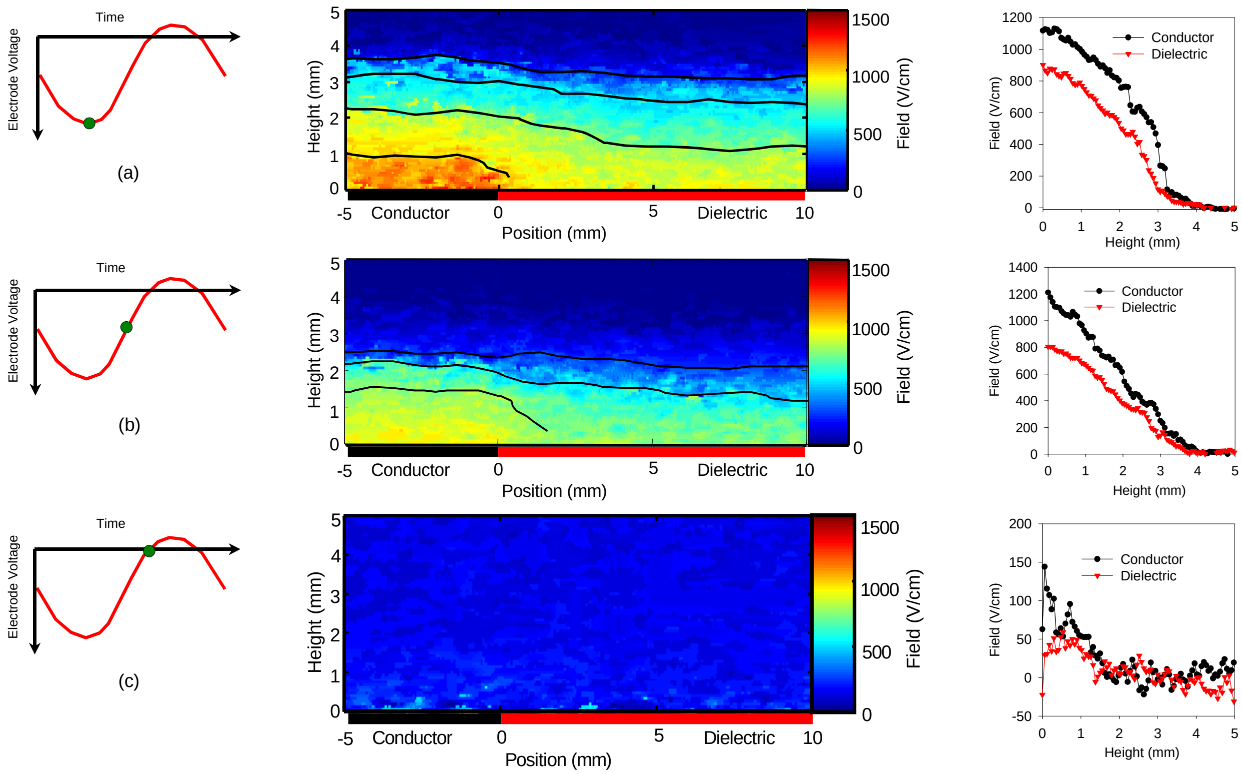
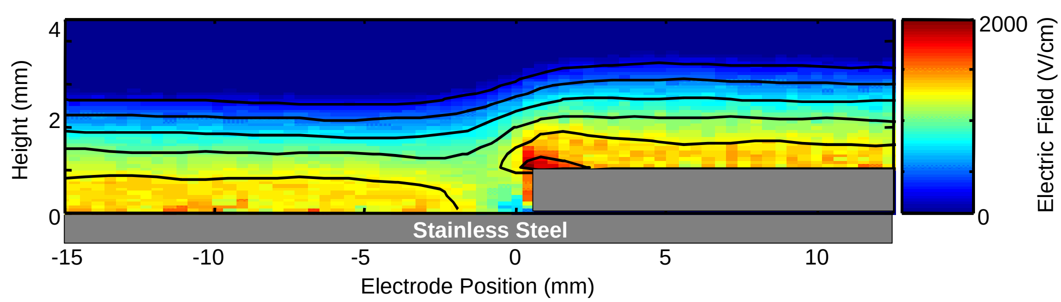
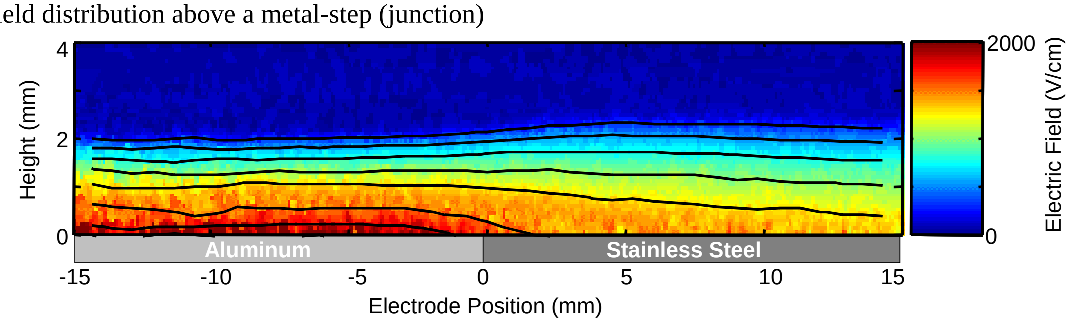


Figure 1: Measured field distribution above a metal-dielectric electrode for three times during the rf phase (a) maximum voltage across the sheath, (b) reduced voltage across the sheath, and (c) minimum voltage across the sheath. Spatially averaged profile of the fields above both surfaces is plotted to the right of each map.



(a) Field distribution above a metal-step (junction)



(b) Field distribution above a metal-metal junction

Figure 2: Measured distribution of electric fields above (a) a stepped electrode and (b) above dissimilar metal electrodes. Both the structure and composition of the electrode are observed to influence the distribution of fields in the sheath.