Sheath reversal during transient radio-frequency bias

Journal Item

Sheath Reversal During Transient Radio-Frequency Bias

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***Abstract*—Optical imaging is performed with temporal and spatial resolution in a capacitively coupled plasma. The region imaged is in front of an RF biased planar probe embedded in the center of the ground electrode of a standard Gaseous Electronics Conference (GEC) reference cell. Two main periods of interest stand out. The local sheath induced by the biasing and the main plasma bulk are affected. The first interesting period is at the onset of the RF burst on the planar probe. The voltage applied to the surface can locally reverse the sheath in front of this surface. A second interesting period is after the build up of self bias and before the extinction of the RF burst. During the steady self-bias phase, the local perturbation of optical emission amounts to less than 10%, whereas in the sheath reversal phase it reaches 70%.**

***Index Terms*—2-D profiles, plasma diagnostics, RF plasmas.**

THE NEED for accurate comparison of diagnostics in RF plasmas has resulted in the establishment of a reference cell by members of the Gaseous Electronics Conference (GEC) [1]. Observations on an *in situ*, "noninvasive" diagnostic are reported here and the actual perturbation caused is quantified.

An ion flux probe [2] has been inserted into the shower-head-grounded electrode of a 13.56-MHz GEC reference reactor, feeding coaxial cables up the inside of the gas line. This probe consists of a small planar surface and a guard-ring, mounted flush with the electrode surface; it creates no geometric perturbation. Measurements also show that the installation of this probe does not perturb the RF impedance of the cell at frequencies below 400 MHz.

In use, the probe center and guard ring are transiently biased, independently and in synchronism. This is achieved by applying amplitude-matched bursts of 12-MHz RF through dc blocking capacitors. The nonlinear response of the sheaths in front of the probe and guard ring rectifies the RF and the surfaces charge negatively with respect to the surrounding ground area. The effect of peak-to-peak RF voltages up to 170 V on the planar probe, in bursts lasting up to 1 ms, is investigated. Two main periods stand out: 1) the initial response before the self-bias potential is established on the blocking capacitors and 2) the "mature" phase when a quasi-steady condition exists. There are two spatial regions that are affected: 1) the local sheath induced by the biasing and 2) the main plasma bulk.

The perturbation associated with the RF burst is monitored using an intensified charge coupled device (ICCD—Andor Technology DH534-18F). The ICCD is gated for 1 μs synchronously with the RF biasing period to highlight perturbations near the planar probe surface. Practically, images are recorded after subtraction of a background image of the plasma formed without the RF bursts on the probe. The light collected by the ICCD is not spectrally resolved in the present setup. The optics are arranged so that the focal volume is located in the center of the region occupied by plasma, just above the installed planar probe.

Prior to the RF burst, the electron and ion fluxes to the probe surface are equal. At the start of the RF burst, negative charge is accumulated on the probe. This is because the probe potential is repeatedly swept by the RF burst toward plasma potential, and then away from it again. When the RF burst is of sufficient amplitude, then the probe potential will transiently exceed plasma potential, so that during the first microsecond or so, the surface is repeatedly swept above plasma potential. The transiently-reversed sheath field accelerates electrons toward the surface of the probe, hence this phase can be identified by the appearance of additional optical emission (70% of bulk intensity) immediately over the RF-driven probe. This is shown in Fig. 1, which records the *difference* in optical emission between the first microsecond of the RF burst and the steady state obtained in the absence of the RF burst. Such local emission only persists while the instantaneous probe potential is able to exceed that of the plasma.

In the second phase of interest, the self bias arising from the RF burst has reached a steady value. Now, the instantaneous probe potential does not exceed that of the plasma. Its mean level is lower than that of the plasma approximately by the amplitude of the RF burst (i.e., $V_{DC} = V_p - V_{RF}$). This is the normal self bias behavior. Within the RF cycle, the probe reaches twice as far below plasma potential ($V_p - 2V_{RF}$).

The dc and RF components of the sheath field will accelerate secondary electrons away from the surface of the probe and guard ring into the adjacent plasma. This is consistent with additional optical emission from plasma excitation close to the RF-driven probe. See Fig. 2, which records the *difference* between optical emission 250 μs into the RF burst and the steady state obtained in the absence of the RF burst. The local enhancement of the optical emission in terms of counts recorded by the ICCD amounts to less than 10%. The image has the appearance of a sunrise. "Negative" counts delineate the RF sheath which is darker than the plasma edge in the unbiased "background" signal.

An alternative explanation of the enhanced optical emission is localized heating of bulk electrons caused by the RF modulation of the sheath. Further experiments are in hand to distinguish between the two possible mechanisms.

Manuscript received July 6, 2001; revised November 13, 2001.

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Publisher Item Identifier S 0093-3813(02)03165-X.

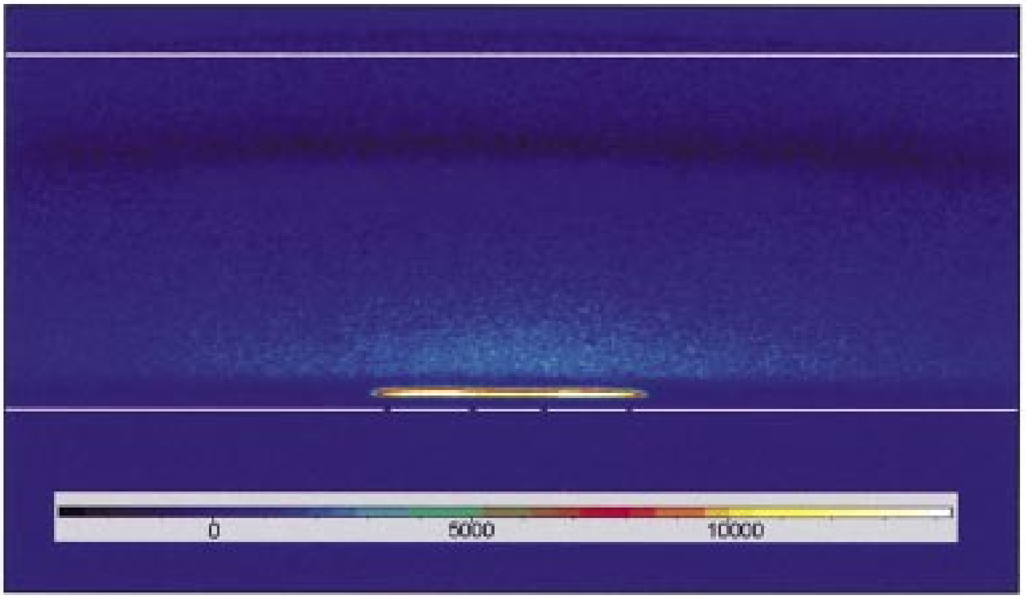

Fig. 1. Local enhancement of optical emission during the first microsecond of the RF biasing, indicating sheath reversal. Superimposed in white, is the RF powered electrode (top) and the grounded electrode with embedded guard ring and probe (bottom). Electrode separation is 25.4 mm. Intensity is in differential counts recorded by ICCD.

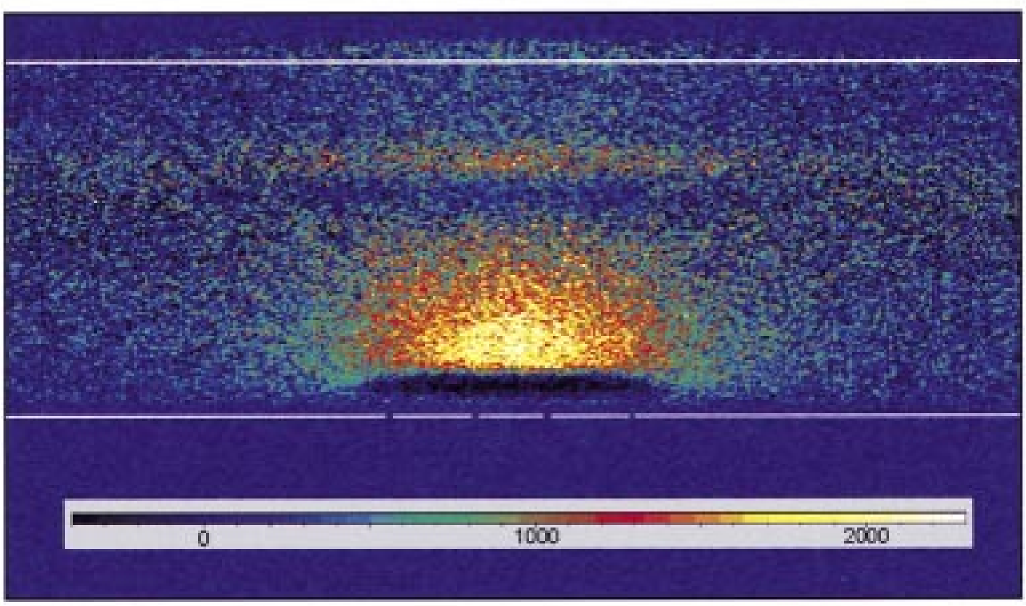

Fig. 2. Local enhancement of optical emission 250 μs into the RF burst (see also caption for Fig. 1).

Data in Fig. 1 and Fig. 2 were recorded with argon plasmas (50 W, 13 Pa), but comparable effects are seen over a range of pressure and power in both argon and hydrogen.

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