On the Structure of Magnetized Sheaths in Radiofrequency Discharges

by **E. V. Barnat and P. A. Miller**

Motivation—Reactive ion etching is a critical process employed in the manufacturing of semiconductor devices. Etching of various materials occurs via a combination of chemical and physical processes on a surface being etched. Considerable effort is made to independently control both the excitation of species in the plasma and the energetics of the species extracted from the plasma to the surface being processed. One such method to do just this is through the application of a magnetic field to the discharge.

Accomplishment—In recent studies, we examined the impact a magnetic field has on the behavior of an rf discharge similar to those employed in etching applications. Particular emphasis was placed on how the magnetic field influences the distribution of electric fields in the discharge and how changes in the electric fields influenced the excitation in the discharge.

A pair of coils, placed in a Helmholtz configuration generated magnetic fields across a discharge region generated by a 100 mm diameter electrode driven at 13.56 MHz. Laser induced fluorescence-dip spectroscopy, a two laser technique, was used to spatially and temporally measure the electric fields present in the discharge. Figure 1 compares the spatial structure and temporal evolution of these electric fields for the case with no applied magnetic field (0 gauss) and for the case with applied magnetic field (120 gauss). Without an applied magnetic field, the electric fields present in the sheath have peak values approaching 700 V/cm, and the spatial extent of the sheath extends more than 5 mm above the powered electrode (defined as a height of 0 mm). On the other hand, when a magnetic field is applied to the discharge, peak electric fields approach 1400 V/cm (twice that of the unmagnetized sheath) while the spatial extent of the sheath is only about 3 mm above the electrode. Furthermore, during the portion of the rf phase in which the electric fields above the powered electrodes are small, a second sheath forms above the grounded electrode (22 mm above the powered electrode).

The distribution of argon excited into the $1s_5$ state (measured by laser-induced fluorescence) in planes parallel and perpendicular to the magnetic field are shown in Fig. 2 for increasing magnetic field strength. While some change in the distribution is observed in the "North-South" plane parallel to the magnetic field, considerable change in the distribution of excitation is observed in the "East-West" plane. In particular, the plasma becomes skewed with an augmentation in the direction of **E**×**B** (East to West). Furthermore, at higher magnetic fields an additional region of excitation becomes evident just below the grounded electrode, consistent with the higher voltage sheath observed in Fig. 1.

Significance—The coupling between the plasma and a given surface are moderated by the electric fields that are (mostly) present in the sheath. Various 2-D models present in the literature have predicted behavior of the electric fields different from those measured here. The differences may stem from treating a 3-D system with a 2-D model, which suggests that different models may be needed to accurately capture the impact of magnetic field on the structure of the rf discharge.

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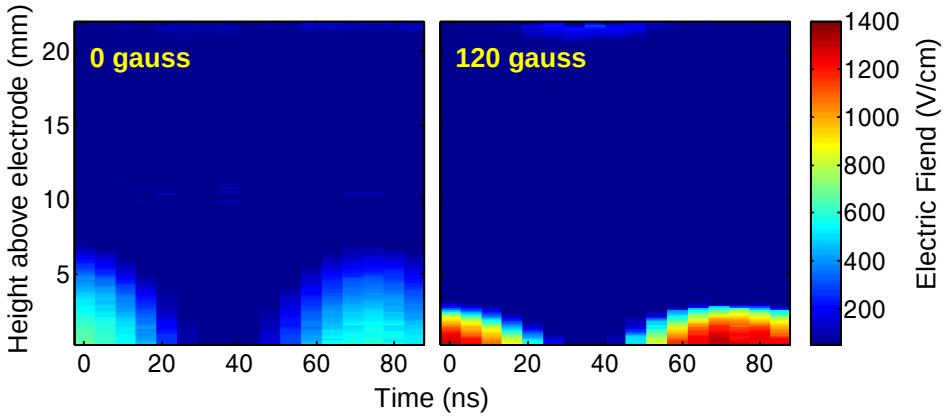

Figure 1. Spatial and temporal evolution of electric fields over an rf cycle in the center of the discharge for a 0 gauss case (left image) and a 120 gauss image. Not only does the sheath collapse at higher magnetic field, but a second sheath forms below the grounded electrode.

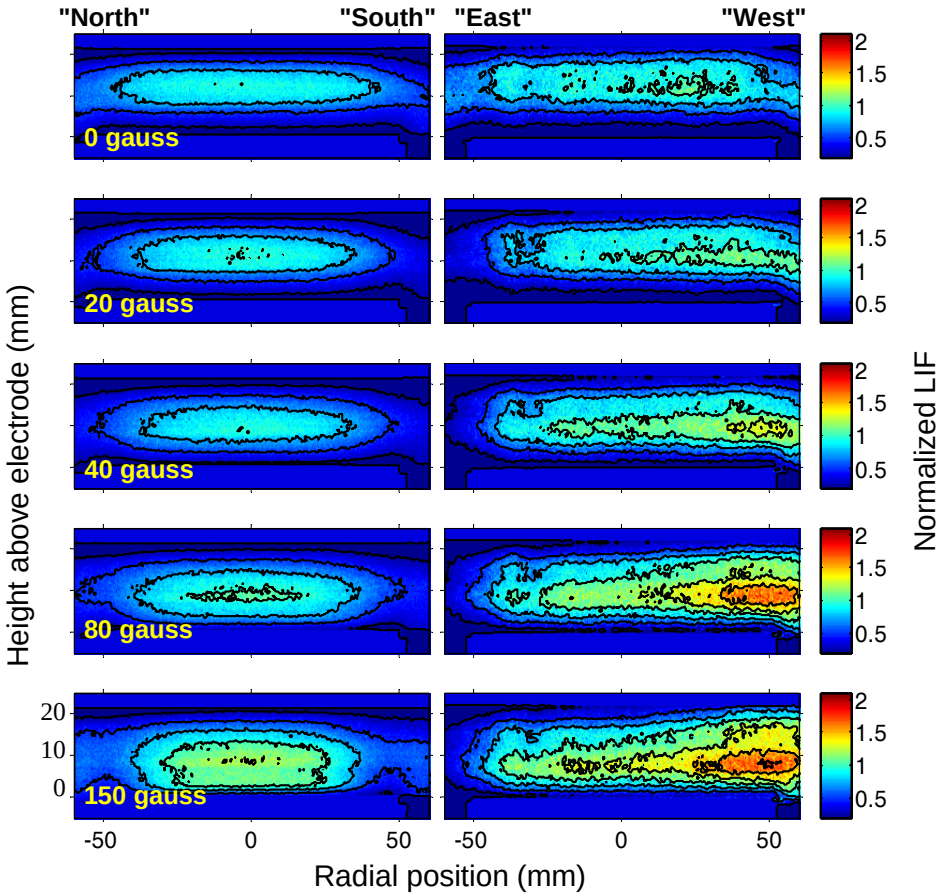

Figure 2. Spatial distribution of argon excited in the $1s_5$ state as measured by laser-induced fluorescence in a plane parallel to the magnetic field ("North"-"South", left) and a plane perpendicular to the magnetic field ("East"-"West", right) for various magnetic field strengths.