Strip-Like Structure in a Low-Pressure Magnetized RF Discharge

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***Abstract*—A 2-D steady structure, which is the so-called strip, has been observed in a low-pressure radio-frequency discharge when applying a magnetic field perpendicular to the flow. The plasma parameters have been measured by means of a compensated Langmuir probe behind the magnetic barrier. Experimental outcomes reveal that the strip, which exists over a broad range of operating parameters, is a region of high electron density, temperature, and potential in comparison with the rest of the plasma medium.**

***Index Terms*—Magnetic fields, plasma sources, radio frequency.**

MAGNETIC fields are often used in the area of plasma sources either to guide and confine charge carriers or to favor the propagation and the absorption of electromagnetic (EM) waves. In the former case, the aim is usually twofold: to enhance ionization within a well-defined region of a reactor and to limit plasma–wall interactions. In the later case, one seeks efficient energy transfer to the plasma for electron or ion heating. Another important application of magnetic fields in gas discharges is the production of ion–ion plasmas, i.e., an electron-free medium that solely contains positive and negative ions. In a magnetic field, which is perpendicular to the plasma stream, electrons are trapped and subsequently cooled down due to heavy particle collisions. The low temperature increases their attachment probability [1], [2].

In recent experiments with a magnetized radio-frequency (RF) discharge in SF_6 aiming at the production of an ion–ion plasma, we have observed the formation of a stationary 2-D pattern in the region of high B-field strength.

The plasma source is outlined in Fig. 1. A four-turn antenna, which is wrapped around a 5-cm-diameter quartz tube, transmits the 13.56-MHz RF power to the gas. The quartz tube is mounted to a large vacuum chamber. As an L-type matchbox is used, the antenna operates in capacitive mode at moderate input power and produces a weakly ionized plasma. Permanent magnets made from neodymium are placed outside the tube. They create a magnetic barrier perpendicular to the flow. The field magnitude is chosen in such a way that electrons are captured, whereas the ion motion is not much disturbed. As soon as the discharge is ignited, a steady luminous trace appears where the B-field is large. The shape is in fact not a filament but a kind of a strip that unrolls here from bottom to top. The pictures of this strip are shown in Fig. 2 for various gases. Outside the source, the strip disperses into the vacuum of the chamber.

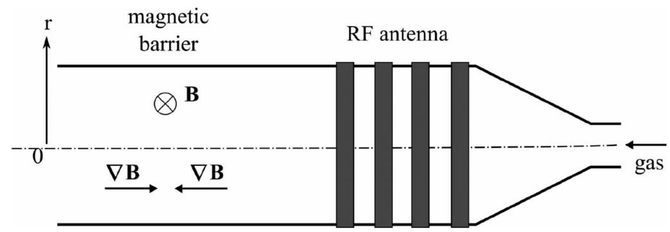

Fig. 1. Layout of the RF discharge with a magnetic barrier.

The orientation of the strip, i.e., top to bottom or bottom to top, depends on the direction of the magnetic field. The strip is observed for a broad set of operating conditions as long as the B-field is perpendicular to the axis. A large variety of gases was employed: Ar, Xe, He, O_2, SF_6, and N_2. The electronegativity of the gases does not influence the strip properties. The gas-flow rate has been varied between 1 and 120 sccm, thus rising the pressure in the tank from 10^{-2} to 10 Pa. The transmitted RF power was varied between 5 and 600 W. The magnetic-field strength was changed from 50 up to 1200 G. By the naked eye, the inclination of the strip seems to increase with the field strength. Finally, the RF was tuned from 10 to 60 MHz. In all cases, the inflection point of the strip corresponds to the highest value of the B-field, and the strip thickness is around 1 cm. Note that the strip is also present when the plasma potential is modified by inserting a biased ring in the barrier.

Electron properties have been measured in a radial direction at the tube outlet by means of a compensated Langmuir probe with and without the magnetic barrier. Electrons are cooled down under the effect of the B-field, as expected. Yet, the plasma column is not symmetrical about the tube axis when the strip forms. The values of both electron density and temperature within the strip are considerably higher. Surprisingly, the density and the temperature are greater toward the wall of the tube. An identical trend is recorded for the plasma potential. In view of results, the strip can be seen as an open path for electrons to cross the magnetic field.

The exact origin of the strip is so far unknown. It is likely that it originates in the EM drifts of the plasma. Recent experiments have suggested an $E \times B$ drift of the electron stream wherein the electric field would originate in a capacitive coupling between

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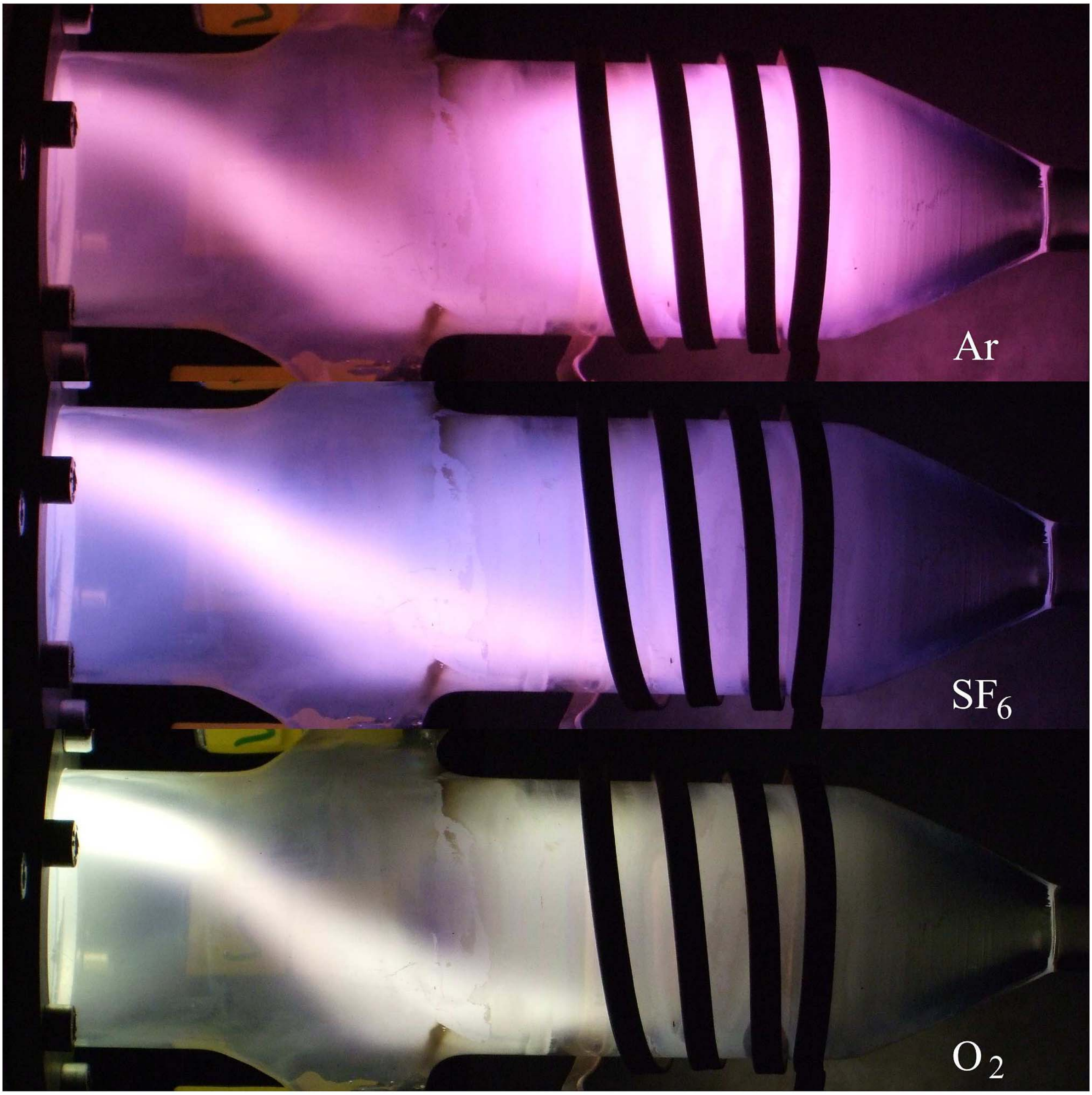

Fig. 2. Side view of the strip-like structure in argon, SF_6, and oxygen (20 sccm, 500-G on-axis, and 250 W).

the antenna and the grounded chamber. A similar setup based on a planar spiral antenna located at the end of the tube shows that the strip vanishes when a Faraday shield is placed between the antenna and the tube. Further investigations, however, are necessary to get insights into the details of mechanisms at work.

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