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PRODUCTION OF PLASMA WITH VARIABLE, RADIAL ELECTRIC FIELDS

by

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ABSTRACT

A device is described suitable for plasma wave experiments requiring relatively large, variable, radial electric fields perpendicular to a static magnetic field. By separately adjusting the potentials of two independent, coaxial discharge plasmas, we have been able to produce plasmas with a radial electric field \( E_r \leq 5 \, \text{V/cm}. \)
A device is described suitable for plasma wave experiments requiring relatively large, variable, radial electric fields perpendicular to a static magnetic field. By separately adjusting the potentials of two independent, coaxial discharge plasmas, we have been able to produce plasmas with a radial electric field $E_r < 5$ V/cm.
I. INTRODUCTION

In this paper we describe a method for applying a relatively large (< 5 V/cm), variable, radial electric field in a cylindrical, argon discharge column. This is an extension of previous work\(^1\) in which radial electric fields, \(E_r = 0.5\) V/cm were applied in order to study the low-frequency Farley-Buneman instability\(^2,3\) which is driven by a relative \(\nabla \times B\) drift of electrons and ions on the order of \(C_s\), the ion-acoustic speed. Lee et al.\(^4\) have shown that for higher relative drifts the maximum growth rate of the instability shifts to higher frequencies. In order to study this instability larger radial electric fields, \(E_r > 1\) V/cm, are required. The ability to vary \(E_r\) while keeping the density approximately constant is also desirable.

A laboratory test of the (low-frequency) Farley-Buneman instability was carried out by D'Angelo et al.\(^5\) in a Q-machine. In their setup the usual tantalum hot plate used to ionize the Cs atoms was replaced by a double-wound spiral of 2 mm diameter tantalum wire, with a spiral diameter of 6 cm. The spiral was heated by applying a 5.9 V potential difference between its edge (positive) and its center (negative). With this arrangement an average radial (inward) electric field of ~ 2 V/cm was produced in the plasma.
Although this electric field was sufficient to produce the required $E \times B$ drift, it could not be varied, since it was largely determined by the applied heating voltage.

Subsequent experiments on EM backscatter from Farley-Buneman waves by Alport et al.\textsuperscript{1} were carried out in a hot filament discharge in argon. In their setup a radial electric field variable from $\sim 0$ V/cm to $\sim 1$ V/cm was produced by applying a positive potential to anode rings concentric with the plasma column (cf. Fig. 4 Alport et al.)\textsuperscript{1} The average radial electric field tended to increase as the anode voltage, $V_A$, was increased, but saturated to $E_r = 0.5$ V/cm for $V_A \geq 40$ V. A similar arrangement had also been used by John and Saxena\textsuperscript{6} and Saxena and John\textsuperscript{7} in their observations of the Farley-Buneman instability and the gradient-drift (cross-field) instability. (See Saxena\textsuperscript{6} for a review of experiments on these instabilities.)

II. EXPERIMENTAL SETUP

We describe in this section the experimental apparatus and the operation of a device used to produce a plasma with a large, variable, radial electric field.

A schematic of the plasma device is shown in Fig. 1. This setup is a modification of the one used by Alport et al.\textsuperscript{1} employing the same vacuum vessel, magnet coils, core plasma filament
structure, and anode rings. We have added a cylindrical aluminum can, 30 cm in diameter, which is electrically connected to anode rings A₂ and A₃, and an additional set of filaments (AP, annular plasma radial filament structure) mounted on anode ring A₂. The anode end plate (EP) and ring A₄ are connected to the vacuum chamber which is grounded. Plasma and primary electrons from the discharge chamber (right side) stream through the aperture in anode ring A₄, thus producing a central (or core), CP, plasma (with a diameter determined mainly by the aperture in A₄) which is terminated in the main chamber on the (grounded) end plate attached to A₁. Typically the main discharge (CP) is operated with a background argon pressure of \( p = 10^{-3} \) Torr, with a discharge current \( I_{d}^{CP} = 1 - 4 \) A, discharge voltage \( V_{d}^{CP} = 50 \) V and at a magnetic field \( B = 225 \) G in the center of the main chamber. The axial variation of the magnetic field is about 15% over 40 cm.

The annular plasma is produced by a discharge between the AP filaments and anode rings A₂, A₃, and the aluminum can. This discharge is operated at \( I_{d}^{AP} = 10 \) mA - 15 mA and \( V_{d}^{AP} = 50 \) V. The potential of the annular plasma is controlled by varying the anode bias \( V_{A} \). The power supplies for producing and biasing the annular plasma are independent of those for the central plasma.

The operation of the device described above is similar to that of a standard double-plasma (DP) device. In a DP device two plasmas separately produced in a common vacuum chamber are partially
isolated by a negatively biased grid which prevents the two electron species from intermixing. In our setup, which may be described as a coaxial DP device, the axial magnetic field inhibits the mobility of the primary ionizing electrons, their gyroradius being \( \approx 1 \text{ mm} \).

The radial electric field is produced when the AP anode structure \((A_2, A_3)\) and aluminum can is biased to a potential \(V_{A}\) from 0 V to 20 V. When this potential is applied, the space potential of the annular plasma rises to a value \(\geq V_{A}\). The core plasma anodes \(A_1\) and \(A_4\) are kept at earth potential, and as \(V_{A}\) is increased the CP space potential rises, but by only a small fraction of \(V_{A}\). The resulting radial profiles of density, \(n_{e}\), and space potential, \(V_{sp}\), are shown in Fig. 2. The discharge parameters for this case are \(I_{d}^{CP} = 4 \text{ A}, I_{d}^{AP} = 10.5 \text{ mA},\) and \(V_{d}^{CP} = V_{d}^{AP} = 50 \text{ V}\), with the anode voltage \(V_{A} = 8 \text{ V}\). Under these conditions a nearly parabolic potential profile is measured as a Langmuir probe is moved across the column over a distance \(-2.5 \text{ cm} < R < +2.5 \text{ cm}\), with a corresponding average radial electric field, \(E_{r} = 1.4 \text{ V/cm}\). Similar curves are obtained for different \(V_{A}\)'s, which show a general increase of the radial electric field with increasing \(V_{A}\). This is illustrated in Fig. 3, where the difference in space potential, \(\Delta V_{sp}\), as measured by a movable Langmuir probe, between \(R = 5 \text{ cm}\) and \(R = 0 \text{ cm}\), is plotted as a function of \(V_{A}\). The discharge conditions for Fig. 3 are \(I_{d}^{CP} = 1.8 \text{ A}, I_{d}^{AP} = 10 \text{ mA with } V_{d}^{CP} = V_{d}^{AP} = 50 \text{ V}\). If the anode voltage \(V_{A}\) is increased above approximately 20 V, the core plasma
potential suddenly jumps to a value \( V_{sp} < V_A \), thus resulting in a small value of \( E_r \). The results of Fig. 3 are in contrast to the earlier data of Alport et al.\(^1\) which showed the radial electric field saturating at \( E_r = 0.5 \, \text{V/cm} \) for \( V_A > 30 \, \text{V} \).

III. SUMMARY AND CONCLUSIONS

We have described a device suitable for plasma wave studies requiring relatively large, variable, radial electric fields. By generating a very low density annular plasma surrounding a denser plasma core we are able to impose radial electric fields \( E_r < 5 \, \text{V/cm} \) by separately fixing the space potentials of each plasma. This represents roughly a factor of 4-5 improvement in \( E_r \) over the setup used by Alport et al.\(^1\)

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REFERENCES

FIGURE CAPTIONS

Fig. 1. (a) The experimental setup, showing a topview of the coaxial plasma device. (b) Core plasma and annular plasma filament structures.

Fig. 2. Radial profiles of plasma electron density, \( n_e \), and space potential, \( V_{\text{sp}} \). Plasma densities are in the range of \( 10^9 \sim 10^{10} \text{ cm}^{-3} \).

Fig. 3. Difference in space potential \( \Delta V_{\text{sp}} \), between \( R = 0 \text{ cm} \) and \( R = 5 \text{ cm} \) as a function of the anode bias voltage \( V_A \).
Fig. 2

$V_A = 8$ V
$B = 225$ G
$\rho \approx 10^{-3}$ Torr
$B = 225 \text{G}$

$p \approx 10^{-3} \text{ Torr}$

**Fig. 3**
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