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Observation of Instabilities in a cylindrical Post magnetron plasma discharge

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ABSTRACT

An electrostatic instability with an intermediate frequency between the electron cyclotron frequency and ion plasma frequency has been observed in presence of crossed electric and magnetic fields in a DC cylindrical magnetron plasma. The amplitude of the instability is maximum at particular values of the magnetic field and the discharge voltage. The different modes of instability are measured and interpreted as ExB/density gradient modes.

1. INTRODUCTION

The study of generation and growth of plasma instabilities driven by the influence of crossed electric and magnetic field (ExB) has been drawing attention of the plasma physicists since last few decades. In this paper, we report the study of instability observed in the frequency range of 50 MHz to 100 MHz in a cylindrical magnetron discharge plasma.

2. EXPERIMENTAL SET UP AND MEASUREMENT TECHNIQUES

The experimental device (Fig.1) is a stainless steel cylindrical chamber (anode) with 20 cm in diameter and 100 cm in length. A small stainless steel cylinder (cathode) with 1.5 cm in diameter and 15 cm in length is placed co-axially inside the chamber. To prevent the end loss of energetic electrons, two stainless-steel discs of 5 cm in diameter are fixed at both ends of the cathode. An axial magnetic field up to 200 Gauss is applied co-axially. The base pressure of the chamber is 6x10^{-6} mbar and working argon pressure is (1x10^{-3} - 5x10^{-3}) mbar.

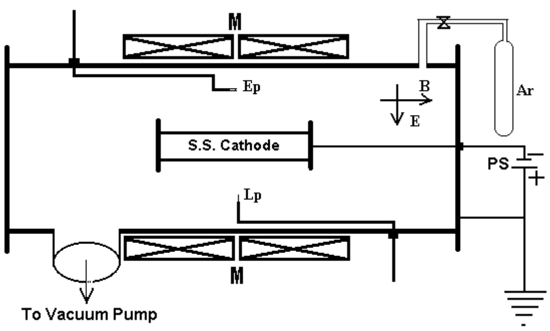

FIG. 1. Experimental set up: MM – Magnetic field coils, S.S. Cathode – Stainless steel target cathode, PS – Discharge power supply (1000 V, 1 A).

A cylindrical Langmuir probe (L_p)

with its collecting surface perpendicular to the magnetic field lines is used to measure plasma density ($n_e = 10^8 \sim 10^{10}$ cm^{-3}) and temperature (T_e= 2 ~ 8 eV). The applied voltage is in the range of(525 – 700) V, magnetic field (60-200) Gauss and gas pressure (1x10^{-3} - 5x10^{-3}) mbar. An emissive probe (E_p) is used to measure the plasma potential (-5 V ~ -20 V) by inflection point method. The instability is recorded from the electron saturation current of the Langmuir probe. The frequency and amplitude of the instability generated in the plasma is measured from the Fast Fourier Transform (FFT) of the signal.

3. EXPERIMENTAL RESULTS AND DISCUSSION

With increasing the magnetic field, the electrons become confined nearer to the cathode. As a consequence the plasma density increases due to confinement and higher rate of ionization.

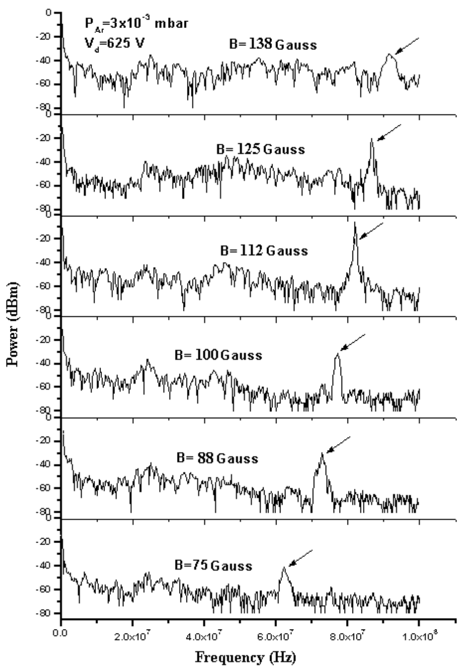

FIG. 2 Typical frequency spectra of instability for six different magnetic fields (B = 75 Gauss, 88 Gauss, 100 Gauss, 112 Gauss, 125 Gauss and 138 Gauss) recorded with the help of a Langmuir probe and Digitizing Oscilloscope.

A sharp radial gradient in the plasma potential and hence strong electric field is noted near the cathode region. Typical frequency spectra of instability, observed and presented in Fig.2, for six different magnetic fields at 3.25 cm from the cathode surface

A constant amplitude test signal having the frequency comparable with the observed signal, is applied to the plasma. The frequency spectra of the instability along with the applied signal are presented in Fig.3 where the observed instability frequency is 80 MHz. The arrow mark indicates the external applied signal. It is noted that the external signal grows at the resonance.

With increasing the discharge voltage the frequency of instability also increases from 60 MHz to 70 MHz when V_d is increased from 600 V to 700 V. At high discharge voltages, the frequency tends to saturate.

In the present experiment the electron cyclotron frequency is (200 ~ 500) MHz and ion plasma frequency is 900 kHz ~ 10 MHz. The observed instability frequency lies between the ion plasma frequency and the electron cyclotron frequency.

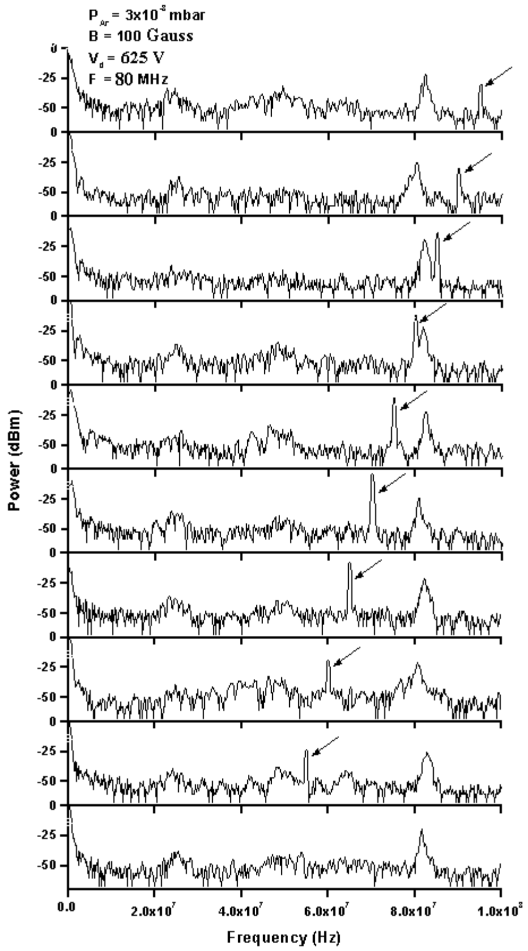

FIG. 3 Frequency spectra of instability showing the growth of a constant amplitude external signal when the frequency of the external signal matches with the frequency of instability. The arrow mark indicates the external applied signal.

The amplitude of instability is found to increase initially with increasing magnetic field and it peaks at an intermediate magnetic field and after that the amplitude decreases. For higher discharge voltage, the amplitude peaks at a still lower magnetic field.

The electrons are drifted in the azimuthal direction due to the action of ExB field. The ExB drift current of electrons (I_{de}) is measured. The drift current initially increases rapidly and after that it changes at a slower rate at higher magnetic fields. With increasing magnetic field the density increases, that is why the drifted electron flux increases. At high magnetic fields, though the density increases, the drift velocity (v_d = E/B) is reduced significantly, as a result the rate of change of drifted electron flux becomes slow and hence the change in drift current becomes slow.

To determine the azimuthal mode number (m) of the instability, three cylindrical Tungsten Langmuir probes (0.5 mm diameter and 5mm long) are placed at three different azimuthal positions at same radial distance at two different angles. The Fast Fourier transforms (H) of the signal are computed. From these, the mode number (m) corresponding to a particular frequency (*f*) is calculated.

The measured phase difference in the signals, are used to obtain the mode numbers. One typical sets of the signals picked up by three probes are presented in Fig.4.

It is found that mode number initially increases from 4 to 6 for the increase of frequency from 50 MHz to 75 MHz and after that it decreases to 3 at the frequency 100 MHz. Since the amplitude of instability is maximum for the frequencies nearly 75 MHz in this condition, it can be concluded that m = 6 mode is dominant.

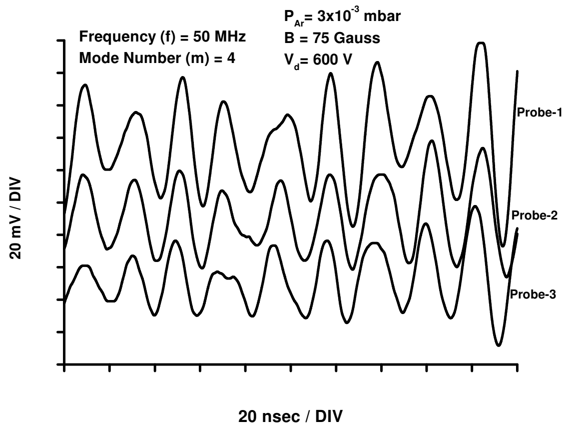

FIG. 4 Fluctuation in electron saturation current received by three Langmuir probes placed at three different azimuthal positions of same radius for for V_d = 600 V, P_{Ar} = 3x10^{-3} mbar and B = 200 Gauss.

As the electrons are magnetized, that is why only the electrons are drifted significantly in the azimuthal direction under the action of ExB field. So a charge separation is created in azimuthal direction due to the difference in drift velocities of electrons and ions. The Argon ions have a mass comparable to that of neutral atoms so the collision between the argon ions and the neutrals take place effectively and hence difference in the drift velocity between electrons and ions increases further due to the viscous drag on ions by neutrals. The reduction in the drift of electrons is very small due to very large mass difference of electrons with the neutrals.

Due to the difference in the drift velocity of electrons and positive ions, charge difference, an electric field (E_θ) is produced in the azimuthal direction. Once this electric field is produced, the electrostatic waves are generated in the azimuthal direction. As there is a radial density gradient, these waves grow up gaining the required free energy from the density gradient and become unstable.

4. CONCLUSION

We can conclude that the instability is excited due to ExB/density gradient. When the amplitude of the instability becomes very high, it affects the density profile to become flat due to enhanced nonlinear transport and hence the amplitude falls down after having a maximum value.