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Resonance cone technique for density measurement in a microwave discharge plasma*

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Abstract. Resonance cones have been measured in a microwave discharge plasma ($n_e = 5 \cdot 10^9\,\mathrm{cm}^{-3}$, $T_e = 3$ eV, $B_0 = 220$ Gauss) at frequencies between 50 and 300 MHz. The electron density is determined and compared with the density obtained with double probe technique. At high frequencies (>150 MHz) these values agree well considering the remaining uncertainties in both methods and experimental errors. At low frequencies (<100 MHz) a systematic deviation is observed which can not be explained by ion motion. But here the errors are also large and represent the limit of the method.

1. Introduction

Since the investigation by Fisher and Gould [1], the resonance cone has been studied by different authors [2–6]. In the high frequency region ($\omega^2 \gg \omega_{LH}^2 \equiv \omega_{ce}^2(\omega_{ci}^2 + \omega_{pi}^2)/(\omega_{ce}^2 + \omega_{pe}^2)$), the ion motion can be neglected [2, 3]. Here ω_{pe} and ω_{pi} are electron and ion plasma frequency, and ω_{ce} and ω_{ci} are electron and ion cyclotron frequency, respectively. Recently the existence of the resonance cone at lower frequencies ($\omega \gtrsim \omega_{LH}$), where the ion motion has been taken into consideration, has been verified experimentally [5].

Also the use of the resonance cone as a diagnostic tool, which provides the direct display of the electron density in a magnetized plasma without measuring the electron temperature, has been described [6]. In a magnetized plasma, the electron saturation current collected by the Langmuir probe disturbs the plasma near the probe and cannot give the correct electron density [7]. So, it is very important to investigate the resonance cone technique as a diagnostic tool.

2. Experimental Apparatus

The experiment was performed using a microwave discharge produced by a slow wave structure ($f = 2.45$ GHz) [8], as shown in Fig. 1. The diameter and length of the vessel were 28 cm and 80 cm, respectively. The dc magnetic field was

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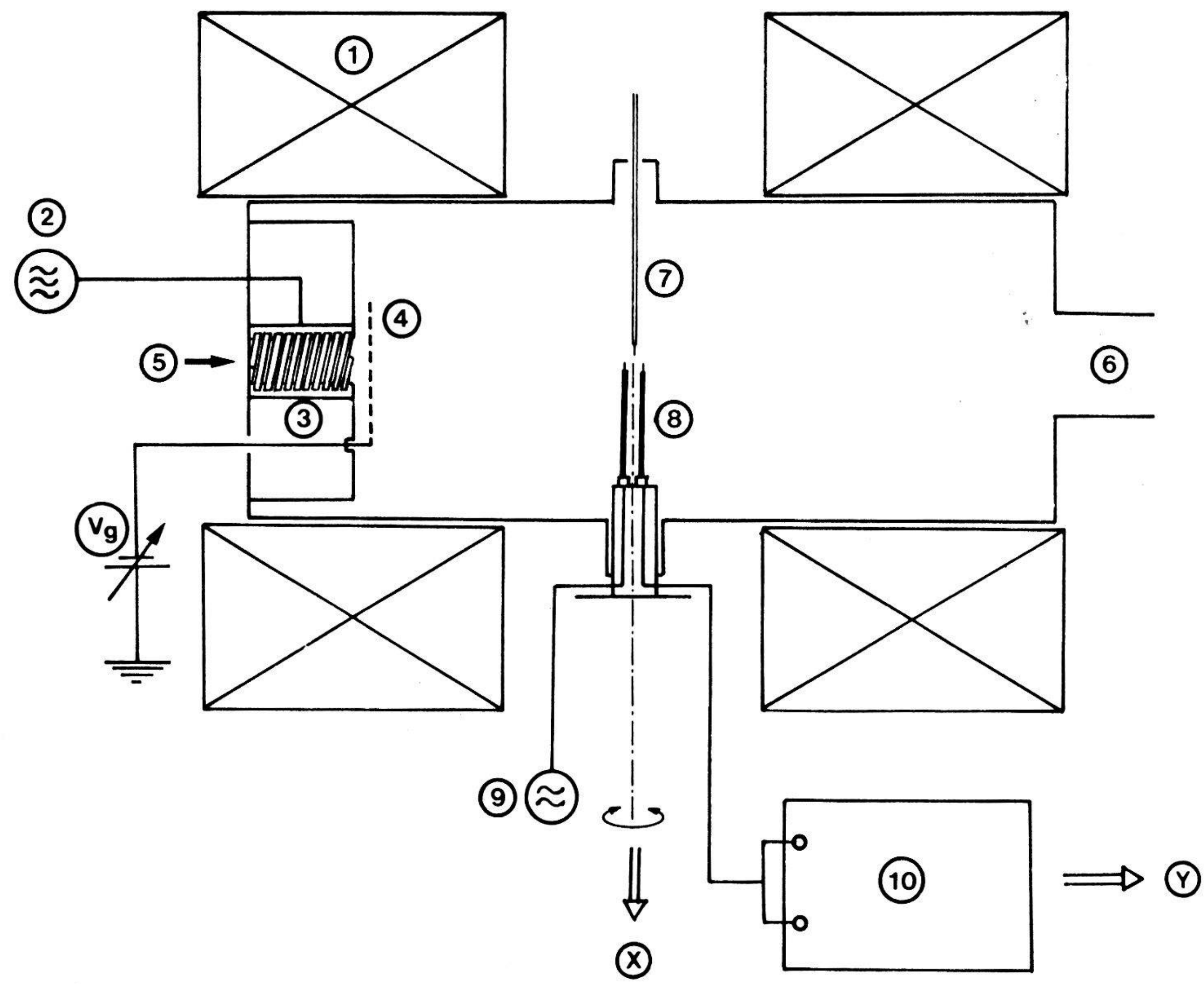

Figure 1.
Experimental setup. ① magnetic field coils, ② microwave generator, ③ slow wave structure, ④ grid, ⑤ gas inlet, ⑥ to pumps, ⑦ double probe, ⑧ emitter and receiver for resonance cone technique, ⑨ rf-generator, 10 network analyzer or spectrum analyzer.

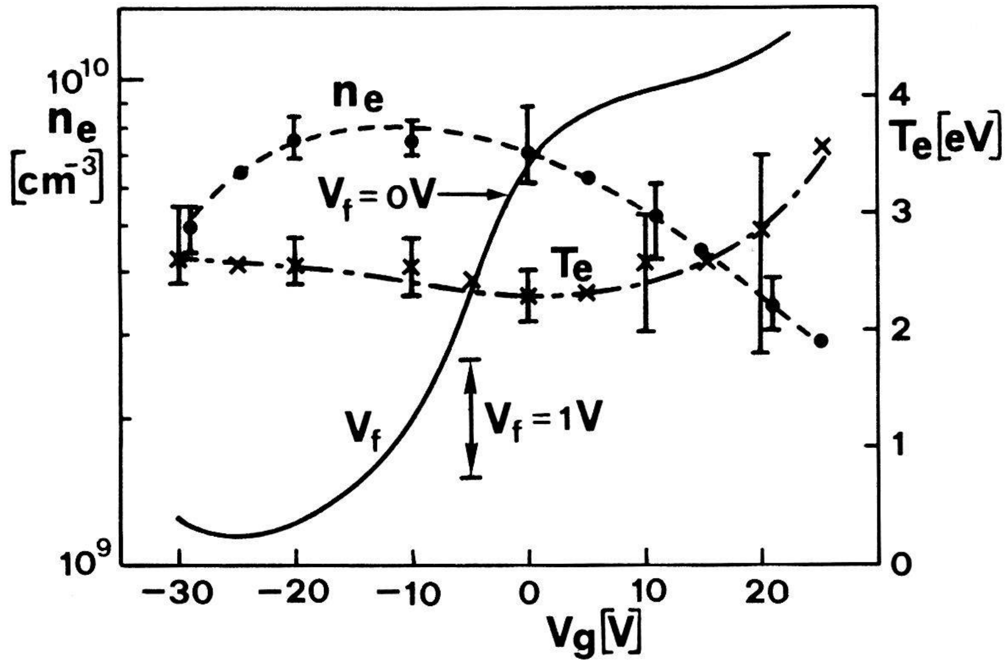

Figure 2.
The plasma density n_e, electron temperature T_e and floating potential V_f as functions of the grid voltage V_g. Argon, $p = 1,\ 2 \cdot 10^{-3}$ Torr and $B = 220$ Gauss.

applied axially in the range of 180–280 Gauss. The discharge was operated in argon gas at a pressure of $6 \cdot 10^{-5} \div 6 \cdot 10^{-3}$ Torr. A double probe with 0.1 mm diameter and 2 mm length was used to compare the plasma density with the density measured by the resonance cone technique. The density by the double probe was determined from the ion saturation current which was not affected by the magnetic field because the ion Larmour radius (~1.5 cm) was much larger than the probe radius (0.05 mm). The density and the electron temperature were controlled by changing the microwave power and the bias of the grid in the range of $8 \cdot 10^{8} - 2 \cdot 10^{10}$ cm^{-3} and $1.5 \div 4$ eV respectively. Figure 2 shows a typical result of the density, electron temperature and the floating potential as a function of the grid voltage.

The rf probes for the resonance cone (0.1 mm diameter, 2.5 mm length, 15 mm spaced) were rotatable around the axis perpendicular to the magnetic field and served as transmitting and receiving antenna. This probe is similar to that described by K. Lucks et al. [5]. An rf signal was fed to the transmission probe and the signal detected by the receiving probe, which was connected to a network analyzer (HP 8407 A) for $\omega/2\pi = 50-110$ MHz and to a spectrum analyzer (TEKTRONIX 7L13) for $\omega/2\pi = 120-300$ MHz. The applied frequency was higher than ω_{LH} so that the ion motion was neglected in this experiment. The amplitude of the rf signal applied was small (~0.1 V peak to peak) in order to avoid the ballistic mode [9]. The resonance cone angle is easily found from the two maxima of the $X-Y$ recorder trace.

3. Results

Figure 3 shows the experimental conditions, where the method has been applied. In this figure also the lines are given where the angle of the resonance cone becomes 5°, 10°, 20° and 40°. These angles were calculated from the theory of Fisher and Gould [1] using

$$\frac{\omega_{pe}^2}{\omega^2} = \frac{1-\omega^2/\omega_{pe}^2}{\sin^2\theta_c - \omega^2/\omega_{ce}^2} \tag{1}$$

Here θ_c is the resonance cone angle. Collisions and ion motion are neglected. No errors are shown in Fig. 3 but it is evident from this diagram that the errors for a density determination for all points below the dashed line ($\omega_{ce} = \omega_{pe}$) increase beyond all limits. This condition is somewhat arbitrary but very useful [6]. It can also be seen from Fig. 3 that even on this line and above the errors become large at small angles if a certain $\Delta\theta_c$ for the apparatus is assumed. These errors can be calculated from equation (1).

But errors are not the only limitation. The condition $\omega \gg \omega_{pi}$ is also important. To test the method we have measured the density with different frequencies applying equation (1). The result is shown in Fig. 4. The errors here are calculated assuming $\Delta\theta_c = 1°$ which is a rough estimate. In spite of the large errors at low frequency – and therefore small angle – a deviation from the expected constant value is observed. Here $\omega_{ce} \sim \omega_{pe}$ but $\omega \approx 10\omega_{pi}$. The correction function due to ion motion amounts to $(1-\omega_{pi}^2/(\omega_{ce}^2-\omega^2))^{-1}$ and is too small to explain the systematic deviation.

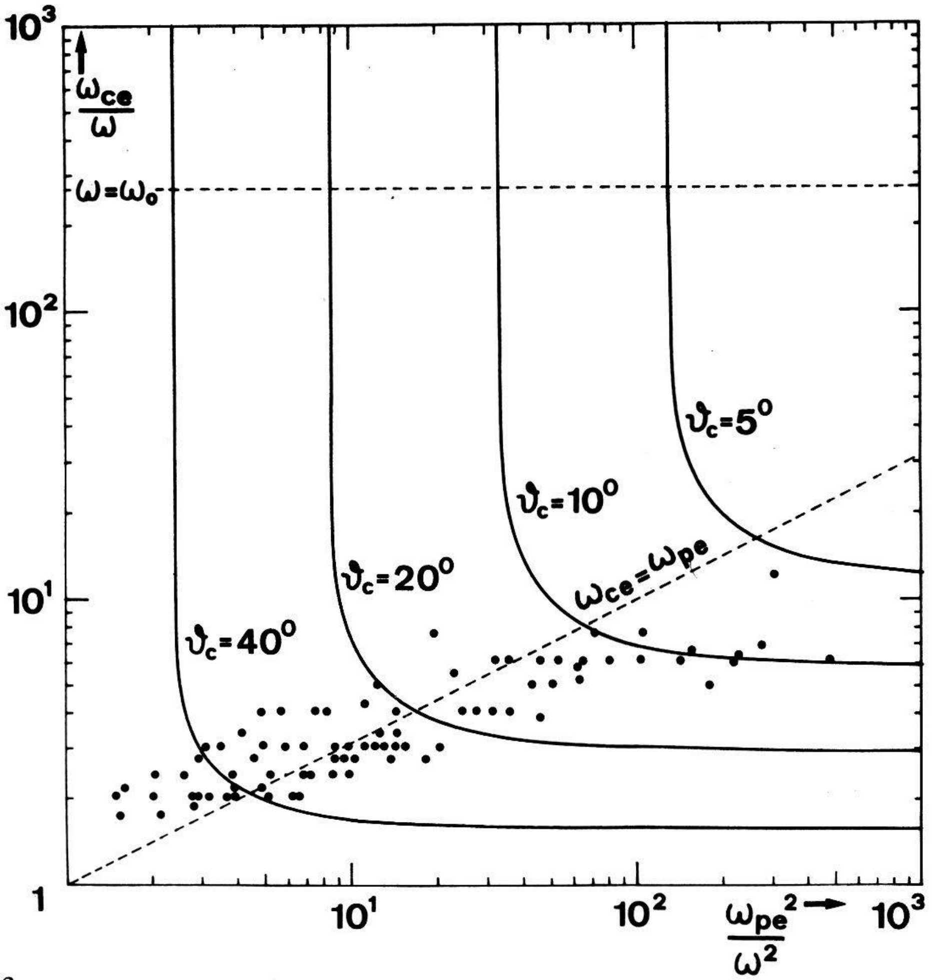

Figure 3
Diagram of resonance cone angle. Experimental conditions where the method has been applied (points) and theoretical predictions by formula (1) (solid line). The dashed lines indicate $\omega_0 = \sqrt{\omega_{ce} \cdot \omega_{ci}}$ and $\omega_{ce} = \omega_{pe}$ respectively.

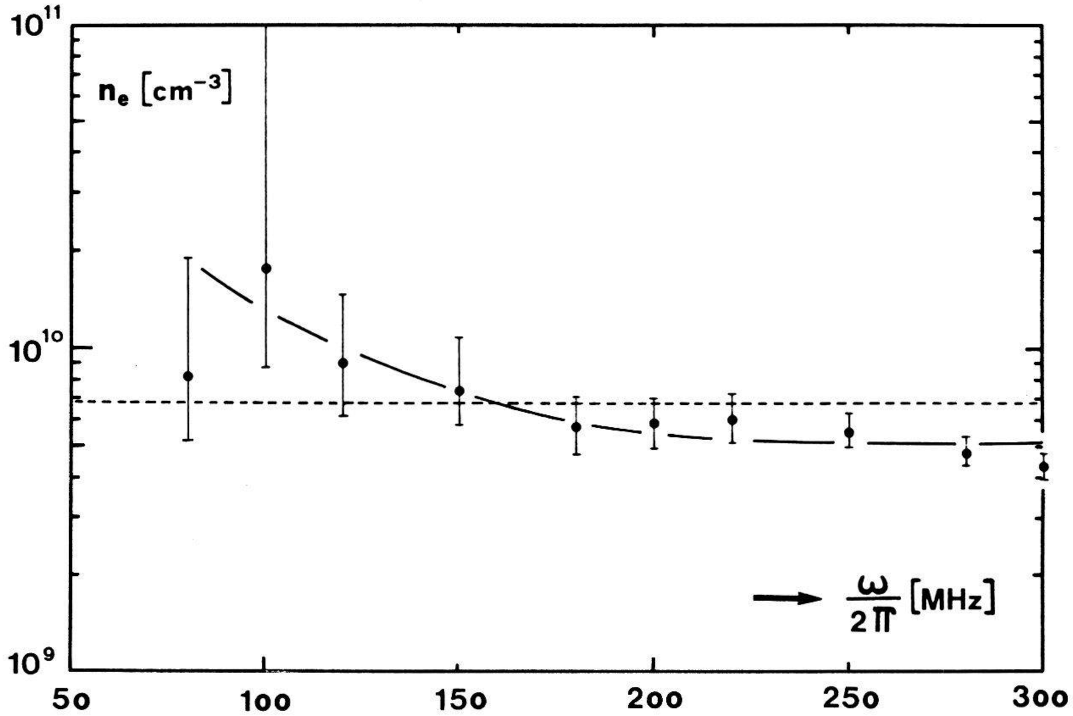

Figure 4
Comparison of electron density obtained with double probe (dashed line) and with resonance cone technique (solid line).

4. Conclusion

The rule that in the resonance cone technique for density measurement the highest possible frequency should be used is correct. A systematic deviation at low frequency is very interesting because it cannot be explained to this amount by magnetohydrodynamic theory for a cold plasma – yielding equation (1) – even if the motion of the ions is taken into account.

REFERENCES

[1] R. K. FISHER and R. W. GOULD, Phys. Fluids *14*, 857 (1971).
[2] R. J. BRIGGS and R. R. PARKER, Phys. Rev. Lett. *29*, 852 (1972).
[3] P. BELLAN and M. PORKOLAB, Phys. Rev. Lett. *34*, 124 (1975).
[4] K. H. BURREL, Phys. Fluid *18*, 1716 (1975).
[5] K. LUCKS, M. KRÄMER and H. SCHLÜTTER, Phys. Lett. *70A*, 205 (1979).
[6] J. ICKOVIC, R. L. STENZEL and W. GEKELMAN, Rev. Sci. Instr. *48*, 485 (1977).
[7] T. DOTE, H. AMEMIYA and T. ICHIMIYA, Japan J. Appl. Phys. *3*, 789 (1964).
[8] J. MUSIL, F. ZACEK, L. BARDOS and J. DATLOV, Czech. J. Phys. *B28*, 75 (1978).
[9] H. FUJITA and Y. NOMURA, J. Phys. Soc. Japan *43*, 1736 (1977).