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Probe Diagnostics of Confined Plasma Produced by 13.56 MHz R.F Plasma Source

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Abstract

In an inductively coupled R.F plasma reactor, the plasma density increases smoothly for low increase of input power, but exhibits discontinuities or jumps. Variation of plasma temperature and density has been studied by using both single and double Langmuir probes. Other measurements showed that there is smooth increase in the plasma density, by increasing magnetic coil current and the R.F power.
Measurements have also confirmed earlier observations that the higher R.F power strongly depends on, to the higher chamber pressure and plasma potential.

Keywords: *Probe Diagnostics, Confined Plasma, R.F Plasma Source*

Introduction:

Ion bombardment during the etching process has been found to be very important in the control of the profiles of the features, etched in silicon and polycrystalline silicon (Suzuki *et al.*, 1985).The ion flux incident on the surface is controlled by the density of the plasma. In the etching of very small device feature in thin semiconductor layers, it is therefore important to be able to control independently the plasma density and the energy of the plasma species bombarding the substrate (Boswell *et al.*,1989). In conventional parallel-plate etching reactors any attempt to increase the plasma density by increasing the input power to the system, will result an increase in the plasma potential (Boswell *et al.*,1989) since this parameter is determined by the peak voltage appearing on the driven electrode (Vella *et al.*,1985).

However, control over the plasma parameter can be achieved by using an inductively coupled R.F plasma as described by (Chen F.F. *et al.*, 1985). In this system the plasma is produced by coupling R.F power at 13.56 MHz through a two matching network to helicon antenna wound around the source. Experiments has shown that this type of reactor can be operated so that the plasma density and the plasma potential are virtually independent of each other
(Haddelstone *et al.*,1965). In this report we will present results of study of the transition to this mode of operation, and a large body of data was recorded using a computer controlled Langmuir probes.

Experimental Apparatus

The apparatus used in this experiment is shown schematically in Figure 1. It consists of a cylindrical aluminum vacuum chamber 25 cm in diameter, and 25 cm in length connected to the R.F source.

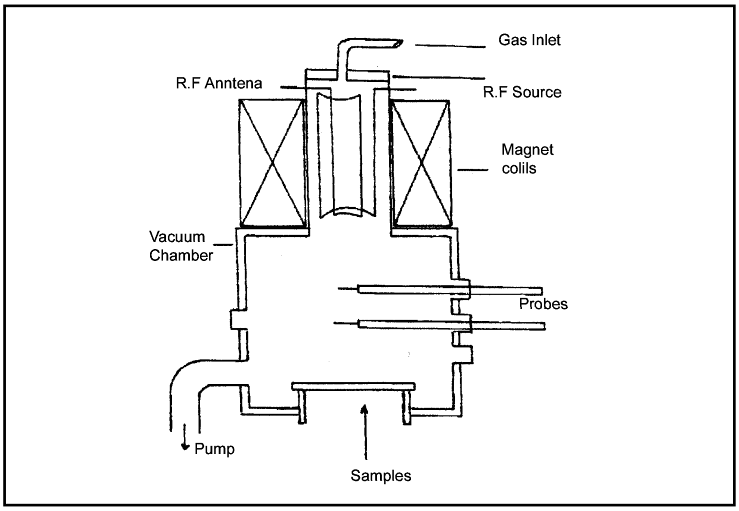

Figure 1- Schematic diagram of vacuum system with R.F source.

This system is evacuated through a 10cm port on the side, using an oil diffusion and rotary pump. The effective pumping speed at the pumping port is about 50 LS .The radio frequency plasma source is placed in a Pyrex cylinder 15cm in diameter and 25 cm in length, with an aluminum cap at the end ,the source is positioned at the center of a solenoid of 25cm in length. This provides a magnetic field up to 150 mT with maximum of 4 A current.

The argon gas used for this study was admitted into the source through the center of the end cap. The helicon antenna was wound around the source tube with self-adhesive copper tape 12.5mm wide. It was folded and soldered at the corner, and the connections were made at each end with copper braided cable. The flexibility of the braid helps to reduce the stress transferred to the antenna from the 3mm copper wires used in the tuning network. The helicon antenna couples energy into the plasma with high efficiency, virtually all R.F power being absorbed by the plasma.

Experimental Results:

A set of measurements was made to develop an understanding plasma parameters by this R.F high power ion source. Thus a conducting probe was used to determine the crucial plasma parameters as density, temperature and potential, with and without the magnet field. Also scan of the radial distribution density were made using the probe, immersed in the plasma which emit or collect current depending upon the voltage impressed. In the absence of magnetic field, the random ion current passing through an area A in the plasma is related to the ion density and ion velocity as the following equation (Haddelstone , 1965)

$$I = \frac{1}{4} A_p n_+ e v_{th}$$

Where, I_+ is the random ion current in amperes, A_p the area of probe in m^2, m_+ the ion mass 1.67×10^{-27} kg per photon, n_+ the ion density No/m^3 and $V = \left[\frac{2KT}{m_+}\right]^{\frac{1}{2}}$ is mean kinetic ion velocity m/sec. This expression holds only when $T_e < T_i$. If this situation does not obtain, the ions arrive at the probe with a velocity that corresponds to approximately $\frac{1}{2}$ KT_e . When $T_e << T_i$ the saturation ion current is modified as:

$$I_+ = 0.4\ A\ n_+ + ev_{th}$$

Thus, if the thermal speed of the electron is known, the plasma density can be found from the saturation current, or can be calculated from the electron temperature, which is found by inspecting the slop of the volt-ampere characteristics (Frank *et al.*, 1972). As the probe potential is increased with respect to the plasma, the surface will start to receive more and more electrons, first the fast electrons, and then slower ones. As the result, when the positive current to the probe is reduced, the current vanishes as the electron and ion flows to the probe are equal. Thus with a negative current to the probe, the electron current is determined from the following relation (Padgarni,1972):

$$I_+ = \frac{1}{4}\ env_e\ Se^{-\frac{ev}{kt}}$$

Where: $$v_e = \sqrt{\frac{8KT_e}{m?‡}}$$

By analyzing the above equation, we find:

$$Ln(I_e) = Ln\left[\frac{1}{4}env_e s\right] - \frac{ev}{kt}$$

Consequently the tangent to the probe characteristics and a semi logarithmic plot is e/kt, which allows us to determine the electron temperature and the ion density. In a magnetic field the motion of particles along the field has a completely different character, than motion perpendicular to it. Therefore in the presence of the magnetic field the electric probe is unstable for absolute measurements. Initial experiments with no magnetic field showed that the plasma was extremely unstable at pressures of about $5x10^{-4}$ to $4x10^{-3}$ Torr.

Figures 2 and 3, summarize a number of plasma characteristics using both single and double probes without the magnetic field to show variation of bias voltage with probe current. The electron temperature obtained by both methods was 0.25-0.7 ev and the relative densities was about 2.8-3.6 x 10^{16} cm^{-3}, for different R.F powers and nearly the same pressure. This difference is possibly due to the pressure fluctuations caused by discharge between the two probes, and varying the ion electron saturation current in the double probe experiments.

Figure 4, shows how the R.F power changes with pressure. These experiments showed that the plasma could change modes spontaneously. At high pressure or low R.F power the plasma simply extinguishes. By this survey of plasma characteristics, the more stable state of plasma was chosen for further experiments.

Variations of plasma density with coil current at about 3 Torr chamber pressure is shown in Figure 5, As the figure shows at 500 watts and 350 watts of R.F power, the density has a nearly sharp maxim at 2-2.5 amps, but at low R.F powers of 80 watts it remains low. Further experiments showed that at zero magnetic field the plasma will not diffuse from the source entirely, so there is a small but non-zero density in the source.

Figure 6 shows the plasma potential with R.F power at 3A , 1.5A and 1A of magnetic coil current at about $5x10^{-3}$ Torr chamber pressure. These variations show that in all cases, the plasma potential increases steadily with power to a peak value at the transition mode. The potential then decreases to a lower value as the power increases. These variations seem to be due to the change of antenna power and density, causing electron ion recombination inside the running plasma.

Figure 7 exhibits the density versus the R.F power. This figure shows that at low power nearly the density remains constant, but at power of 200-300 watts it increases rapidly. These changes reach a maximum up to few times more than previous values at higher coil current. These variations seem to be due to magnetic field with high electron density which draws more and more power from the source.

An attempt was made to measure the axial profile of plasma characteristics. Therefore in these investigations the single probe position was changed in a line perpendicular to the source axis at 2cm intervals. Figure 8, shows the radial variation of temperature and density with probe positions. It can be seen that the plasma had a higher temperature around the axis. Also the plasma density decreases more steadily at both sides of the source axis. Further experiments showed that at very high pressure the plasma fluctuates, so that further from the axis the plasma density is low and unstable around the axis.

DISCUSSION:

The plasma characteristics have been measured over a large range of each of the external parameters. This has allowed the plasma behavior to be studied, and has provided an accurate basis for chasing the modes of operation. However we have demonstrated that a high density diffusion plasma can be created at certain conditions. At pressure below 2 m Torr and source power of 400- 700 watts a uniform plasma over at least 15 cm in diameter can be formed by a confined magnetic field.

The plasma density and temperature determined in this work can be changed by varying the R.F power. Thus the R.F coupling technique employed in etching of thin film purposes, can be improved.

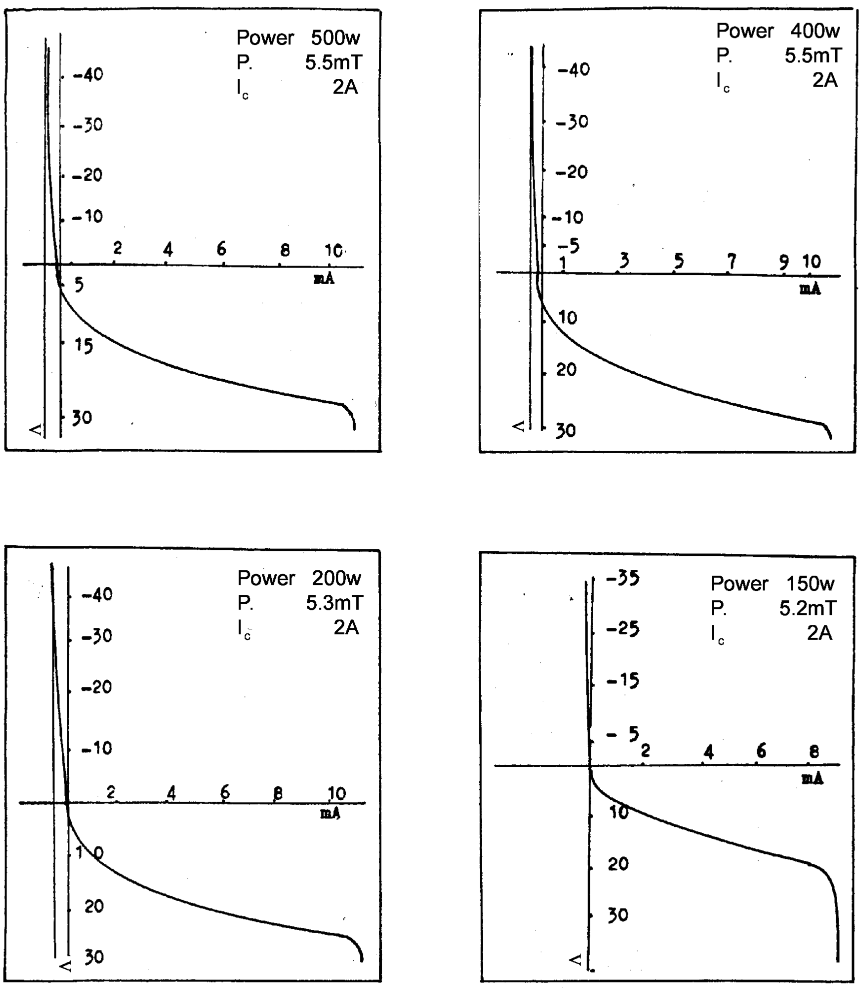

Figure 2 – Single Langmuir probe characteristics around the source axis.

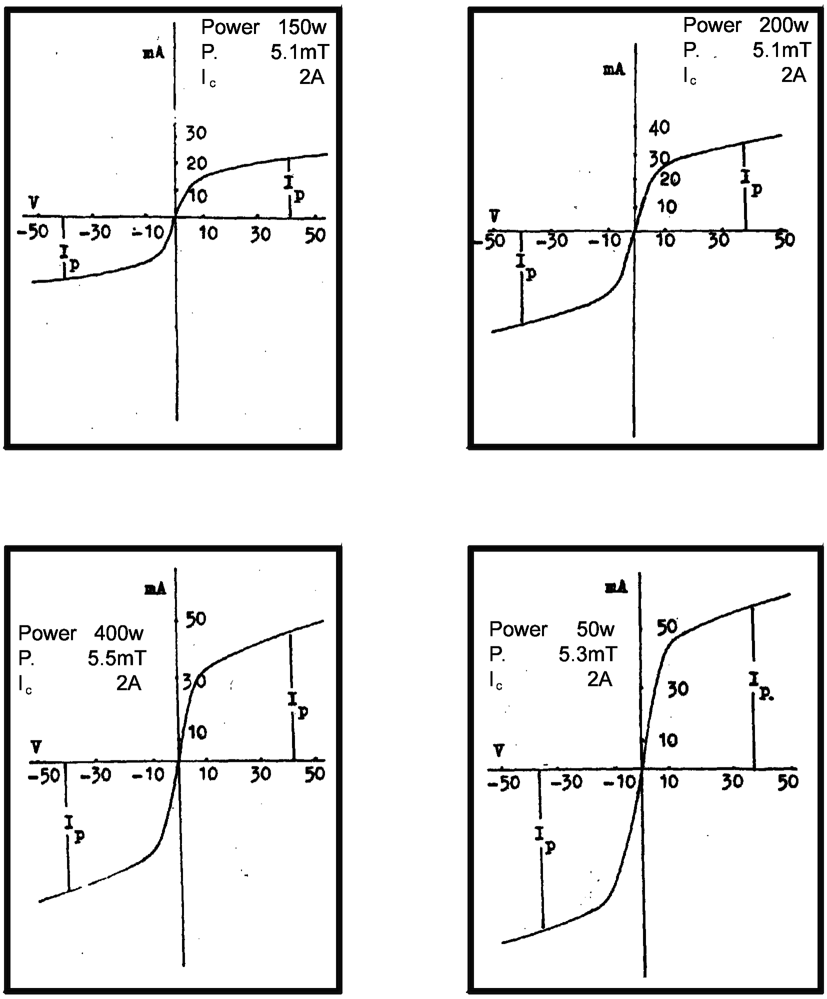

Figure 3 – Double Langmuir probe characteristics around the source axis.

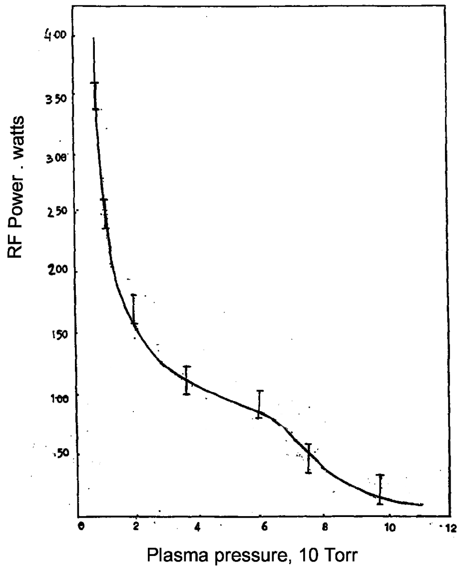

Figure 4 – Plasma mode changes due to the variation of pressure with RF power.

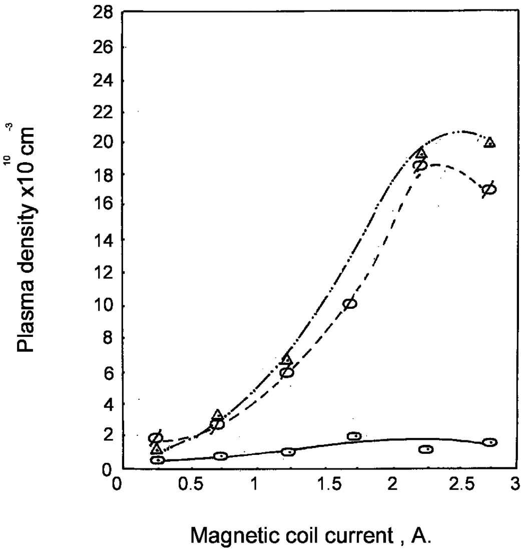

Figure 5 – Variation of plasma density with magnetic field 500 (∆), 350 (ø) and 80 (?) watts.

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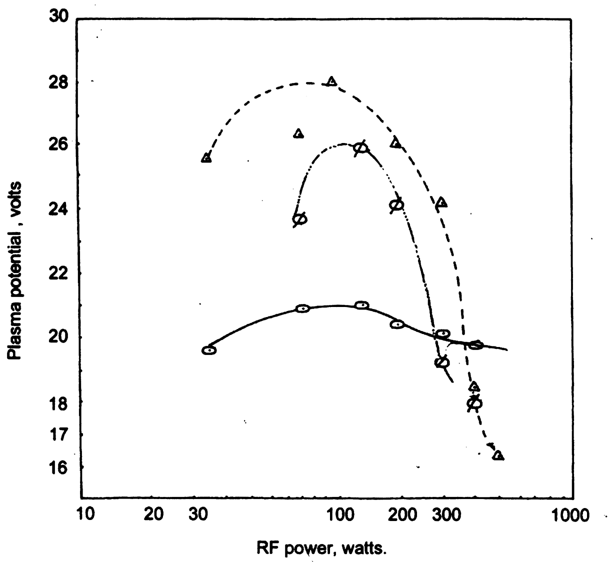

Fig. 6 - Variation of RF power with plasma potental at 3A (△), 1.5A(⌀) and (⊝) magnetic coil current.

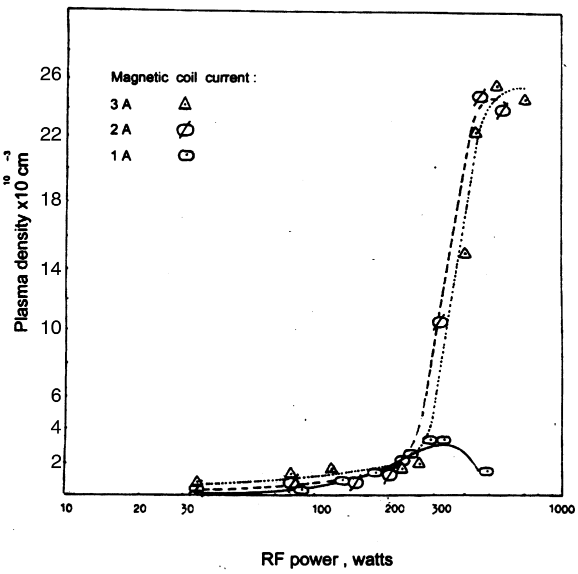

Fig. 7 Variation of plasma density with RF power at 3.5x10^{-3} torr pressure

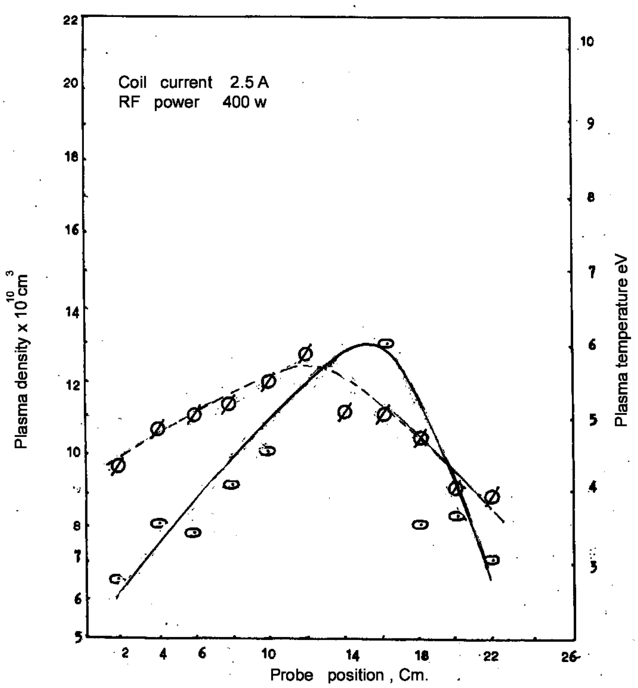

Figure 8 – Radial profile of probe position with plasma density (ø) and plasma temperature (?Â).

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