Radiofrequency Initiation and Radiofrequency Sustainment of Laser Initiated Seeded High Pressure Plasma

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Abstract. We examine radiofrequency initiation of high pressure(1-70 Torr) inductive plasma discharges in argon, nitrogen, air and organic seed gas mixtures. Millimeter wave interferometry, optical emission and antenna wave impedance measurements for double half-turn helix and helical inductive antennas are used to interpret the rf/plasma coupling, measure the densities in the range of $10^{12} cm^{-3}$ and analyze the ionization and excited states of the gas mixtures. We have also carried out 193 nm excimer laser initiation of an organic gas seed plasma which is sustained at higher pressures(150 Torr) by radiofrequency coupling at 2.8 kW power levels.

Introduction

Radiofrequency plasma sources have a variety of applications including material processing, decontaminating environmental waste and gaseous pollution. The application of these plasma sources require plasma densities $n_e \sim 10^{11-13} cm^{-3}$ at low rf power levels. The discharge characteristic of a mixture gas is quite complex and differs significantly from that of the individual gases. By appropriate choice of mixture and seed gas concentration, the operating pressure can also be increased. Here we choose to study a mixture of nitrogen and argon gas and laser photoionization of organic seed gas in the pressure range of 1-150 Torr.

Radiofrequency Plasma Source

The schematic of the radio frequency helicon plasma source [1] is shown in Fig. 1. The plasma chamber is a 10 cm diameter Pyrex glass tube of length 120 cm. The plasma chamber is pumped to a base pressure of 3×10^{-7} Torr using a turbo molecular pump. A magnetic field of 1.2 kGauss is provided by a set of five electromagnet coils. Flow controllers and a gas mixer are used to control the argon and nitrogen gas concentrations. The diagnostics include spectrum analysis using an Ocean Optics ST2000 fiber optic spectrometer in the frequency range $\sim 200 - 800 nm$ and impedance measurement using network analyzer.

The experiments for $N_{2\,x}Ar_{1-x}$ mixtures for x =.25 to .65 (x: percent gas concentration) are conducted at gas pressure of 1 Torr with a half-turn double-helix antenna. We find that if we have more than 50% nitrogen in our concentration, the N_2 discharge dominates giving us a pinkish color plasma, being strongest under the

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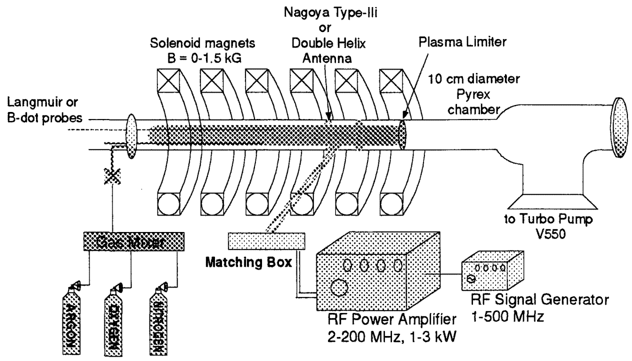

Figure 1: Experimental setup for radiofrequency production of plasma.

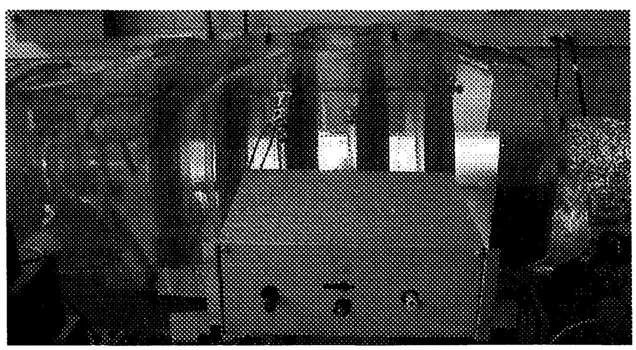

Figure 2: N_2/Ar Mix plasma at 1 Torr.

antenna and extending up to 20 cm away from the antenna. Similarly, for more than 75% argon, the Ar dominates with the plasma extending 20-30 cm away from the antenna. However for $N_2\,{}_{x=.5}Ar_{1-x=.5}$ to $N_2\,{}_{x=.4}Ar_{1-x=.6}$, there is a stronger orange/yellow color plasma being very intense under the plasma and extending almost 0.75 m axially as shown in Fig. 2. Both argon and nitrogen lines are present prominently in the spectral emission. There is a distinct improvement in plasma size, implying thereby the positive effect of the gas mix.

It is also seen from the power measurements that the reflected power is about 17% for 40% nitrogen with 60% argon at 1 Torr, indicating efficient power coupling. The estimated power density, after accounting for the antenna and plasma losses, needed to sustain the the plasma is 0.04 W/cm^3

The impedance of the half-turn double helix coil is measured using the network analyzer using the conjugate match principle. For the optimum match at 1 Torr, antenna plasma impedance $Z_{antenna} = 0.3 + j4\Omega$. This matches very closely to the ANTENA-II simulated value $Z_{antenna} = 0.28 + j1.6\Omega$ for a plasma density of $5 \times 10^{12} cm^{-3}$ at 1.4 kGauss with 1 eV electron temperature.

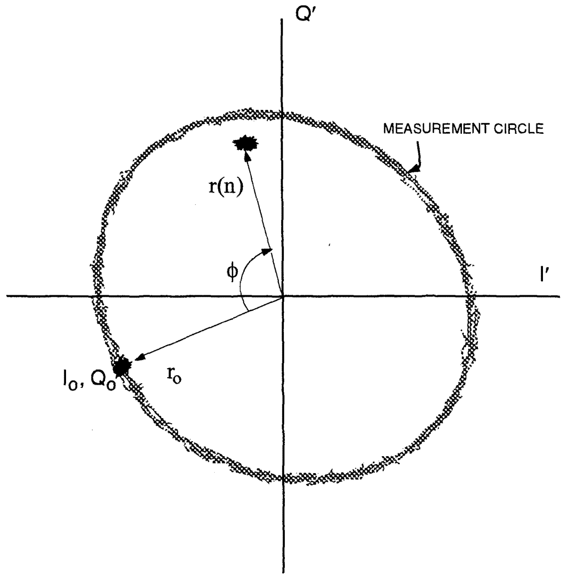

Figure 3: Interferometer trace: The phase difference is determined by rotation of the vector along the measurement circle.

Laser Ionization and Radiofrequency Sustainment of High-pressure discharge

An excimer laser(Lumonics Pulsemaster PM-842) produces a 193 nm ultraviolet (UV) beam of 20($\pm$2) ns pulse width(1/2 max) with a maximum laser energy of 300 mJ [2]. The laser ouput cross section is 2.8 cm$\times$1.4 cm. The plasma chamber is a pyrex tube of diameter 5 cm and length 150 cm. The radiofrequency source is a 13.56 MHz single frequency source of maximum output power 3000 Watts (Advanced Energy RFG3000). The laser beam enters through a 2.5 cm window (98% transparency) mounted at one end, while rf power is coupled through a five turn helical antenna. The gas mixer and inlet are the same as in the earlier experiments.

The plasma density measurement is carried out by means of 105 GHz millimeter wave interferometer located 8 cm axially from the antenna. This is a phase bridge interferometer and works on the coherent signal principle. A sample measurement is shown in Fig.3.

The plasma was successfully sustained with an inductive discharge at 2.8 kW up to 80 Torr in argon. Above 80 Torr, the voltage required for breakdown was more than the maximum output power of the generator. The interferometer measurements of plasma density as a function of argon pressure is shown in Fig. 4. The plasma density is seen to be constant above 1 Torr. At pressures above 80 Torr, the plasma can be initiated only by adding the organic gas Tetrakis (dimethylamine) ethylene or TMAE and using the laser for preionization. With 2-8 mTorr of TMAE in argon

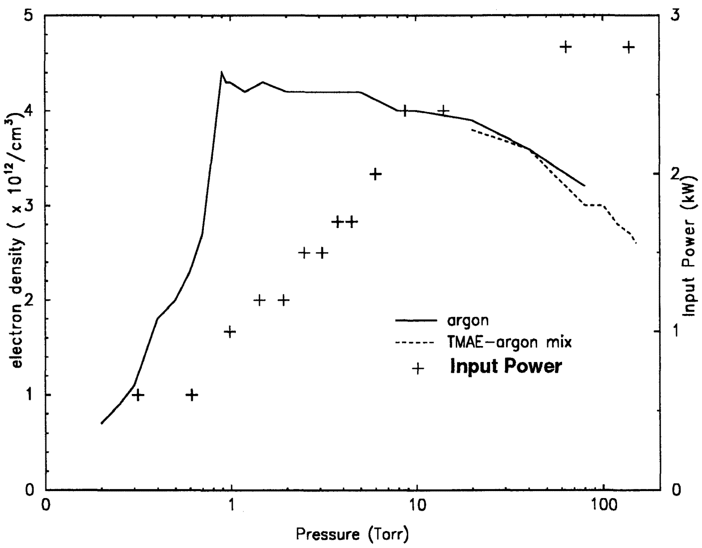

Figure 4: Plasma density vs. pressure for the five-turn helical antenna in pure argon and a mixture of 2-8 mTorr TMAE in 20 Torr to 150 Torr argon (dashed line) .

and laser photoionization [3], the plasma can be consistently sustained up to argon pressure of 150 Torr with 2.8 kW of rf power.

We are currently obtaining inductive plasma discharges in nitrogen and air at 50 Torr and will continue research on noble gas mixes and laser initiation of seed gas to minimize the rf power levels at high-pressures.

Conclusion

We have shown that the discharges characteristic can be altered by using a argon mix or seed gas at high pressure. The use of an organic seed gas and its laser photoionization considerably increases the operating gas pressure to 150 Torr at moderate power levels.

Acknowledgments

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References

1. Guo, X., Scharer, J., Mouzouris, Y., and Louis, L.,*Physics of Plasmas*, **6**(8), 3400, (1999).
2. Kelly, K.," Laser Ionization and Radio Frequency Sustainment of High-pressure Seeded Plasmas", Ph.D. Thesis, University of Wisconsin, Madison, 2001.
3. Ding, G., Scharer, J., and Kelly,K., *Physics of Plasmas*, 334-342, January, 2001.