Electron density modulation in a pulsed two-frequency two-antenna inductively coupled plasma discharge

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Electron density, n_e, modulation in a pulsed two-frequency two-antenna inductively (2/13.56MHz; 2MHz is pulsed) coupled plasma discharge produced in Ar-C_4F_8 (90-10) gas mixtures is measured using resonance hairpin probe. The effect of rf power levels, gas pressure and duty ratio on the quasi-steady state n_e, decay time constant and rise time is investigated. It is observed that the quasi-steady state n_e is affected by both low frequency (LF) and high frequency (HF) power levels. The density decay time constant and rise time of n_e is decreasing with a rise in LF and HF power levels. Furthermore an overshoot in the n_e is observed in the beginning of pulse on-phase. On increasing gas pressure the quasi-steady state n_e is first increasing, reaching to a maximum value at 10-20mTorr gas pressure, and then decreasing with further rise in gas pressure. Density decay time constant is increasing with a rise in the gas pressure. Increasing duty ratio up to 30-40% shows increase in the peak/quasi-steady state n_e in the pulse on-phase and decreasing at higher duty ratios.

1. Introduction

Inductively coupled plasma systems (ICP's) are widely investigated and used in the semiconductor processing industry for etching and depositions [1]. Multiple-frequencies plasma excitations are proposed to independently control the flux and energy of the reactive/charged species onto the substrate and to scale-up the existing ICP's [2-3]. This gives flexibility to achieve an excellent process reproducibility and stability with an enhanced plasma processing rates and uniformity over large-area wafers. Pulsing rf discharges provides additional control over the plasma such as gas dissociation rate and tailoring of electron energy distribution function [4]. In the pulsed plasma system the power balance is maintained over the pulse period thus the discharge kinetic is significantly affected by the pulsing parameters during the plasma on-off period in addition with the other operating parameters (rf power level, gas pressure/mixtures). n_e is one of the basic plasma parameters that drives most of the plasma chemistries and also required to validate the plasma simulation models. In this article we presented the n_e modulation in a pulsed two-frequency (2/13.56MHz) two-antenna ICP's. 2MHz power is applied in pulsed mode at a frequency of 1KHz whereas 13.56MHz is applied in CW mode. The discharge is produced in Ar and fluorocarbon gas mixture. The effect of rf power levels, gas pressure and duty ratio on the quasi-steady state n_e, decay time constant and rise time is investigated.

2. Experimental set-up

The schematic of the two-frequency two-antenna inductively coupled plasma discharge is shown in figure 1. Discharge is produced in a cylindrical anodized aluminium chamber with an internal diameter of 630mm and height 40mm by using two planar concentric spiral coils with 13 and 3 turns respectively. The coils are separated by the plasma via a 35mm thick dielectric (quartz) window. Inner coil is powered by 2MHz (NOVA-50A, ENI) and the outer coil is powered by 13.56MHz (CX-5000S, COMDEL) with two separate matching networks. The output of the 2MHz power generator is pulsed using a pulsing unit with an ability to change the pulsing frequency and duty cycle. A multihole shower ring is located inside the plasma chamber for a distributed gas flow. The gas pressure inside the chamber is regulated by a mass flow controller (2900 series, Tylan) together with an adaptive pressure controller (PM-7, VAT) for the gate valve control above a turbo molecular pump backed by a dry pump. The n_e modulation is measured by using resonance hairpin probe. The principle behind this technique and the method to determine time-resolved electron density is described elsewhere [5-6]. The probe is positioned at the centre of the discharge and ~2cm below from the dielectric window.

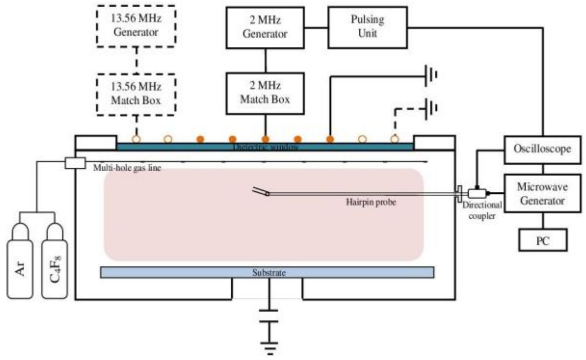

Fig 1. Two-frequency two-antenna ICP system along with the hairpin probe and its data acquisition system.

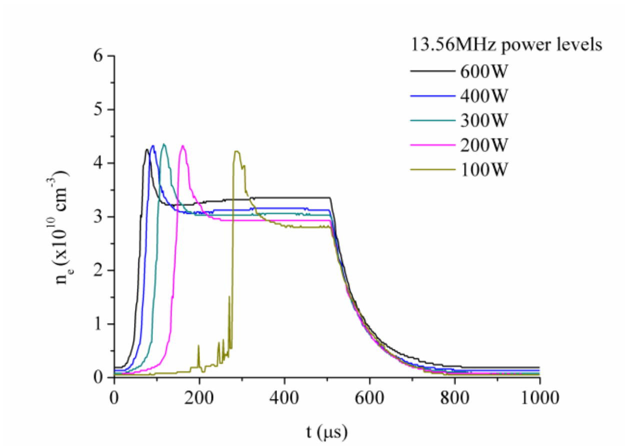

Fig 2. n_e modulation over a course of one pulse period for different 13.56MHz power levels. Operating gas pressure is 10mTorr. 2MHz peak power level is 300W and pulsing frequency is 1KHz.

3. Results

The experimental results reveal that the quasi-steady state n_e is greatly affected by the 2MHz power levels and slightly affected by 13.56MHz power levels. It is observed that the plasma density increases by a factor of 2-2.5 on increasing 2MHz power level from 300W to 600W whereas it is increasing by ~20% from 100-600W 13.56MHz power level. Both, the rise time and decay time constant of plasma density are decreasing monotonically with an increase in the 2MHz and 13.56MHz power levels. For all the operating conditions, it is observed that the plasma density overshoots in the beginning of on-phase (shown in figure 2) before reaching to a quasi-steady state value. The relative overshoot found to be dependent on the 2MHz and 13.56MHz power levels. On increasing gas pressure the plasma density is first increasing, reaching to a maximum value at ~10-20mTorr gas pressure, and then decreasing with further rise in gas pressure. Decay time constant of plasma density is a function of pressure, it is increasing rapidly up to ~20mTorr gas pressure and then increasing slowly. At a fixed 2/13.56MHz power level and 10mTorr gas pressure the steady state plasma density shows maximum for 30-40% duty ratio and decreasing with further increase in the duty ratio.

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4. References

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