Experimental investigations on time resolved characteristics of pulsed inductively coupled O_2 /Ar plasmas using Impedans Langmuir Probe.

INTRODUCTION

Compared with CW plasma, the pulsed plasma has been widely investigated since the late 1980s, as it has tremendous advantages, i.e. improved etching selectivity, higher etching/depositing rate, better uniformity along with less structural, electrical and radiation damage.

In this paper, the time-resolved electron density and effective electron temperature have been measured using an Impedans Langmuir probe under various O_2 ratios, gas pressures and discharge powers.

EXPERIMENT

The schematic of the experimental setup is shown in Fig 1. The plasma is formed using a three-turn water cooled coil located on the quartz window at the top of the chamber. The 13.56 MHz power has been modulated by a pulse signal which is also used to trigger the Langmuir probe from Impedans Ltd which is located at the centre of the chamber and 7 cm below the quartz window. The grounded substrate is placed 10 cm below the quartz window. The probe tip is made of tungsten, 5 mm in length and 0.08 mm in diameter.

RESULTS

Fig 2 shows the temporal evolution of the measured electron density and effective electron temperature at various gas ratios at 30 mTorr with a 1 kHz pulse frequency and 50% duty cycle. The density increases in the first 200 μs.

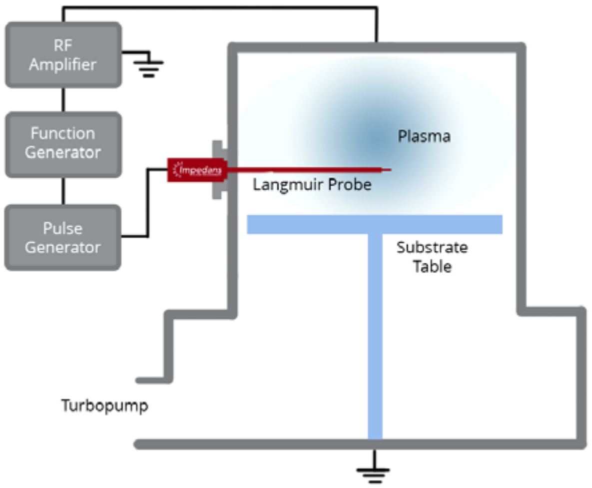

Figure 1. Schematic diagram of the Inductively Coupled Plasma Reactor.

During this period, the ionisation rate is higher than the electron loss rate, due to the highly energetic electrons. After 200 μs, the electron density reaches a stable state. During the pulse on-time the plateau that the density reaches decreases as the O_2 content increases due to the higher electron attachment rate of molecular oxygen along with power being dissipated in the vibrational and rotational heating of O_2 molecules. The electron density increases to a peak value at the beginning of the afterglow. The most likely explanation for this is that more electrons were released due to the detachment of negative ions resulting in a sharp increase in the electron density. This detachment produces slow electrons (hence the drop in effective temperature) which cannot cause enough excitation or ionisation during the power-off

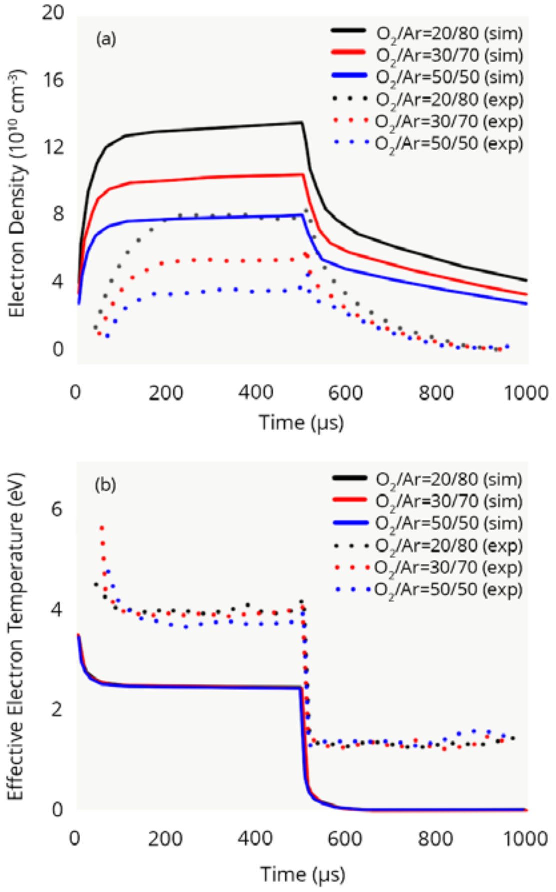

Figure 2. Temporal evolution of the electron density and effective electron temperature for various Ar/O_2 plasmas.

$O_2/(O_2+Ar)$	20%	30%	40%
Δne (10^9 cm^{-3})	2.07	5.27	7.67

Table 1. The electron density difference between early afterglow and steady state value in the active glow at various O_2 ratios.

phase resulting in the decrease in the electron density. The difference between the peak value at the early afterglow and the steady state for the three different O_2 concentrations are shown in Table 1. The clear increase in Δne as O_2 increases is due to the corresponding increase in electronegativity providing a higher O^- concentration when the power turns off. The initial spike in the effective electron temperature is attributed to the high power deposition to each electron due to the low electron density.

Fig 3 shows the temporal evolution for a range of pressures for a fixed O_2/Ar=20/80 ratio. The electron density peaks at 30 mTorr. This is due to the ionisation rate peaking for a constant applied power. The Δne also peaks at 30 mTorr.

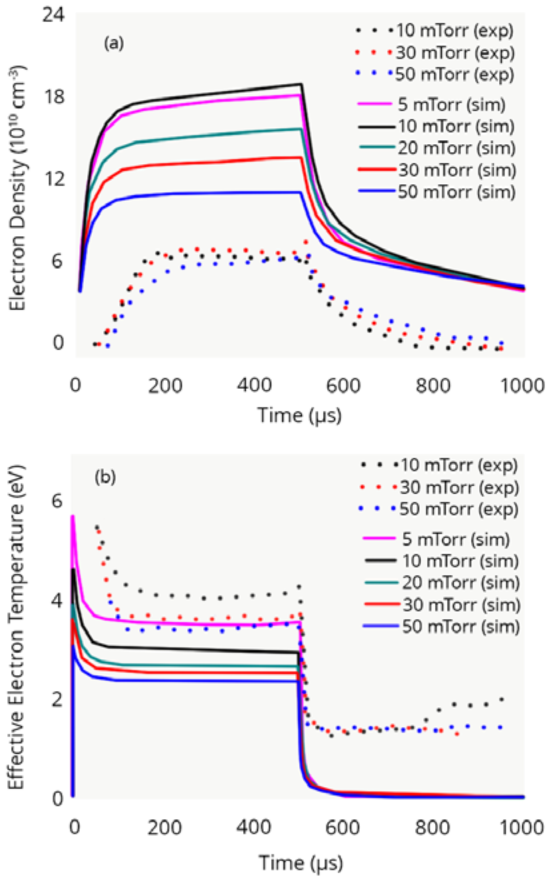

Figure 3. Temporal evolution of the electron density and effective electron temperature for various pressures.

The effective electron temperature during the power-on time decreases with pressure due to an increase in the frequency of collisions.

Fig 4 shows the temporal evolution for a range of powers for a fixed O_2/Ar=20/80 ratio. The electron density, in the steady state, increases with increasing power. This is because the electrons absorb more energy enhancing the ionisation and detachment processes. Furthermore, as the power increases, the electron density peak in the initial afterglow becomes more pronounced. This might be caused by the enhanced electron impact detachment of O^- due to more energetic electrons existing at the higher powers. The effective electron temperature remains relatively stable as the power increases with a more pronounced afterglow peak.

CONCLUSION

The influence of the O_2 ratio, pressure and power on the electron density and effective

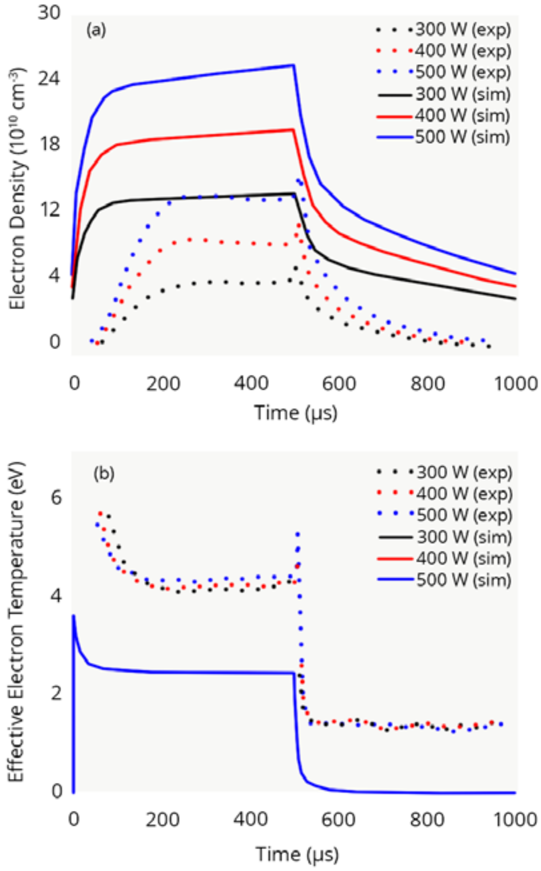

Figure 4. Temporal evolution of the electron density and effective temperature for various powers.

electron temperature is investigated in an inductively coupled, pulsed O_2/Ar plasma. The results indicate that when the power is switched on, the electron density increases rapidly before it reaches a steady state. Once the plasma enters the afterglow period there is a brief spike in the density before it decays.

The effective electron temperature exhibits a peak at the beginning of the power-on time before settling to a steady state. There is also a peak in the effective electron temperature in the initial stage of the afterglow. The influence of the O_2 ratio, pressure, and power on the pulsed plasma properties at the steady state is similar to that observed in the CW discharge.

REFERENCES:

* Xue, C. et al, "Experimental and numerical investigations on time-resolved characteristics of pulsed inductively coupled O_2/Ar plasmas"

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