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Recombination and Decay of Plasma Produced by Washer Stacked Plasma Gun inside a Curved Vacuum Chamber

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Abstract - This paper presents the recombination coefficient of the plasma blob is calculated by measuring the electron density n_e of the order of $10^{18}m^{-3}$ and time (~μs) to move a particular distance.A washer stacked plasma gun is designed to produce high density plasma blob which is moving with speed~10^4 m/s. As the blob moves radially outward the particle density as well as drift velocity of the blob decreases. Since both charged and neutral components are present in the blob, the recombination may play a dominant role for the blob motion. It has been observed that the recombination co-efficient α (~ 10^{-12} m^3s^{-1}) is almost constant across radial distance from gun mouth and in that spatial length the electron-excited molecular collisional ionization is negligible, so two body recombination is dominant.

Key Words: *Blob, Washer stacked plasma gun, Langmuir probe*

I. INTRODUCTION

Several plasma techniques are available for studies of ion recombination with electrons. Typically the decay of plasma (in time and space) in which a certain type of ions dominates is monitored and from the measured decay curves the rate coefficients are extracted in such experiments. In the majority of these experiments electron number densities are measured by Langmuir probes and recombination rate coefficients are calculated under the assumption of quasi-neutrality [1].

In the present work a washer stacked plasma gun (PG) is used to produce blob of pulsed plasma and is injected with high speed ~ 10^4 m/s [2] into the curved vacuum chamber (CVC). Using Langmuir probe, we have been characterized the pulsed plasma by measuring plasma parameters. This method has the advantage that the probes are simple to operate as well as measurements of local plasma parameters can be done without disturbing the entire plasma. The dimension of the probe should be small in comparison with the mean free path of the electron in the gas at the corresponding pressure. The plasma density and temperature are measured by biasing the probe with respect to the grounded chamber at different distances from the plasma gun. Probe behavior differs significantly between situations where collisions can be ignored and those where they can not.

II. DIAGNOSTIC AND MEASUREMENT

2.1. Principle: The single probe method is based on the Boltzmann relation and application of Kirchhoff's current law which requires in this case that at any instant the total current of positive ions and electrons flowing to the system from plasma must be zero. The single Langmuir probe is biased with respect to the grounded chamber and the plasma blob interacts with it resulting signals on a four channel storage oscilloscope which connected to the computer. From the acquired signals the probe current has been measured across a resistance for a particular probe potential.

2.2. Theory: When the current voltage dependence should be exponential by obeying Maxwellian energy distribution, the electron density n_e is given as [3, 4]—

The electron density is given as

$$n_e = (I_{es}/A_p)(2m_e / e^3)^{1/2} (e / kT_e)^{1/2} \tag{1}$$

Where $I_{es,}$ A_p, e, m_e, T_e and k are saturation current, expose area of probe, charge, mass, temperature of electron and Boltzmann's constant respectively.

For pulsed plasma the electron current does not show saturation region in characteristic curve. From the equation (1) electron density n_e is obtained at different radial points inside CVC.

When an ion and electron collide, particularly at low relative velocity (low temperature), they have a finite probability of recombining into a neutral atom. The rate of recombination is proportional to $n_i n_e \approx n^2$, where n_i and n_e are ion and electron density respectively such that for quasineutrality $n_i \sim n_e$. The effect can be represented as a particle sink in the equation of continuity by ignoring the diffusion and gives,

$$\partial n / \partial t = - \alpha n^2 \qquad (2)$$

Where α is the recombination coefficient [1, 5, 6]. The equation is non-linear and has solution

$$\partial n / n^2 = - \alpha \partial t$$

Integrating with limits, it gives

$$1 / n(r,t) = 1 / n_o(r) + \alpha t$$

It implies, that

$$1 / n_e(r,t) = 1 / n_o(r) + \alpha t, \quad \text{for electron} \qquad (3)$$

Where n_0 is the initial number density (t= 0) and n_e is the number density at t.

As n_e is measured at different values of t, then $1 / n_e$ is plotted against t and the slope of the curve gives the value of α.

The density decays inversely with time, as well as with distance from mouth of plasma gun [3]. This is different from the case of diffusion in which the time variation is exponential. The electron loss is expected to be dominated by electron–ion recombination, whereas the loss due to ambipolar diffusion is negligible because of a large characteristic length of electron density non-uniformity and electron attachment to other is not important since these processes have too high energy thresholds.

2.3. Experimental: The work is carried out in a curved vacuum chamber made of stainless steel (SS-304) having major radius 40 cm and minor radius 20 cm. The vacuum chamber is evacuated by means of a diffusion pump coupled with a rotary pump and low pressures (0.01mb, 0.03mb, 0.05mb) were maintained during the time of experiment. A blob of plasma is injected into the chamber by a washer stacked plasma gun which fitted at radial extension port of the chamber. The gun is energized by a multistage pulse forming network (PFN) consists of capacitors (~5µF each) and inductors (~1µH each), which shown in figure-1.The PFN is discharged after triggering the silicon controlled rectifier (SCR), which used as a switch and the high speed plasma blob interact with a biased cylindrical Langmuir probe. The signals are recorded on a Tektronix TDS-2014B (100MHz, IGS/s) four channel storage oscilloscope and transferred to the computer. From the acquired signals we measure the probe current across a resistance 1KΩ for a particular probe voltage.

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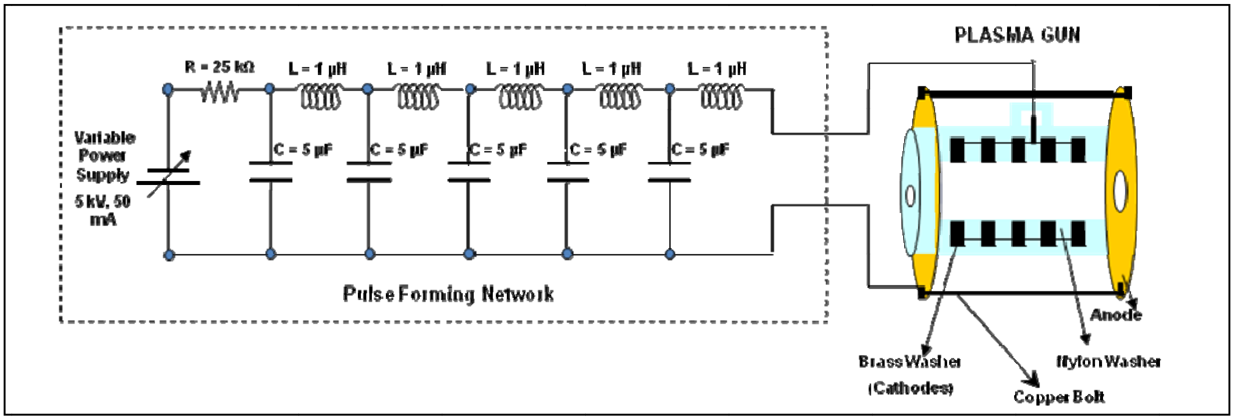
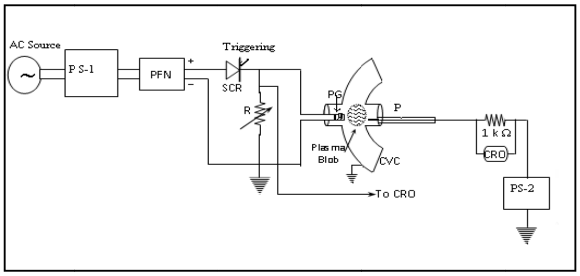
Figure-1 Block diagram of the Plasma gun and Pulse forming network



.The radial distance of the probe from the plasma gun is varied from 2cm to 16cm. The probe current was measured at different bias voltage at a constant base pressure (0.01 mb), discharging potential (750V) and pulse time (35µs). The observation is repeated for base pressure 0.03mb and 0.05mb at same discharging potential and pulse time. The schematic diagram of the experimental arrangement is shown in figure-2 and the signal recorded in oscilloscope via Langmuir probe is shown in figure-3.



PS-1- Power supply for PFN (5kV, 50mA)
PFN - Pulse forming network.
SCR- Silicon controlled rectifier
PG – Plasma gun.
P- Single probe
CVC – Curved vacuum chamber
PS- 2- Power supply for the probe to bias (0 -50V)

Figure- 2: Schematic diagram of experimental arrangement

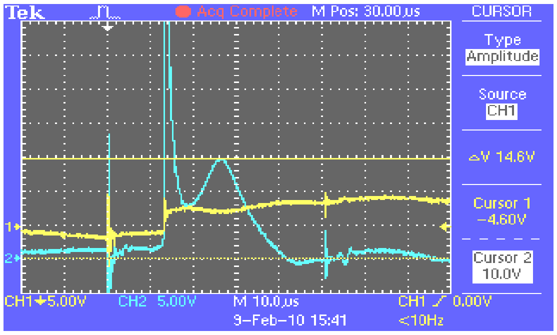


Figure -3 (CH-1 shows the discharge of Plasma Gun, CH-2 shows Signal received by oscilloscope via biased Langmuir probe across the resistor).

The evolution of electron density during plasma blob motion was monitored by Langmuir probe. From the electron density decays the recombination coefficient was determined and its dependence on base pressure was observed [7]. Langmuir probe measurements suggested that the loss of high energetic electrons to the wall of the vacuum chamber is the main energy loss mechanism. Electron-heavy particle collisions play only a secondary role for the energy loss. The loss of energetic electrons occurs rapidly while low energy electrons remain confined in the space charge potential field [8].

The dissociative recombination acts generally to regulate energy balance and composition in conventional plasmas. The escape of electrons in the first few microseconds of plasma formation creates a cationic space charge that acts as an attractive potential for the electrons and that electrons trapped by this potential can decay only by electron-ion recombination [9].

III. RESULTS AND DISCUSSION

The electron density (n_e) of the pulsed plasma blob is measured of the order of $10^{18}m^{-3}$. For a particular base pressure the density decreases with radial distance [3, 10 -12]. It has been observed that the electron density decreases exponentially with radial distance when the blob moves outward, whereas the magnitude of the density increases as base pressure increases, shown in figure–4. At lower pressure departure from single decay nature is observed which indicates there may be more than one layer of electron with different energy are formed when blob moves.

The explanation of plasma density behavior in the experiment is required for the recombination process with the rate constant. It is difficult to conclude about the mechanism of recombination, which may be due to the existence of recombinative plasma agrees with the energy and particle balance in the presence of a beam of runaway electrons [13].

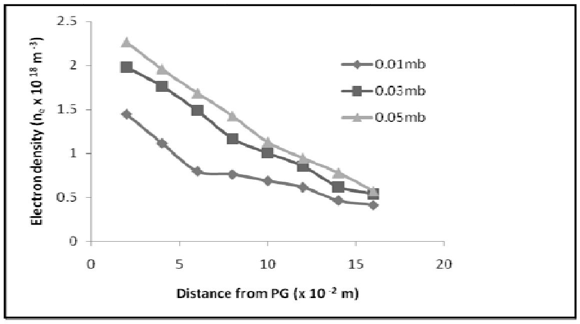
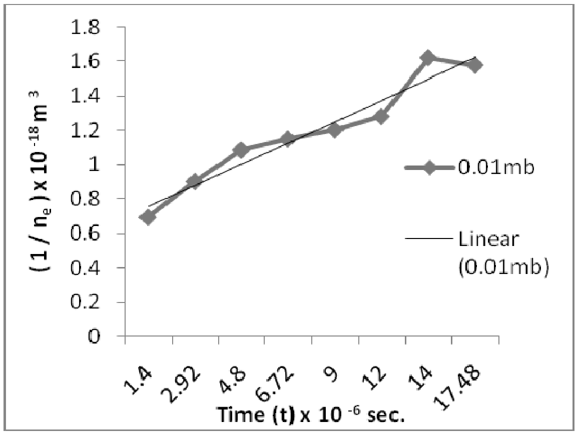


Figure-4 Variation of electron density (n_e) with radial distance.

The decaying plasma remains quasi-neutral and we represented the kinetics of charge recombination by differential equation written simply in terms of the time-dependent electron density [9]. The elementary processes leading to the irreversible loss of charged particles include electron-electron-ion three-body recombination, followed by pre-dissociation of a state. Here, the plasma decay is delayed because, at the beginning of the pulsed discharge, electrons are yet heated and recombine with ions with a lower rate that decreases with increasing electron temperature. The decrease in the recombination rate may leads to higher ion densities [6].



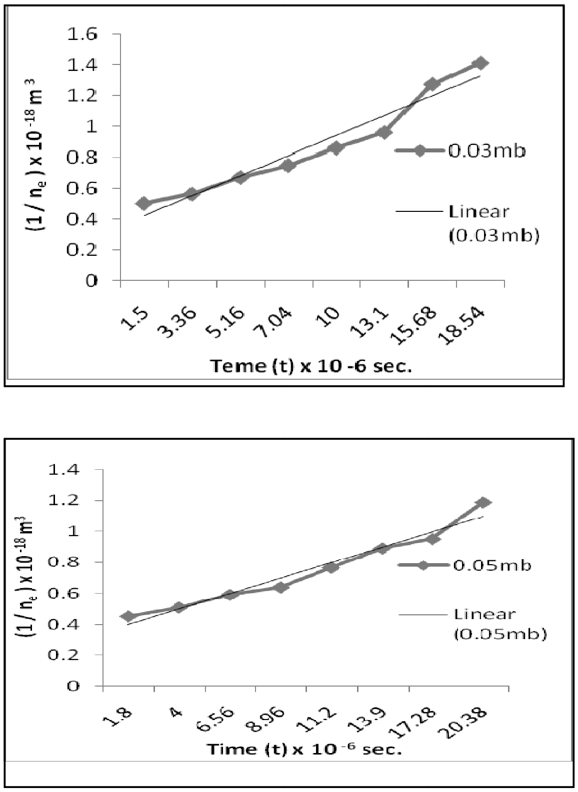


Figure -5 Variation of $1/n_e$ with t at base pressures 0.01mb, 0.03mb and 0.05mb

Under the conditions where diffusion can be neglected the analytical solution yields a proportionality of $1/ n_e$ to the decay time t, as is the case for recombination in plasma with a single type of ions [1]. We can assume that electrons are thermalized within few microseconds during which they have thousands of collisions. Because of the relatively high number density we can also assume that the recombining ions are rotationally and vibrationally relaxed to the temperature.

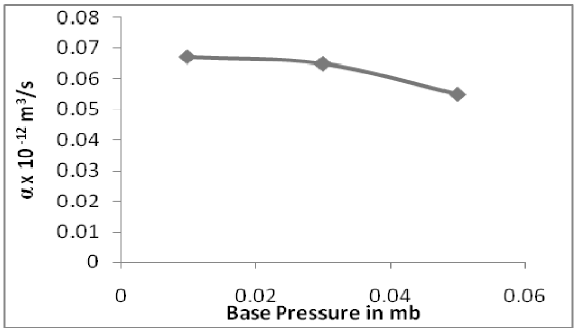


Figure -6 Variation of recombination coefficient with base pressure

It was shown that the recombination coefficient varies in time and depends on pressure and the loss of electrons is governed by dissociative recombination with complex ions, their density being dependent on pressure [6]. At low pressure, a hindered electron thermalization in collisions with molecules led to a delay in the plasma decay. Therefore, dissociative recombination of electrons with simple ions is important only for low pressures and only at the beginning of the decay; at longer times and at higher pressures electron loss is dominated by dissociative recombination with complex ions.

The recombination co-efficient α can be measured for the region where the electron-excited molecular collisional ionization is negligible and two body recombination is dominant. Figure –5 shows the variation of $1/n_e$ with t [1, 6, 7, 14,] whose slope gives α of the order of 10^{-12} m^3s^{-1} for pulsed plasma. The effect of the recombination is seen deep in the far away region from the PG where the neutral component is vanishing.

IV. CONCLUSION

We have designed a washer stacked plasma gun which is capable of producing high density plasma blobs moving with speed ~ 10^4 m/s. As the blob moves radially outward the particle density as well as drift velocity of the blob decreases. Since both charged and neutral components are present in the blob, recombination may be playing a dominant role for the blob motion. Due to high density the recombination may play an important role for balance between the plasma components. In this paper the recombination coefficient of the plasma blob is calculated by measuring the electron density (n_e ~$10^{18}$$m^{-3}$) and time (~μs) to move a particular distance. It is observed that the recombination co-efficient ~ 10^{-12} m^3s^{-1} is almost constant across radial distance from gun mouth and in that spatial length the electron-excited molecular collisional ionization is negligible, so two body recombination is dominant. At higher base pressures the higher value for electron density is observed while the recombination coefficient remains almost constant.

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