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Voltage-Current Measurement and Circuit Model Simulation to Characterize Electrical Properties of 40 kHz Capacitive Coupled Plasma (CCP) By Means of Pressure Variation

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Abstract

The change of plasma conditions caused by pressure increasing can affect the change of electrical characteristic of plasma and influence in each of plasma process is done, its change can be estimated by means of voltage-current characteristics from V-I measurement and simulation of the plasma equivalent circuit model. This study is investigation of electrical characteristic of 40 kHz Capacitive Coupled Plasma (CCP) from V-I measurement were combined by simulation of the plasma circuit model, the goal study is observation of the change of electrical properties of plasma in different pressure conditions. The simulation results show that the output of circuit model in the simulation are similar with voltage-current characteristic from V-I measurement in 300 mTorr-900 mTorr pressure conditions. From the characterization, can be concluded that the electrical properties of CCP can be estimated by using the resistor and capacitor values of circuit model in the simulation to get similarity characteristic with voltage-current from V-I measurement.

Keywords: 40 kHz Capacitive Coupled Plasma, circuit model, pressure

1. Introduction

To obtain the succesful operation of plasma is required equilibrium condition, which is said to be stabilized or controlled (Harry, 2010). The exact plasma conditions like pressure, temperature and discharge geometry can affect the way power is coupled to generate plasma (Spiliopoulos et al., 1996). The change of plasma conditions have to be observed to reach optimum value from our plasma system and the successful operation in each of plasma process. This observation can be done by the way characterization process of electrical properties of plasma based on electric measurement. After characterization process we will get a character which can be represented into electrical model and it can be used to determine stability parameters. An electrical models of plasma can be developed by experimental or numerical approximation, it has been used to predict transitions from different power-pressure regimes or the influence of different attaching gases on plasma impedance (Scanlan, 1991).

Several studies have been proposed to determinate the electrical characteristic of plasma, such as: (a)electrical characteristics of argon rf glow discharges in asymetric cell (Sobolewski, 1995), (b) electric current oscillations in parallel plate plasma reactor (Seebock, Deutsch, & Reuchle, 1993), (c) measuring current, voltage and impedance in rf plasma (Vender, 2001) can be used to predict the change of electrical properties of plasma discharges, but in every experiment method only suitable with several systems not all. The different systems have to use other methods due to the operational frequency of plasma generator or coupling process mechanism, if the output voltage of plasma generator is not sinusoidal wave, it will be difficult to measure the output impedance directly. So the simulation results of the plasma equivalent circuit model can be used to help characterization proses to know the change of electrical properties of plasma in different pressure conditions.

In this paper describes how to extract the electrical properties of 40 kHz Capacitive Coupled Plasma (CCP) from voltage and current measurement and compared it with the circuit simulation by using the plasma equivalent circuit model as known in the reference (Scanlan, 1991). The measurement and simulation results are used to

predict the change electrical properties in different pressure conditions. The circuit simulation is made in Circuit Maker 2000 as representation of the real model of electric components.

2. Experiment Method

The experiment set up as shown in Figure 1. There are vacuum system, LF plasma generator, parallel electrodes, pirani gauge sensor and V-I sensor. Plasma is generated by LFG 40/1000 Generator (Diener Electonic Inc.), has maximum power 1 kW and a maximum voltage up to 2 kV, the ouput signal of generator is square wave with 40 kHz fundamental frequency. Gas sample using nitrogen (99%), gas enter into chamber trough vent valve and it is evacuated by a 1.6 *l*/s rotary pump results base pressure about 10 mTorr. Gas flowing is regulated by set the flow rate valve to get pressure variation. The pressure condition was set by 100 mTorr, 300 mTorr, 500mTorr, 700 mTorr and 900 mTorr and power delivery into system is fixed at 40 watt. Plasma voltage was measured by resistor devider circuit has voltage ratio 100:1, plasma current was measured by voltage across the 10 Ω resistor that connected in series of plasma load. All data were acquired using a Digital Oscilloscope (Textonix TDS 100B) with sampling rate up to 40 MHz.

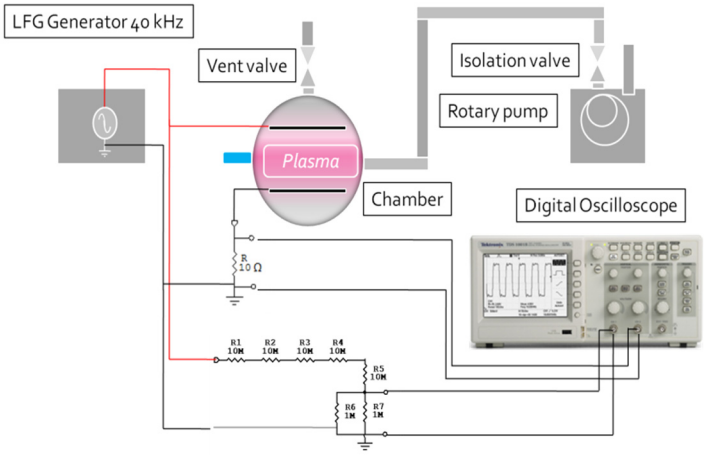

Figure 1. The schematic of experiment set up

3. Circuit Model Simulation

The electrical characteristics of Capacitive Coupled Plasma (CCP) in several studies were represented as the equivalent circuit model (Scanlan, 1991; Miranda, 1996). In this study we use Lieberman's Model to characterize the electrical properties of plasma from voltage-current measurement. The equivalent circuit model of plasma as shown in Figure 2 below.

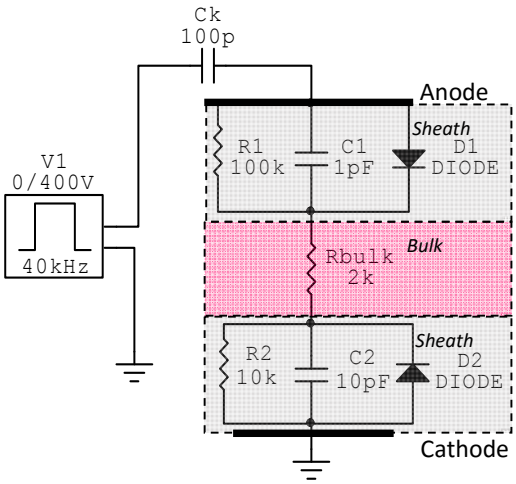

Figure 2. The Circuit model simulation

There are two regions of plasma which known as bulk and sheath region. The electrical properties in the bulk region is represented by resistor that represents the power dissipation due to collision, the resistance of this resistor depend on electron mobility in the bulk plasma. The sheath region of most the models is represented by capacitor due to charged particles array with any space and its capacitance is determined from variation of sheath thicknesses. The current transport phenomena in the sheath region is represented by a large parallel resistor which its resistance can be estimated experimentally, the different of sheath resistances create the different time characteristic of voltage and this phenomena can be observed in voltage measurement results. Asymmetry of the ion and electron current is represented by parallel diode, this current may be important when operating at low pressure where electron temperature have higher than gas temperature, so probability electron current more dominant than ion current.

In this circuit simulation, the LF generator was modeled by signal generator has square wave to drive parallel electrode (the plasma circuit model) with frequency 40 kHz and peak amplitude 400V. The coupling mechanism in this model use capacitor 100 pF is coupled between LF generator and the circuit model, its capacitance as same as capacitance value of the coupling capacitor in the reference (Scanlan, 1991). The different of pressure conditions as they were regulated in V-I measurement, were represented by different resistor and capacitor values in the simulation to give different characteristics of the voltage-current output which are similar to the voltage-current characteristic from V-I measurement.

4. Result and Discussion

The voltage characteristics of CCP in different pressure as shown in Figure 3. After pass the coupling capacitor, the square wave changes to be spike wave, this condition occurs to be caused by using input signal with low frequency. If plasma system as seen in the circuit model where capacitor coupling and resistor in the sheath plasma construct RC circuit with time characteristic τ=RC, the output voltage characteristic will depend on input signal frequency and RC constant. For input signal frequency was fixed, the different output voltage characteristic of CCP may be caused by decreasing of resistance in the sheath plasma.

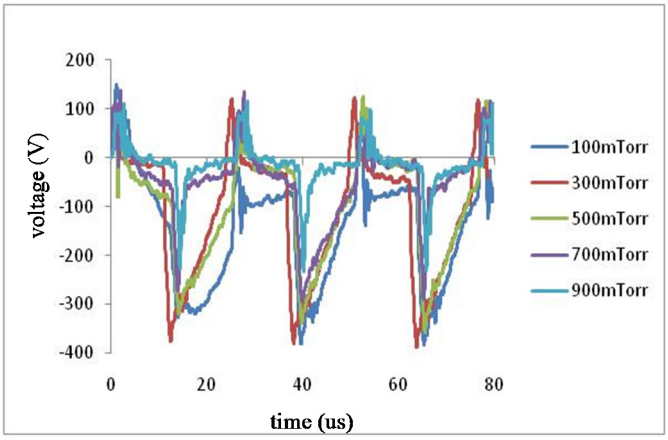

Figure 3. The voltage characteristic of CCP

As seen in Figure 3, shows that the output voltage of CCP has a variety of decay time in different pressure condition. This variation caused by different time for charging and discharging capacitor component in RC circuit (as discussed before). If the capacitance of coupling capacitor has the fixed value, so the different time characteristics of the output voltage are possible caused by the change of resistor value in the sheath regions, because the change of resistor value in the bulk region is very low then it does not influence significantly.

The current is characteristically as impulse wave and it has short time delay due to charging and discharging capacitor, it is similar with current of square wave in capacitor components. The current characteristic of CCP as shown in Figure 4. The increasing of pressure can effect to increase both CCP current and electron density, at the same time, the resistance in sheath region will decrease due to the increase of electron mobility, but current increasing is limited by surface area of ground electrode due to secondary electron product. Asymmetry form of the current is estimated by different capacitance in the sheath region. If capacitance in the positive sheath electrode is too small, the asymmetry will be positively, otherwise the asymmetry current will be negatively.

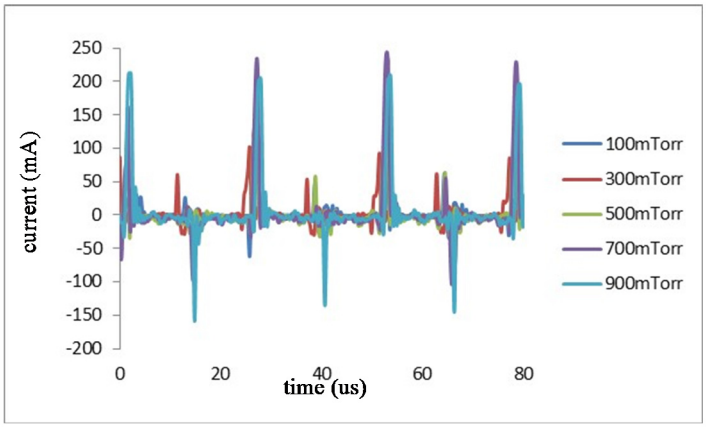

Figure 4. The current characteristic of CCP

The simulation is done by using two approximations: firstly, the change of resistor value in the sheath region is being to change the decay time of the output voltage of CCP. Secondly, the change of capacitor value in the sheath region is resulting to decrease the current output, the different capacitor value of both sheaths are affecting on asymmetry current form too. Therefore, to get different conditions as illustrated in pressure conditions, the simulation has been made in variety of resistor and capacitor values in the sheath region where their initial values were set as same as the values in the reference, then they are swept to give any characteristics of voltage-current which are similar with the voltage-current from V-I measurement. Whereas, the bulk resistor value was set by increasing or decreasing as magnitude of current has been occurred.

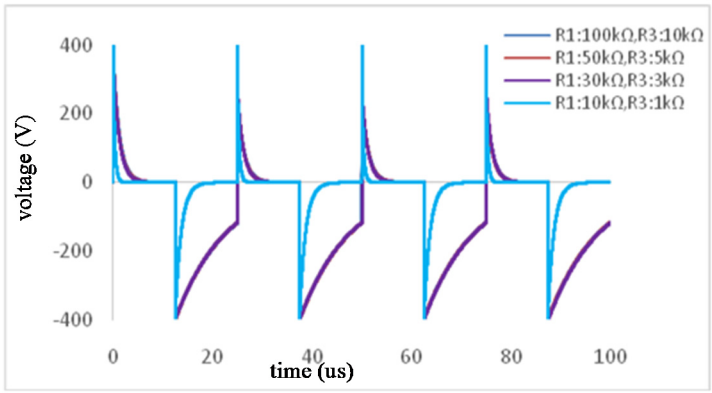

Figure 5. The voltage characteristic of CCP from simulation

The resistor values in the positive sheath electrode were set by 10 kΩ and 100 kΩ and the resistor in the ground sheath were set by 1 kΩ and 10 kΩ, whereas the capacitor value in the positive sheath electrode were set by 0.1 pF, 0.5 pF and 1pF and the capacitor in the ground sheath were set by 10 pF and 100 pF. The simulation results as shown in Figure 5 and Figure 6 have similar with the V-I characteristics from measurement. The output voltage characteristics from the circuit model simulation for 100 kΩ and 10 kΩ sheath resistor value (R1 and R3) are compatible with the output voltage characteristic from measurement in 300 mTorr-500 mTorr pressure conditions (Figure 3), whereas 10 kΩ and 1 kΩ of R1 and R3 values has similar with the voltage characteristic at 900 mTorr.

The current characteristic from the measurement has been changed in each of pressure conditions, so the capacitor and the bulk resistor were set by different values. The capacitor in the positive sheath was set by 0.1 pF to give similar characteristic with the current form in 100 mTorr-500 mTorr pressure conditions, similar way for 700 mTorr pressure condition it was set by 0.5 pF, whereas the capacitor in the ground sheath were fixed at 1pF. To give different of rate current, the bulk resistor was set by 2 kΩ, 1.5 kΩ and 1kΩ respectively in 300 mTorr, 500 mTorr and 700 mTorr pressure conditions. In higher pressure, where the change current of CCP occurs, the

capacitors in the sheath region (C1 and C3) were replaced by 1 pF and 10 pF, these values give result are similar with the current characteristic at 900 mTorrr pressure condition.

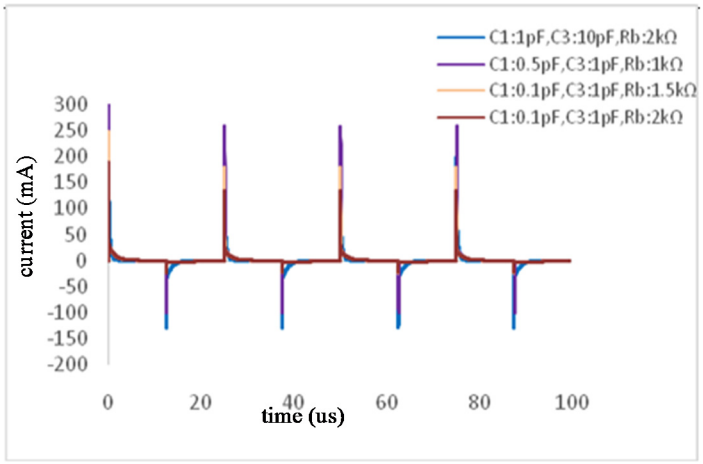

Figure 6. The current characteristic of CCP from simulation

From simulation result, we can predict that the change of the electrical properties in pressure range condition can be estimated using the resistor and capacitor values of circuit model in the simulation. In low pressure condition the resistor of sheath plasma is typically high, together with increasing both pressure and number of collisions due to high density of particles causes the increase of electron mobility and affect to decrease of resistance in this region. The voltage characteristics from measurement and simulation results show that the decrease of resistance in the sheath region occurs at 900 mTorr pressure. The resistance in the sheath plasma decreases close to ten smaller than the resistance at 300 mTorr, affects to different decay time characteristic of the output voltage of CCP. At same condition, the capacitance in the sheath plasma increase due to the increase of pressure, it caused by mean free path of particles be shorter in high density condition. The increase of capacitance occurs in each pressure increasing, affect to the current value and current waveform characteristic. For 300 mTorr-500 mTorr pressure conditions, the typical of current waveforms are asymmetric. This representation shows that capacitance in the positive sheath is lower than capacitance in the ground sheath, so in this condition the current values are dominated by decreasing of bulk resistance and capacitance in the sheath is constant relatively. But at 700 mTorr, capacitance in the positive sheath increase and affect to the capacitance ratio between the positive sheath and ground sheath to be small, so asymmetry current decrease as shown in Figure 4 and Figure 6. Finally at 900 mTorr, capacitance in the ground sheath to be ten higher than the capacitance before and creates symmetry form of the output current, at same condition resistance in the bulk plasma increase due to power dissipation and causes the decrease of current value.

5. Conclusion

The electrical properties of CCP can be characterized from voltage-current measurement by using the circuit model simulation. The change voltage characteristics due to the increase of pressure are estimated by different value of resistor components in the sheath plasma region. Whereas, the change of current characteristics are predicted by different value of capacitor components in the sheath and the change of resistor value in the bulk plasma. The increasing pressure causes resistance decreasing in sheath plasma relate to the increase of electron mobility and in otherwise the increase of capacitance caused by mean free path of particles would be shorter.

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