Chapter 5

Summary and Conclusion

Simulations of DC and RF glow discharges have been done using the XPDP1 code. The basic parameters in the simulations were set based on the system and experimental work by Safaai [3] carried out in the Plasma Research Laboratory, University of Malaya. Two sets of results were obtained from the simulation of the DC glow discharge in the experimental work. The first set of simulation was run with condition similar to the experimental work, which predicted a lower anode potential of around 150 V compare to the result of experimental work (around 200 V). In order to raise the anode potential to around 200 V, second set of simulation was obtained by changing the power supply voltage from 366 V to 450 V, and the value of SEEC from 0.2 to 0.09. Generally both sets of simulation results have good agreement with the experimental results. However, it is clear that the second set of simulation result has better agreement with the experimental result.

The electron energy distribution obtained from the simulation shows that the simulated electron energy distribution is not Maxwellian, but appears to be a Druyvesteyn distribution. Good agreement was obtained when attempted to compare the simulated electron energy distribution functions with those measured experimentally.

In term of electron temperature and electron density profiles, the trend of the simulation result is slightly different from the experimental result. Since the electron temperature and density of argon glow discharge plasma in experimental work were measured by using a single Langmuir probe which collected values at a localized point in the plasma, while the electron temperature (in eV) in the XPDP1 simulation was the average kinetic energy of the electrons in the plasma and large variation of the simulated electron density within the plasma was observed, the agreement between the experiment and simulation by order of magnitude is acceptable.

When looking at the power deposition profile and the plasma processes profiles which include electron-neutral and ion-neutral collisions, it was observed that all profiles are peak at the region near cathode.

Subsequently, the simulation model (XPDP1) was used to investigate on the effect of various parameters on the fundamental properties of low temperature plasma by using the parameters based on the experimental setup. All the simulations in this thesis were run in the voltage driven mode. The effects of the interelectrode gap length, operating pressure and operating voltage on the fundamental properties of the low temperature plasma were investigated.

The DC glow discharges with interelectrode gap lengths ranging from 2 cm to 5 cm were simulated. It was that the plasma sheath thickness remained the same, while the length of the positive column varied with the change of interelectrode gap length. The electron energy distribution functions were of the Druyvesteyn type for all the cases of interelectrode gap length within 2~5 cm.

For the effect of operating voltage, when the driving voltage was increases from 300 V to 500 V, the electron density, and electron temperature increased as well as the resulting discharge current. The electron energy distribution functions obtained from the simulation with discharge voltage within the range of 300~500 V were found to be of the Druyvesteyn type.

Finally the effect of operating pressure in the range of 0.5~10 Torr was investigated. From the simulation results, electron heating mode transition was observed in low pressure of 0.5 Torr (0.67 mbar). This electron heating mode transition occurrence was formed to change the electron energy distribution from a Druyvesteyn distribution to a Maxwellian distribution. In this Maxwellian distribution condition, the dominant electron heating mode is stochastic heating which is mainly localized in the sheaths region. The same phenomenon was observed by Sang-Hun Seo [26]. The evolution of electron energy distribution with pressure could be explained by low energy electron heating due to the Ramsauer effect in collisions between argon neutrals and electrons and the energy dependence of the electron energy diffusion coefficient [26].

Besides DC glow discharge, the simulation of the RF glow discharge was alone done for comparison. The RF discharge simulation was done by changing the DC voltage to AC voltage, and putting a non-zero magnitude of frequency (13.56 MHZ). It is observed that glow discharge with similar plasma condition can be obtained by using both DC power source and RF power source. Since the power source in the case of RF glow discharge is time-varying, one significant difference of RF glow discharge from DC glow discharge is that the potential at one of the electrodes is changing sinusoidally between positive maximum and negative maximum at a fixed frequency, while the other electrode is fixed at ground potential. Hence the discharge current is also changing with time in a sinusoidal manner. For the electron energy distribution functions and the distribution of cross section of other fundamental processes such as scattering, excitation and ionization, they remain almost the same although the discharge current is alternating as long as the discharge has reached steady state.

In general, it can be concluded that simulation is to complement both theory and experiment. The simulation results reported in this thesis reveal and predict the behavior of the plasma in the system with settings based on the experimental work by Safaai [3] in certain range of parameters. Further investigation and studies on the system can be done numerically and experimentally for exploration into new parameters, trying out new ideas, or recognizing new and unexpected behavior.

Future work

Further studies and investigation on the XPDP1 simulation model could be done at lower secondary electron emission coefficient (SEEC), e.g. SEEC 0.01~0.02, since it is likely to have such low value in an actual experimental work. By lowering the value of SEEC, the anode potential or glow voltage is expected to rise. In order to obtain an anode potential comparable to the experimental result, other parameters such as power supply voltage and resistance could be adjusted in a certain range achievable by the system, since the parameters from the existing experimental results are insufficient. This investigation or studies may lead to either a better agreement with the existing experimental results or recognize a new behavior which can be investigated experimentally by the system.

For RF discharges, investigation can be done to explore the effect of driving frequency. Electron energy distribution function is one of the most important characteristics in plasma processing, as all types of rate constant are determined by the electron energy distribution function. In order to control the plasma process and improve device performance, one should examine the electron energy distribution with external parameters. Electron energy distribution function changes drastically during the heating mode transition from collisional heating to collisionless heating or vice versa. According to S. J. You [27], at high frequency, the collisionless stochastic heating becomes inefficient heating mechanism. Electron heating mode is predicted to change from stochastic heating to ohmic heating when driving frequency increases. This investigation on the driving frequency can be done by using XPDP1, ahead of doing the comparable experiments. Simulation can be used to verify theory, as well as completing explanations obtained from the observations in an experiment.