# Monte Carlo simulation of radio-frequency breakdown in argon in electron dominated regime

M. Savić, M. Radmilović-Radjenović and Z. Lj. Petrović

*Institute of Physics, University of Belgrade, POB 68 11080 Zemun, Belgrade, Serbia*

This paper is dedicated to studies of the radio-frequency (RF) breakdown, performed by Monte Carlo (MC) simulation. Presented results include our first steps in developing the MC code that follows electron transport. Later on, effects of the electrode surface was examined and their influence on the breakdown voltage curve and spatial distributions such as concentration of electrons, electron energy distributions and rate of ionization have been determined.

## 1. Introduction

Capacitively coupled RF discharges are attracting an increased attention due to their wide applications in many technological processes such as plasma etching for semiconductor materials, thin film deposition and plasma cleaning. One of the crucial problem in optimizing plasma technology processes is determination of the plasma operating conditions which can be obtained from the breakdown voltage curve, known as Paschen curve.

We have performed calculations in RF argon discharge by using developed and tested MC code. [1]. Simulation conditions were based on the available experimental data [2].

## 2. Simulation technique

MC code includes electrons only and follows their transport across the gap between the electrodes. The background gas is argon which is shown to be good benchmark gas. Electrodes are plan-parallel and infinite. Gap between them is 23mm and frequency is 13.56MHz.

Starting number of electrons is 10 000 and their starting point is in the middle of the interelectrode gap. Their motion is due to RF field and they suffer collisions, including elastic scattering, ionization and two excitations.

Breakdown voltage curve, so called Paschen curve, is determined by trial and error, by observing how number of electrons evolve in time. The breakdown point is determined to be the one in which number of electron in time is rising in reasonable time interval. Left hand branch of the Paschen curve is obtained by fixing voltage point and changing pressures in similar way as in experiment [2]. Right hand branch of the Paschen curve is obtained by fixing pressure and changing the voltage until breakdown occurs.

## 3. Results and discussion

In figure 1 we compare the Paschen curves obtained by MC simulation (open symbols) and experiment (solid symbols) [2]. Since our simulation includes electrons only, agreement between these two curves is satisfying.

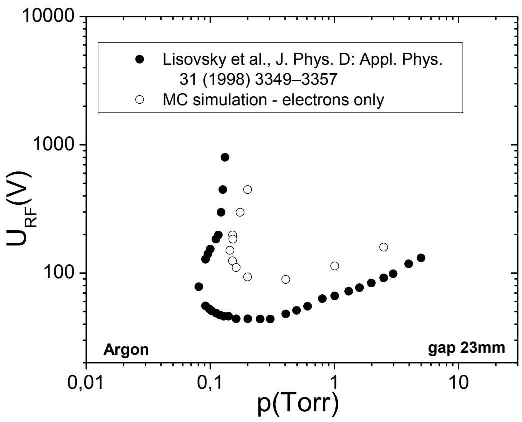


**Figure 1.** Comparison of the results obtained by MC simulation and the experiment data. Distance between electrodes is 23mm and frequency is 13.56MHz.

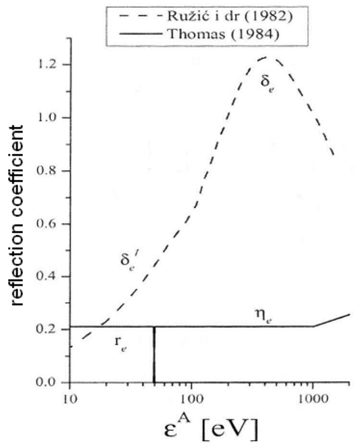


**Figure 2.** Coefficients for reflection and emission of secondary electrons from the electrode surface made of steel [3].

In our previous paper [3] we have examined double valued nature of the breakdown (Paschen like) curve in RF discharges, in electron dominated regime.

Next step in our MC code development is to add effects on the surfaces of electrodes. When electron hits the electrode electron can be elastically reflected, reflected with some losses of energy and incoming electron can eject secondary electron from surface. In figure 2 one can see data that we have used as input, for reflection and emission of the secondary electrons from electrode made of steel [4].

In figure 3 we have examined how surface effects change spatial plot of electron concentration, their energy and rates of ionizations without and with surface effects included.

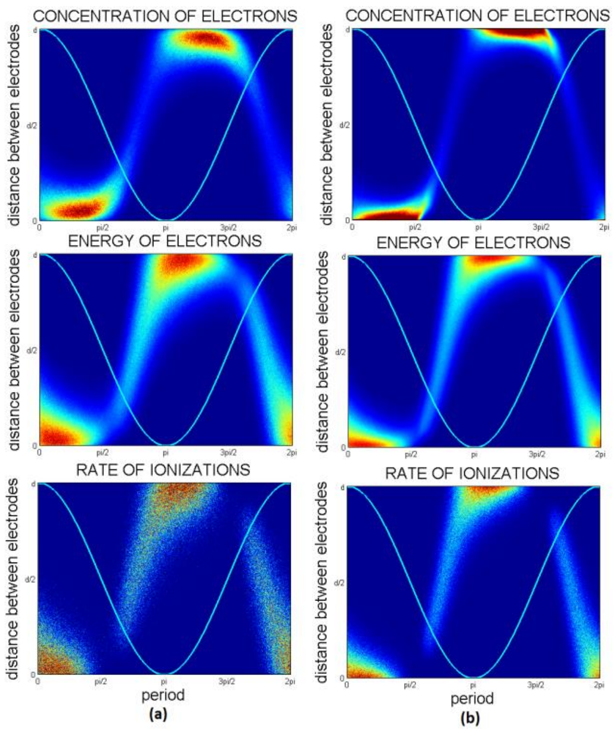


**Figure 3.** Electron density, electron energy and rate of elastic scattering and ionization, respectively, for initial conditions of U=447Vp=0.18Torr. (a) WITHOUT surface effects and (b) WITH surface effects. Calculations were carried out in argon at 13.56MHz .

In figure 3(a) spatial plots in the case when surface effects are not included are presented. Light blue line represents the applied field. As can be observed, electrons are pushed near electrodes due to strong field. Also, electrons with highest energies are concentrated near electrodes and in that area ionizations are more frequent as expected. Plots in figure 3(b) are similar with small adjustment in close proximity of electrodes due to large number of secondary electrons with mean energy of 2eV and reflected electrons with energy smaller compared to their incident energy.

## 4. Conclusion

In this paper we demonstrate how a Monte Carlo collision code can be used for investigation of the radio-frequency breakdown. Code was tested in electron dominated regime and points in which breakdown occurs were studied. By using spatial plots of electron concentration, energy and ionization rate we have explained particle behaviour between two plane-parallel electrodes. We have examined spatial plots without and with surface effects included.

## 5. Acknowledgement

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