# MONTE–CARLO SIMULATION OF THE INITIAL STAGE OF THE DC ELECTRICAL BREAKDOWN OF A GAS

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## 1. Introduction

The phenomenon of electrical breakdown of gases is intrinsically present in many experiments and applications of the plasma physics. It has been extensively studied for many years, both experimentally and theoretically. Some of the properties of gas breakdown, such as its short time scale and implicit instability of the process, made deeper insight extremely difficult to achieve. In recent years, the progress in computers opened another way to solve this problem by means of computer simulation.

Due to the fact that electrical breakdown is a non-deterministic process, the stochastic (Monte-Carlo) method, namely MCC–PIC, was chosen as the most appropriate. The availability of cross–sections for argon was the reason for selecting it as a model gas.

## 2. The model

Discharge volume is subject to a uniform electric field and at the moment $t = 0$ one or several initial electrons are released from the cathode. Being accelerated by the field, they multiply in number and electronic avalanche is formed. The by-products are the positive ions and excited atoms. Both can substitute to creation of secondary electrons at cathode, thus starting the series of avalanches. The evolution of system depends on experimental conditions (field, pressure, etc.) and can lead either to a discharge, either to extinction of free electrons.

Supposing low ionisation, only the first-order processes are taken into account. The collision between an electron and a neutral atom has one of the forms: scattering, excitation or ionisation. The elastic scattering is calculated using theoretical differential cross-sections, calcultaed by [1]. Cross section for ionisation and excitation are taken from [2]. To reduce the need for computer resources, calculations are done in the reduced phase space (Fig. 1).
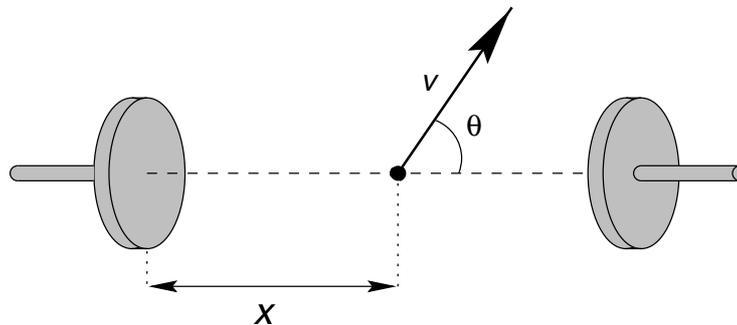


**Figure 1.** Configuration of the phase space.

For the used range of reduced electric field $E/N$ ($10^1$–$10^2$ Td) the collisions of positive argon ions with neutral background may be approximated by charge transfer collision with a

cross section measured by [3]. When the ion arrives at cathode, it may release by Auger de-excitation a secondary electron from metal surface.

Excited atoms, created by electron – neutral collisions, will return to their ground state and emit the electromagnetic quantum. Photoelectric work function of most common metals is about 4 eV, thus only irradiating of cathode by wavelengths in UV range can lead to emission of a photoelectron. The most important energy levels, capable of producing UV photons are those of $4s$ group. Being the lowest ones, they emit resonant photons, which are very easily absorbed by other argon atoms. In this case, the ordinary model of a diffusion of the radiation is not valid and we must use more precise theory of the resonant radiation propagation [4].

## 3. Results

Our code permits to simulate initial stage of the breakdown until a moment, when the number of particles is too large. Then, the fluid model should be used.

In Fig. 2 we can see the evolution of the ionic current at cathode. The simulated experimental conditions are: pressure $p=1$ torr of argon, inter-electrode gap $d=2.5$cm and the voltage $U=244$ V. When the space charge effects are negligible, we can launch many initial electrons at once (1000 in this case) to achieve better statistics. Sawtooth shape of current pulses is consequently flattened during the time and the mean value of the ionic current raises, as predicted by [5] for voltages above breakdown trehshold.
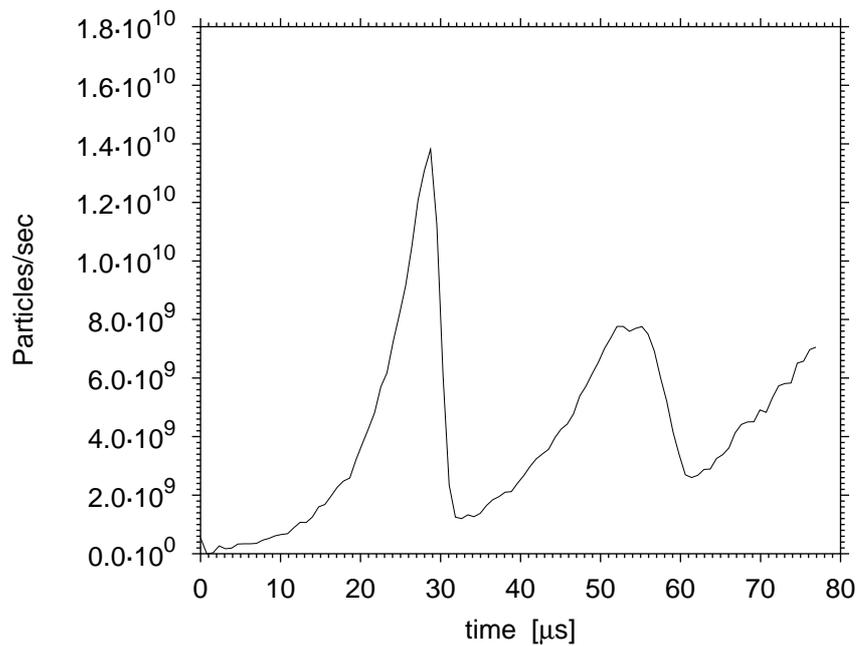


**Figure 2.** Temporal development of the ionic current at cathode.

Figure 3 shows the development of irradiation of cathode by resonant photons. One observes that back-feed via photons is much quicker, but the total number of photons reaching the cathode is much lower than in the case of ions. Its caused mainly by the fact, that photons propagate in all directions but the ions are forced by electric field to move to the cathode.

Integral of currents (i.e. number of particles collected or emitted by electrodes) is shown in Fig. 4. One observes that first photon appeared at $\triangle t=20$ ns and that the first ion appeared at
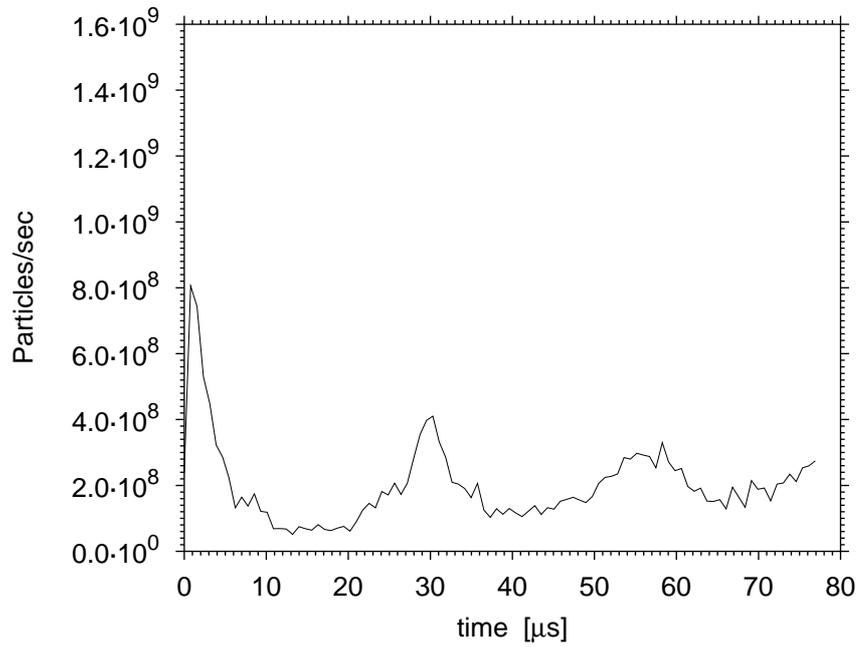
**Figure 3.** Dependence of irradiation of cathode by resonant photons on time.
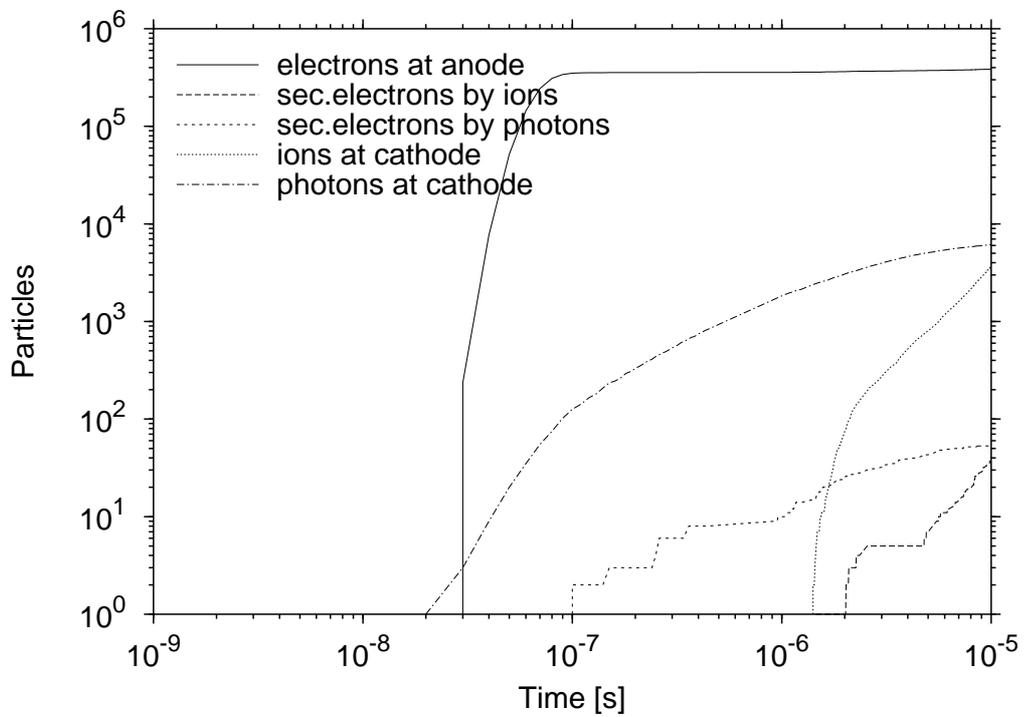


**Figure 4.** Total number of particles collected on cathode and/or anode.

$\triangle t = 1.5 \mu s$. Due to the fact that secondary emission coefficients are generally much less than unity,  the first secondary electrons appear much later.

## 4. Conclusion

The results show the very important role of UV photons for breakdown. During the initial stage, the secondary processes are dominated by photoelectric ones. But due to the geometric factor, only small portion of photons emitted in plasma will strike the cathode. In contrary, the ions are much slower (several orders of magnitude for interelectrode gap $d$=2.5 cm, pressure $p$=1 torr and voltage $U$=300 V), but their current becomes consecutively greater than flux of photons. Thus in the later stages of discharge development the exponential current growth is mainly caused by positive ions.

## References

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