Effect of space charge on electron emission in vacuum

B. Seznec[1,2], Ph. Dessante[2], Ph. Teste[2], T. Minea[1]

[1]LPGP, Laboratoire de Physique des Gaz et Plasmas, UMR 8578, CNRS, Univ. Paris-Sud, Université Paris-Saclay, Orsay CEDEX, 91405, France
[2]GeePs, Group of electrical engineering – Paris, UMR 8507, CNRS, CentraleSupelec, Univ. Paris-Sud, Sorbonne Universités, UPMC Univ Paris 06, Université Paris-Saclay, 91192 Gif sur Yvette CEDEX, France

Vacuum electron sources exploiting field emission are generally operated in direct current (DC) mode. The development of nanosecond pulsed power supplies facilitates the emission of high density electron bunches. The breakdown levels are taken as the highest value of the voltage avoiding the thermo-emission instability. However, the space charge limits the performance of these electron sources by decreasing the electric field and consequently the thermo-field emission at the surface of the electrode. A comparative study of the space charge effect for different protrusions, operated in DC and pulsed modes for a given voltage, shows the decrease of the electron current by a factor of 2 with respect to its value in vacuum (no charge).

1. Introduction

Controlled electron emission in vacuum is very interesting for applications such as high frequency amplifiers, accelerators, etc. Most of the sources of electron emission are localized thermo-field emitters, known as micro-protrusions (MP), present on the surface of the cathode. The electric field is locally enhanced at the MP tip where initially the cold field-emission occurs. This current flowing along the MP leads to the MP heating by the Joule effect. Consequently, the temperature increases, facilitating the electron emission by the thermo-ionic effect. If the temperature of the MP tip reaches the melting temperature, the cumulative effects develop thermo-emissive instabilities and the breakdown can occur. In this work, we present the numerical analysis of the effect of the space charge on the electron emission and the breakdown voltage.

2. Numerical model

This theoretical work focuses on the description of the electron emission of a field emitter. The problem is reduced to a 2D axisymmetric time dependent model. The electron emission is given on the MP surface with the Murphy and Good approximation [1]. The MP surface temperature, the electric field and the work function (ϕ=4.3 eV for titanium (Ti)) are the inputs of the Murphy Good model. The MP temperature is governed by the Joule heating effect The Joule heating effect is induced by the current inside the MP. A complete description of this part of this model is given in [3]. The electric field is obtained as solution of Poisson equation. The electron density is determined from the mean number of emitted electrons filling each mesh during their flight.

3. First results

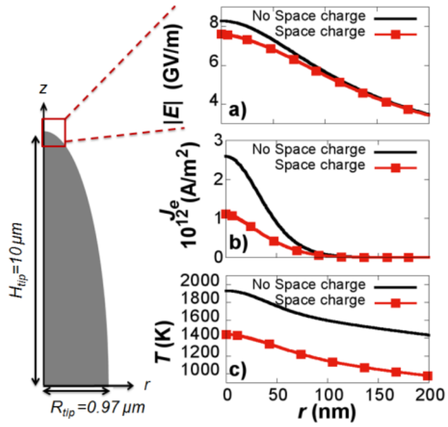

Fig.1. Electrical field (a), normal current density (b), and temperature (c) at the surface of the emission zone of a titanium elliptic MP for V_{cath} = -33.1 kV and d_{gap}= 0.2 mm with and without space charge.

For V_{cath} = -33.1 kV and d_{gap} = 0.2 mm, Figure 1.a shows a decrease (9 % at the tip) of the electric field at the MP surface when the space charge is considered. This decrease causes a reduction of the current density (2.5 times lower Fig 1.b) at the MP tip. As a consequence, the Joule effect is less important and the temperature at the surface decreases as well (Fig 1.c). Neglecting the space charge, the melting point ($T_{melting}$ = 1930 K for Ti) is reached whereas with the space charge considered, the maximum tip temperature is only 1400 K.

3. References

[1] E L Murphy *et al*. *Phys. Rev*.**102** (1956) 1464
[2] W B Nottingham Phys. Rev.**59** (1941) 906
[3] B Seznec *et al*. J. Phys. D: Appl. Phys. **49** (2016) 235502