Magnetic insulation of a space-charge dominated flow

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We report experimental results of magnetic insulation of a space-charge dominated electron flow in a low energy vacuum diode with ferroelectric cathode. Although in the absence of the magnetic field the high current densities are measured well above the estimated space-charge limiting current, the diode is shown to be insulated by a relatively low magnetic field controlled primarily by the anode voltage. A model which accounts for the two-dimensional nature of the electrons flow in the diode has been developed and it reveals the microscopic picture of the flow. From the space-charge dominated vicinity of the cathode, electrons leave the small emitting area towards the large radius anode ring, along a trajectory that is parallel to the applied magnetic field. Only in the close vicinity of the anode plane, their trajectory bends towards the ring. Good agreement between the experimental data and theory was found. © 2003 American Institute of Physics.

I. INTRODUCTION

More than a decade ago Gundel et al.1 reported on strong electron emission from ferroelectric ceramics. This discovery was followed by extensive research2–4 reporting various aspects of electron emission from ferroelectrics. In most cases, the research was motivated by finding an alternative emitter to be used in high-power microwave sources. A typical ferroelectric cathode consists of a ferroelectric “capacitor” with a uniform back electrode and a thin gridded one, facing the diode gap. Electron emission from the gridded surface follows the application of a triggering electric field of ~1 × 10^6 V/m and duration of 100–500 ns to the capacitor.

Basically, two different approaches have been adopted in order to explain the strong electron emission from ferroelectric cathode. The first approach focuses on variation of the internal properties of ferroelectric induced by an external field, while the second relies on electron emission from the surface plasma formed on the gridded electrode.5,6 The only quantitative model for strong electron emission from ferroelectric available to date was proposed by Schächter et al.7 and it explains a wide variety of experimental data which was presented in Refs. 8 and 9. Moreover it has been shown theoretically that even when the ferroelectric is treated as a linear medium with a very high dielectric coefficient, strong electron emission is expected,10 and high current densities above the space-charge limited current is feasible in a diode with a gridded dielectric cathode.11

Direct evidence of plasma formation on the surface of the ferroelectric cathode was given by observation of the plasma flashover with a fast charge-coupled device (CCD) camera12,13 and by direct measurement of the ion and electron currents.14 However the conclusive role of plasma on the electron dynamics in the diode gap is still to be determined. In fact several authors have shown experimentally that the ferroelectric cathode governs the electron dynamics in the first few microseconds for diode gaps on the orders of 1 cm.9,15,16

The external triggering of the electron emission by a relatively low voltage is the main advantage of ferroelectric cathode over field emission sources. Other advantages include the availability of high total current and relatively low vacuum requirements. One of the main characteristics of ferroelectric emission at low anode voltages is that the measured current exceeds Child–Langmuir (CL) limiting current by several orders of magnitude.5,9,17 It is important to emphasize that the CL limiting current is given only as a reference to the high current densities involved with strong electron emission from ferroelectric cathode, and by no means we consider the one-dimensional calculation of the limiting current to be valid in this case. We are contemplating to take advantage of this characteristic for construction of a low voltage (<1000 V) miniature coherent source of radiation. While the high currents associated with a low voltage ferroelectric emission guarantees high available power for radiation, the space-charge forces associated with this current may deteriorate the bunching process entailing considerably lower the conversion efficiency.

A possible solution for the bunching deterioration is using a cross field configuration. In a cross field device,18 like the magnetron, a magnetic field is applied perpendicularly to the dieode electric field. Above a certain value of the magnetic field (B_C) the electrons are magnetically insulated from the anode. Drifting of the electrons towards the anode occurs only when the initially uncorrelated electrons, become bunched losing some of their energy to the radiation field. As energy is lost, electrons approach the anode where the radiation field is stronger thus enhancing the energy conversion. It is therefore possible that a low energy cross field oscillator based on a ferroelectric cathode will allow us to investigate the important trade-offs between a space-charge dominated beam and high conversion efficiency.

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