Energy coupling in a diode with a dielectric-gridded cathode

A. Lahav, a V. Berezovsky, and L. Schächter
Department of Electrical Engineering, Technion-Israel Institute of Technology, Haifa 32000, Israel

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It is shown experimentally that electrostatic coupling between the ferroelectric ‘‘capacitor’’ and the anode-cathode gap controls the emission process in ferroelectric cathode. Three main quantities were demonstrated to be directly correlated to the energy stored in the ferroelectric: the energy in the diode, the diode impedance, and the delay of the peak (anode) current relative to the triggering time of the ferroelectric. The polarity of the triggering voltage does not seem to have a significant impact on the performance of the diode. © 2000 American Institute of Physics.

I. INTRODUCTION

Among the various electron emission mechanisms the emission using ferroelectric ceramics is the ‘‘junior’’ process. It was observed at very low current density levels (10 pA/cm²) in 1984 by Rosenman.1 Five years later, Riege and his co-workers at CERN demonstrated current densities that are 13 orders of magnitude higher. In 1990 Airapetov3 reported the highest current density so far when measuring order of 400 A/cm². From the early nineties a significant effort was devoted to the investigation of the emission from ferroelectric ceramics: Nation and his group4,5 at Cornell University has pioneered this activity in the US followed by Integrated Applied Physics (IAP)6 in collaboration with MIT, LLNL,7 and University of New Mexico.8 In parallel the topic has been investigated in Japan.9

In all the experiments performed so far the cathode consists of a ferroelectric ‘‘capacitor’’ with a uniform back electrode and a thin gridded one, facing the diode gap. Electrons emission is triggered by applying to the back electrode a fast electric field that is larger than the coercive field ~1 × 10⁶ V/m. Anode current occurs independent of the initial polarization state of the ceramic and irrespective if the ferroelectric undergoes phase-transition or not, however, its intensity is dependent on these characteristics. The electron emission was shown to be accompanied, in case of phase transition, by a burst of energetic electrons (25 keV)² and of microwave radiation in the GHz range.10 In this context it is important to distinguish between two cases: pure ferroelectric emission and assisted ferroelectric emission. As Riege et al. emphasize in Ref. 11, in the case of ‘‘pure’’ ferroelectric emission, electrons are emitted from the surface without the need of an anode voltage and this is a result of internal polarization reversal that releases the screening electrons from the surface. In what we call the ‘‘assisted’’ ferroelectric emission, the cathode takes advantage of the high dielectric coefficient of the ceramic, its nonlinear character as well as part of the screening charge to facilitate emission. It is the last regime that will be the focus of our investigation here.

A comprehensive theory that can explain all the experimental data observed is not existent as of today, however, several models have been developed throughout the years and they provide some insight into the physical processes that occur during emission. These models are summarized in Ref. 12. In the remainder of this section we shall highlight the main features and the limitations of the so-called redistributed cloud model (RCM). This model has been developed based on experimental data accumulated and reported in Ref. 4. Its main assumption is that whatever happens in the diode gap is controlled by the ferroelectric ceramic via electrostatic coupling. This is facilitated by the gridded electrode and significantly affected by the nonlinear dynamics (hysteresis) of the ceramic. For the description of the latter, RCM adopts the Weiss model for ferromagnetic materials and adapts it to ferroelectrics ceramics. With the polarization field known, it is possible to establish the charge on the surface at any instant. In particular, the change in surface charge relative to the equilibrium state can be established; for simplicity it is assumed that there is an excess of electrons on the gridded electrode facing the anode–cathode (A–K) gap.

The second basic assumption of this model is that a substantial fraction of this excess of charge redistributes in the A–K gap. In order to understand this redistribution process, envision the equilibrium state as a deep and steep potential well (delta function) that confines the free electrons which screen the polarization field from the external world; this potential well is located at the surface of the ceramic. When the polarization field is altered, this potential well becomes broader and shallower—in other words it expands into the A–K gap and with it, the electrons redistribute.

In zero order the exact distribution of the electrons is not critical since it is possible to evaluate the potential well distribution by solving the Poisson equation assuming zero voltage on the anode and cathode and ignoring the anode current. Subject to these assumptions the potential in a diode gap (g) is given by

\[ \Phi(x) = \frac{g\bar{Q}_{\text{gap}}^x}{3\varepsilon_0 g} \left( \frac{g-x}{g} \right)^2, \]

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1Electronic mail: lahav@tx.technion.ac.il

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