Electron emission from lead–zirconate–titanate ceramics

D. Flechtner, C. Golkowski, J. D. Ivers, G. S. Kerslick, and J. A. Nation

Laboratory of Plasma Studies and School of Electrical Engineering, Cornell University, Ithaca, New York 14853

L. Schächter

Department of Electrical Engineering, Technion—Israel Institute of Technology, Haifa 32000, Israel

(Received 16 August 1996; accepted for publication 1 October 1997)

We report extensive experimental data on electron emission from lead–zirconate–titanate ferroelectric ceramics. A 1–2 MV/m pulse is applied to a gridded ferroelectric cathode and diode currents of up to 120 A/cm² are measured across an A–K gap of 5 × 10⁻² m, with the anode at 35 kV. Both the current and the anode voltage pulse duration may extend to several microseconds. The measurements extend previously reported data by nearly two orders of magnitude in the diode voltage and by a factor of more than 3 in the diode spacing. Two major regimes of operation were identified. In the first ~1 μs the ferroelectric cathode controls the electron flow through the diode. Beyond this time plasma effects dominate the current flow. The results are of importance to the development of novel cathodes for high current electron beam generation. © 1998 American Institute of Physics. [S0021-8979(98)06401-9]

I. INTRODUCTION

Copious electron emission from a ferroelectric was first reported by Gundel and Riege in 1989. The electron emission is based on the change in the polarization of a prepared ferroelectric sample. In contrast to ferromagnetic materials which exhibit an external magnetic field, charge layers develop on any exposed surface of ferroelectrics, screening the remnant polarization (P_r ~ 0.1–0.5 C/m²) and substantially reducing any external field outside the ceramic. In what follows we shall refer to this as the equilibrium state. The emission of electrons is triggered by pulsing the ferroelectric with a rapidly rising electrical pulse providing an applied field comparable to the coercive field (~ 1 × 10⁶ V/m). The rapid change in material polarization leads to a surplus of free electrons on the gridded front surface of the ferroelectric, a fraction of which is repelled into the diode gap, enabling the diode current flow. When the polarization state of the material is altered by external means (e.g., by an applied electric field) the ceramic is considered to be off-equilibrium. A variant on this basic concept include the use of rapidly rising electrical pulses to switch lead–zirconate–titanate (PLZT), from the antiferroelectric to the ferroelectric phase. More recently, various groups have reported experimental measurements of emission at current densities on the order of 10⁶ A/m² (Refs. 2–4) and theoretical explanations for the high emission current densities have been proposed.

The use of ferroelectric materials as advanced cathode sources is appealing as they do not easily suffer from atmospheric contamination, operate at room temperature, are retraceable, and have a high enough brightness (10⁹–10¹¹ A/m² rad²) to be useful as electron beam sources for a variety of microwave devices. Many other applications have been proposed and are currently being studied, including: triggers for low pressure switches, thin film applications for flat panel display technology, and trigger sources for plasma lighting devices. In the remainder of this introduction we shall briefly describe the system under consideration, and outline the new results obtained.

In this article we present data describing the performance of diodes with ferroelectric cathodes operating at 1–50 kV and with diode spacings of up to 5 × 10⁻² m. These data extend the parameter range previously reported by factors of 50 in the voltage and more than 3 in the diode spacing. We show, consistent with our earlier results, that even at high voltages (up to 50 kV) the current–voltage (I–V) characteristic is, within a good approximation, linear. We also report on the effects of delaying the application of the diode voltage up to ~2.5 μs after triggering the ferroelectric source. We found that the anode current is strongly dependent on the time delay between the ferroelectric and anode voltage pulses. With short delays the beam emission is found to be controlled by the ferroelectric, whereas with long delays plasma fills the diode and dominates the current flow. The actual time to onset of plasma dominated flow will depend, of course, on a number of parameters including the diode spacing, and the amplitude and rise time of the trigger pulse on the ferroelectric. These observations, which shed light on the physics of the emission process, are combined with a detailed examination of the diode current rise time, amplitude, and even reversal, to ascertain the respective roles of plasma formation in the diode compared to ferroelectric processes in determining the current generated.

It should be noted that the results presented here apply only to commercial (Transducer Products Inc. or American Piezo Ceramics) PZT 55/45 [Pb(Zr₀.₅₅Ti₀.₄₅)O₃] and to a situation where the emission is enabled by the rapid pulsing of the material around a minor hysteresis loop. No attempt has been made to investigate the emission associated with antiferroelectric to ferroelectric phase transitions, such as that used in the work by Riege et al. In addition, no attempt has been made to interpret the phenomena presented here in terms of the microscopic processes which occur in ferroe-

---

*Electronic mail: jnation@lps.cornell.edu*