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Study on the characteristics of ferroelectric electron emission

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Abstract

Electron emission from ferroelectric cathodes is commonly suggested as an electron source for different applications due to its special characteristics such as high current density, easy treatment and operation. In this experimental research, the electron emission properties of ferroelectric cathodes made of lanthanum-doped lead zirconate–titanate (PLZT) ceramic are studied. The electron beam spot shape was recorded via proximity-imaging techniques.

Keywords: D. PLZT; E. Functional applications; Polarization reversal; Plasma

1. Introduction

Electron emission from ferroelectrics was noted by Miller and Savage [1]. Early experimental results of that period were mainly weak electron emission. Strong electron emission of more than 100 A/cm^2 from ferroelectric ceramics was observed by Gundel et al. and reported in 1989 [2]. Since then many groups have investigated mechanisms for ferroelectric electron emission [2–8]. Gundel et al. explained that electrons were emitted from the bare ferroelectric surface due to spontaneous polarization switching. In the last decade much attention has been focused on ferroelectric plasma cathodes. It has become generally accepted that the source of intense emission is the plasma formed on the surface of the ferroelectric ceramics as a result of incomplete discharges. These discharges are initiated in triple junctions (metal–vacuum–ferroelectric junctions) by the application of a driving pulse between the rear and front electrodes. Compared with traditional cathodes, ferroelectric cathodes have many advantages, such as easy manufacture, low cost, room temperature and low vacuum operations, high emission current density (the theoretical value could be up to 10^5 A/cm^2 [2]), which make ferroelectric cathodes into attractive cold electron emission sources and have prospective applications in strong pulsed-electron beam technology. In this paper, the details of emission current dependent on triggering voltage and extraction voltage are reported and the electron beam spot shape was recorded via proximity-imaging techniques.

2. Experimental

The samples used in the study are PLZT 9/65/35 ferroelectric ceramics, where the numbers refer to lanthanum, zirconium, and titanium atomic percentage, respectively. It was prepared via conventional mixed-oxide processing technique. Silver electrodes were made on both sides of the ceramic disk by the technique craft of the silk screen printing, which is 21 mm in diameter and 1 mm in thickness. As shown in Fig. 1, the rear electrode is a solid circular electrode of 15 mm in diameter positioned at the center of the disk and the front electrode is a striped grid surrounded by a metal ring with an outer diameter of 17 mm and inner diameter of 11 mm. Both the width of the grid stripes and the space between the stripes are 200 μm, thereby the total exposed area on the surface of this sample is about 0.47 cm^2.

The experimental setup for electron emission is shown in Fig. 2. The ferroelectric cathode samples were placed in the vacuum chamber with the grid electrode (GE) side facing the flat graphite collector (GC). The GE is kept at ground potential when the driving pulse is coupled to the rear-electrode (RE). The distance between the sample and GC is 7 mm. A DC high-voltage generator is connected with the anode to provide an

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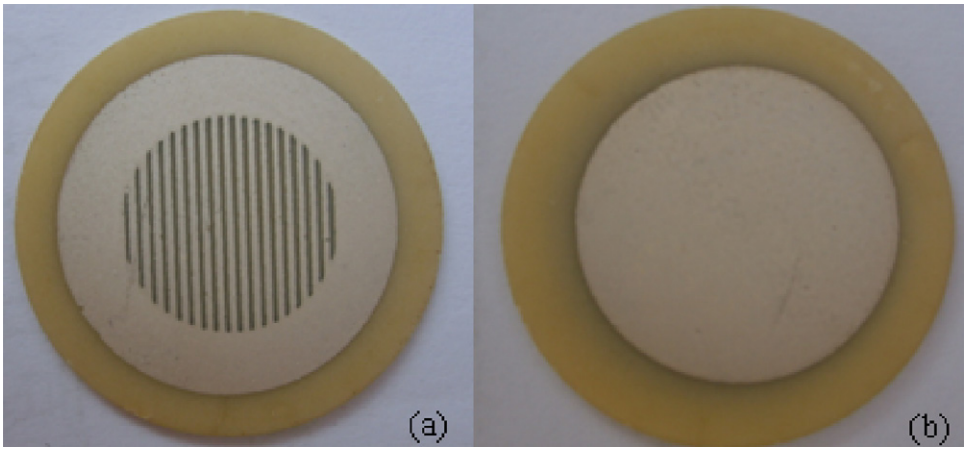

Fig. 1. Sketch of cathode electrodes (a) front electrode, (b) rear electrode.

external accelerating voltage through the diode gap. A Pearson current monitor model 65/85 is used for measuring the emission current from the surface of ferroelectric sample. In the electron emission experiments, the cathode is subjected to unipolar positive rectangular voltage pulses (<2.2 kV) with a fast rise time (t_{rise} = 1 ns ± 30%) generated by a generator. A two-channel digital real-time oscilloscope (Model TDS 460, Tektronix) with a 50 MHz bandwidth is used to monitor the voltage drop across the ferroelectric cathode sample and the emission current. All experiments are performed in a vacuum of $\sim 10^{-3}$ torr and at room temperature.

3. Results and discussion

3.1. Emission current with no extraction voltage

Fig. 3 shows a typical emission current waveform with no accelerating voltage and it behaves a single current peak with the amplitude of 1.11 A when the triggering voltage is 1251 V, the emission current density is 2.36 A/cm^2. The emission current occurs at the end of the pulse voltage.

3.2. Emission current dependent on extraction voltage

The DC extraction voltage is loaded to anode GC. The pulse voltage kept unchanged at 1285 V. It can be found in Fig. 4 that the emission current shows exponential rise along with the increase of extraction voltage when it is less than 400 V and shows linear growth when it is greater than 400 V. The mathematical fitting relationship can be expressed as

$$I = -2.3 + 3.0 \times e^{U/158} \quad (U < 400\,\mathrm{V}) \tag{1}$$

$$I = -6.78 + 0.08 \times U \quad (U > 400\,\mathrm{V}) \tag{2}$$

Here I and U refer to the current amplitude and extraction voltage respectively.

Fig. 5(a)–(d) shows typical emission current waveforms with a positive triggering voltage of 1285 V and a DC extraction voltage of 20 V, 40 V, 60 V, 100 V respectively. It can be found that there are two distinguishable electron emission pulses per triggering voltage when extraction voltage is less than 100 V as shown in Fig. 5(a)–(c). Pulse 1 occurs during the application of a positive triggering voltage. Pulse 2 occurs at the end of triggering pulse. The amplitude of pulse 1 has a fast increase than that of pulse 2 with the increase of extraction potential. When extraction voltage $U > 100$ V, the two emission pulses merge, and a single electron emission current pulse with a rather high amplitude and duration is observed. Fig. 5(d) shows a typical current waveform with extraction voltage $U = 100$ V.

Based on the experimental results, we suggest that domain movement near the triple junctions under the application of the

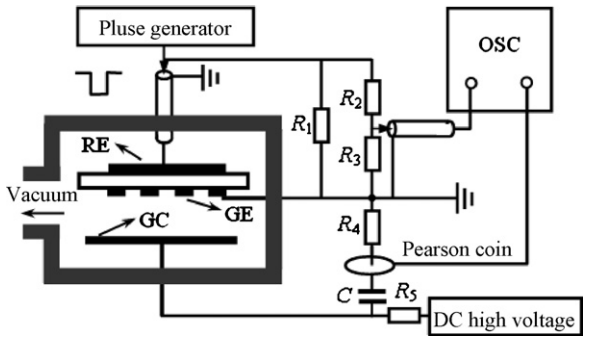

Fig. 2. Experimental setup of electron emission.

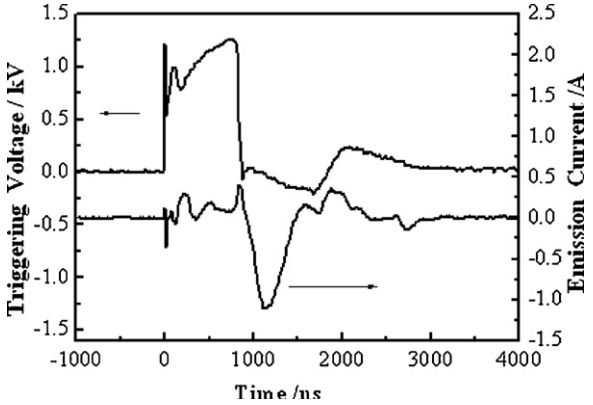

Fig. 3. Typical emission current waveform with no extraction voltage.

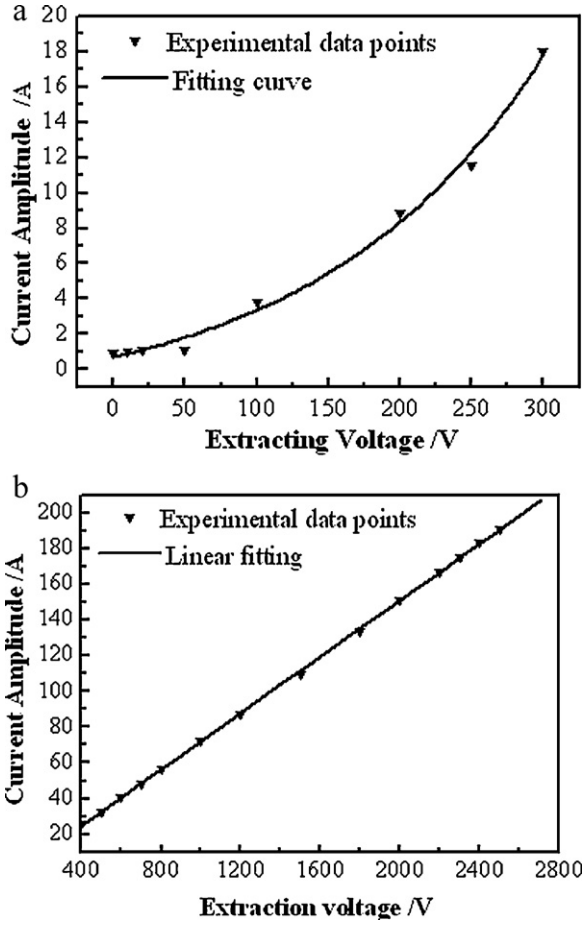

Fig. 4. Emission current dependent on extraction voltage (a) $U < 400$ V, (b) $U > 400$ V.

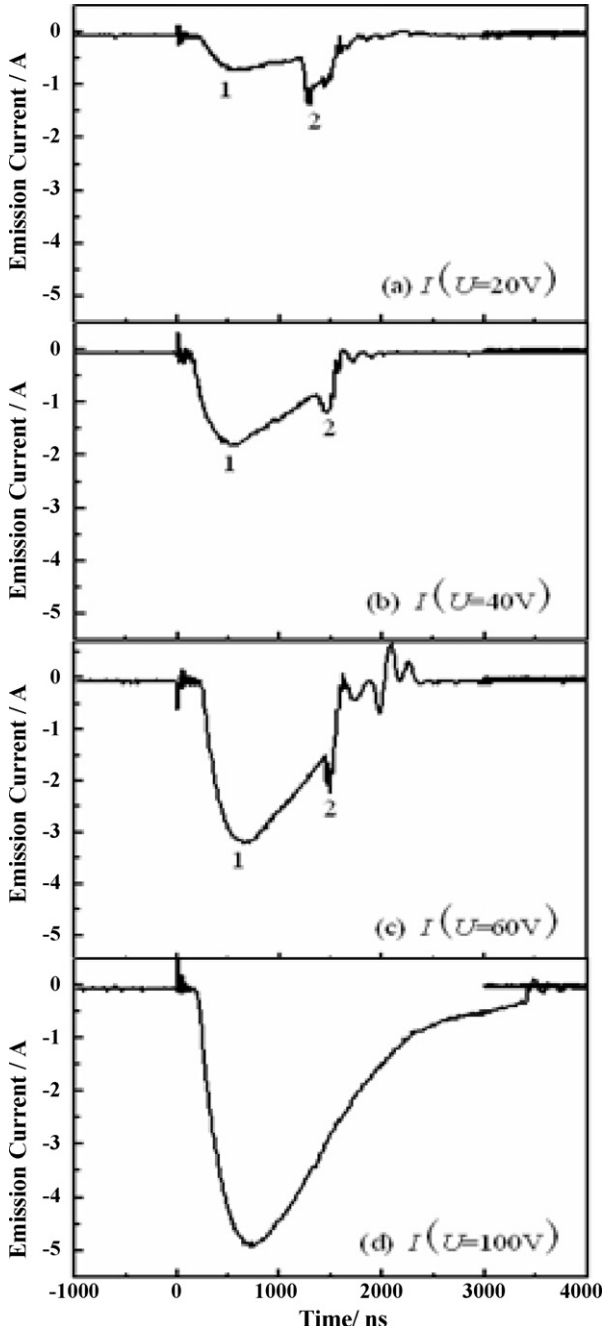

Fig. 5. Typical current waveform at different extraction voltage.

triggering voltage pulse may be responsible for the emission from PLZT sample. In the triple junction region, the electric field can be roughly estimated as $E = \varepsilon_r U_0/\delta$ [7], here U_0 is the triggering voltage, δ is the sample thickness, and ε_r is relative dielectric constant. The parameters mentioned above of the ceramic sample tested in the experiment are 1285 V, 1 mm, and 4000, so the electric field in these regions can be 5.14×10^6 V/mm, which is sufficient to induce local field emission in the vicinity close to the triple junctions, and provide initial emission electrons for the formation of plasma.

When the cathode is undertaken a unipolar positive voltage pulse, a tangential component of the electric field near the triple junctions should appear as well as normal component relative to the front surface of the ferroelectric cathode. The tangential electric field may promote the formation of flashover discharge and the initial plasma can continue the process of surface plasma formation. The abundant plasma electrons are pulled out of the surface to form pulse 1 with duration of several hundred nanoseconds. The plasma expands over the entire bare ferroelectric area under the action of the tangential the electric field. For plasma expansion with a typical velocity of ~2 cm/μs [8], pulse 1 has a relatively long duration. A certain amount of plasma electrons are attracted by the non-compensated positive charge of the domains. At the end of the triggering pulse, domain reverse, these electrons are ejected into the vacuum due to the accelerating field and repulsive force of the domains, which forms the sharp emission pulse 2, so pulse 2 is induced by polarization reversal. This means that electron emission both because of polarization reversal and plasma format ion can be collected.

3.3. Recording of electron beam spot shape

The experiment was conducted in the condition with a positive driving voltage of 1.0 kV and a repetition frequency of 80 Hz and the extraction voltage is 2500 V. In the experiment, a

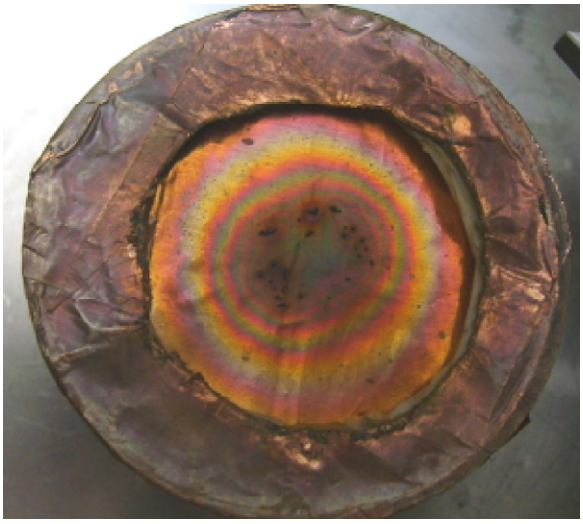

Fig. 6. Electron beam spot shape.

double-side conductive copper paper was coated on the graphite collector to record the electron beam spot shape, which is shown in Fig. 6. It was photographed after 2.8×10^5 shots.

4. Conclusions

Stable copious emission of energetic electrons from a ferroelectric ceramic is obtained when the front electrode is a uniform pattern of unconnected metal patches contained within a metallic ring. Extraction voltage plays a decisive role for high emission current. The electron beam spot pattern was recorded clearly by a double-side conductive copper paper.

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References

[1] R. Miller, S. Savage, Motion of 180° domain walls in metal electrode barium titanate crystals as a function of electric field and sample thickness, Journal of Applied Physics 31 (4) (1960) 662–669.
[2] H. Gundel, H. Riege, J. Handerek, K. Zioutas, Low-pressure hollow cathode switch triggered by a pulsed electron beam emitted from ferroelectrics, Applied Physics Letters 54 (1989) 2071–2073.
[3] M. Miyake, S. Ibuka, K. Yasuoka, S. Ishii, Effects of polarization reversal and surface conditions on the ferroelectric electron emission, Japanese Journal of Applied Physics 36 (1997) 6004–6007.
[4] D. Shur, G. Rosenman, Ya.E. Krasik, Surface discharge plasma induced by spontaneous polarization switching, Applied Physics Letters 70 (1997) 574–576.
[5] D. Shur, G. Rosenman, Two modes of plasma-assisted electron emission from ferroelectric ceramics, Journal of Physics D: Applied Physics 32 (1999) L29–L33.
[6] D.N.J. Shannon, P.W. Smith, P.J. Dobson, M.J. Shaw, Dual mode electron emission from ferroelectric ceramics, Applied Physics Letters 70 (1997) 1625–1627.
[7] Y. Krasik, A. Dunaevsky, J. Felsteiner, Formation of discharge plasma on the surface of cathodes with different dielectric constants, Journal of Applied Physics 85 (1999) 7946–7951.
[8] A. Dunaevsky, Ya.E. Krasik, J. Felsteiner, A. Sternlieb, Electron diode with a large area ferroelectric plasma cathode, Journal of Applied Physics 90 (2001) 3689–3698.