

## Electron Emission into Vacuum from PZT Ferroelectric Ceramics Induced by Polarization Reversal

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Electron emission into vacuum from a thin plate of PZT ferroelectric ceramic has been observed by applying comparatively low pulse voltage. This electron emission has been obtained even in poor vacuum of less than  $10^{-1}$  Torr. The lowest applied pulse voltage is 75 V, and the largest emission current in a sample having  $2.1 \text{ mm}^2$  electrode is 30 mA. These electrons are considered to be emitted out from the surface of the ferroelectric material near the electrode by very high field induced by polarization reversal. This electron emission can be applied for electron emitter in vacuum electronic devices such as micro triode and flat panel display.

### §1. Introduction

Recently, electron emission from cold solid in vacuum has attracted much attention for applications to vacuum microelectronics such as micro triode and flat panel display. In the vacuum microelectronics, various kinds of electron emitters have been developed by many workers.<sup>1)</sup> For example, field emitter arrays are studied vigorously by fabricating sharp micro-corn and micro-edge.<sup>2)</sup> On the other hand, electron emission from single crystal of ferroelectric materials such as  $\text{BaTiO}_3$  and  $\text{LiNbO}_3$  has been studied.<sup>3)</sup> A variety of physical parameters—temperature, light, stress, and their combinations—were used to cause fast polarization changes and electron emission from a ferroelectric surface. However, since the emitted current density was at most  $10^{-9} \text{ A/cm}^2$ , these could not be applied to the electronic devices. In recent years, large amount of electron emission has been obtained from surface of PZT or PLZT ceramics excited by an electric field.<sup>4)</sup> In this case, the emitted current density reached several  $\text{A/cm}^2$  but a high voltage pulse of some kV should be applied to induce a polarization reversal and emit many electrons. We have also tried to reduce the applied voltage by improving the sample structure from viewpoint of applications to the microelectronics devices.

In this report, we have studied a series of experimental data of the electron emission from thin plate of PZT ceramic at applied voltage lower than that of the reported.

### §2. Electron Emission from ferroelectric and Measurement System

Figure 1 shows schematic illustration explaining electron emission from ferroelectric material. (a) When dielectric polarization is previously oriented upward, electrons and ions exist on the surface of ferroelectric material around the edge of top electrode to compensate the polarization. (b) When enough voltage is applied to the bottom electrode, the polarization is rapidly reversed

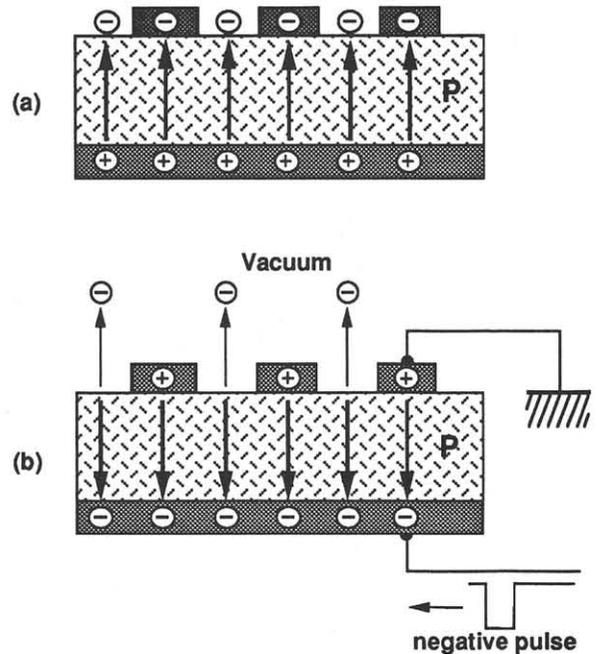


Fig. 1. Polarization and charge in ferroelectric material (a) before and (b) after negative pulse application.

not only under the electrode but also near the edge of the electrode. Then, the surface charge near the electrode suffers a high electric field by change of dielectric displacement. For example, this electric field is estimated to about 250 MV/cm when remanent polarization of 10  $\mu\text{C}/\text{cm}^2$  is reversed. Then charge that is bound at surface states on the ferroelectric material near the electrode will go out into vacuum. Electron is considered to be main part of the emitted charge as its mass is much lower than masses of ions.

Figure 2 shows the experimental set-up for measuring the emitted electron. The samples are PZT ceramic plates of about 30~45  $\mu\text{m}$  thickness, which are covered with evaporated-Al electrodes, solid(SE) on one face and grid(GE) on the opposite face. The grid electrode(GE) has stripe configuration of  $7 \times 0.3 \text{ mm}^2$  and the spacing between the stripes is 0.2 mm as shown in Fig. 3. The sample was not electrically poled before the electron emission experiments. A set of pulses, a negative pulse following a positive pulse, was applied to SE for orienting the polarization up and down successively.

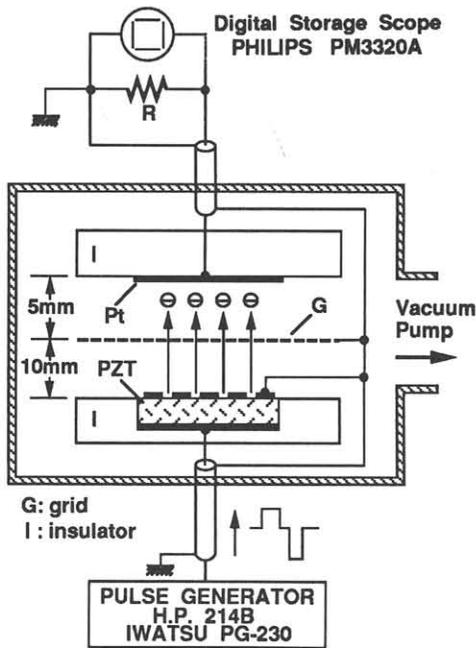


Fig. 2. Experimental arrangement for electron emission measurement.

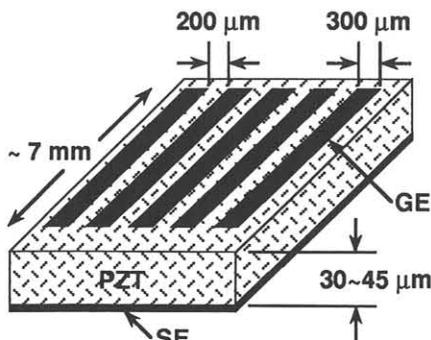


Fig. 3. The sample structure.

GE was connected to ground to suppress electromagnetic radiation. The emitted electrons were collected on Pt plate collector of 11.3  $\text{cm}^2$  which was set over the PZT sample, and measured as voltage signal through a register by digital storage oscilloscope. The grid G consisting of metal mesh is connected to ground. This grid is an electromagnetic shield to eliminate noise originating by the pulse application, and is set between the sample and Pt plate. Part of electrons were collected by grid G and the rest through this grid reached at the Pt collector.

### §3. Results

Figure 4(a) shows an example of oscilloscope traces of the emitted current(top) and the applied negative pulse of 240 V(bottom). The pressure of the vacuum chamber was  $1 \times 10^{-2}$  Torr. The electron emission happens when the negative pulse reaches about 50 V. The signal of the emitted current appears at about ~100 ns after the start of the applied negative pulse. The electron emission could not be observed in atmosphere(Figure. 4(b)). The lowest pulse voltage for this emission is 75 V and the largest emission current is 30 mA in the sample having 2.1  $\text{mm}^2$  electrode(GE).

The emitted charge of the PZT sample of 30  $\mu\text{m}$

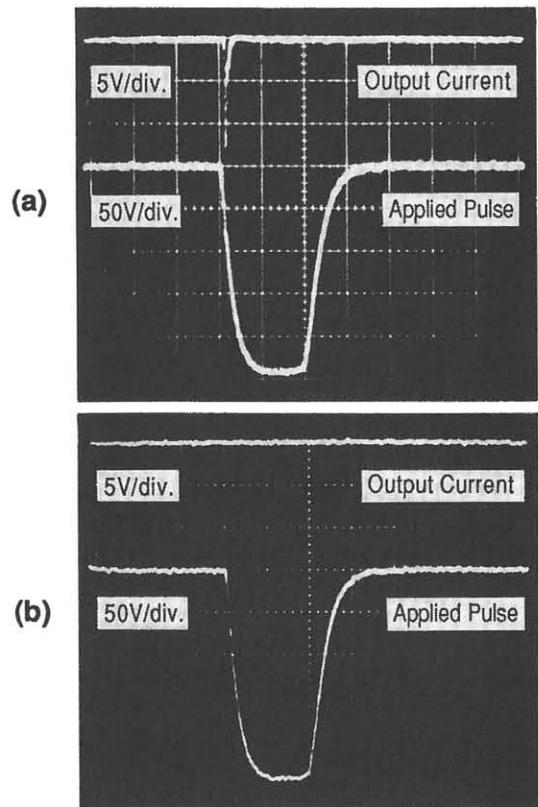


Fig. 4. Oscilloscope traces of the emitted current (top) and applied negative pulse (bottom) (a) at  $10^{-2}$  Torr and (b) at atmosphere. The time scale is 5  $\mu\text{s}/\text{div}$ .

thickness as a function of applied pulse voltage is shown in Fig. 5. The pressure of the vacuum chamber was  $5 \times 10^{-3}$  Torr. The charge begins to be emitted at a threshold of about 75 V (25 kV/cm), and increases rapidly as the applied voltage becomes high. Saturation of the emitted charge was not found in this experiment, and large amount of the emitted charge can be expected at high applied voltage below a breakdown voltage. Taking account of the effective voltage for starting the emission, this curve is explained by the charge calculated from D-E hysteresis of the sample.

Figure 6 shows the emitted charge as a function of the pressure of the vacuum chamber. The PZT sample is 45  $\mu\text{m}$  thick and the applied voltage is 175 V. It appears that the emitted charge is approximately constant in high vacuum below about  $10^{-4}$  Torr, whilst begins to increase above  $10^{-4}$  Torr, probably because of increase of charge supplied to the surface of the sample by ionization due to the emitted electron. The emitted charge was not observed at more than  $10^{-1}$  Torr because electrons were scattered so much by dense molecules of air.

The emitted charge as a function of the GE electrode length is shown in Fig. 7. The PZT sample is 45  $\mu\text{m}$  thick and the pressure of the vacuum chamber was  $2 \times 10^{-3}$  Torr. Applied pulse voltage are 175 V and 240 V. If electrons are emitted from the edge around GE electrode by polarization reversal, the emitted charge must be proportional to the GE length. The obtained charge increases with increase of the GE length below about 3 mm. Rise time of the applied pulse become long with increase of capacitance of the sample. So it is considered that slow rise of the applied pulse might induce the saturation of the emitted charge.

#### §4. Summary

The electron emission from PZT ceramic induced by electric field has been investigated at low applied voltage whose minimum is 75 V. There is a threshold in electric field of the electron emission, and the emitted charge increases rapidly as the applied voltage becomes high. The emitted charge is observed less than  $10^{-1}$  Torr and does not depend on the pressure in high vacuum. As the electrode length increases, the emitted charge also increases but saturates above about 3 mm.

#### References

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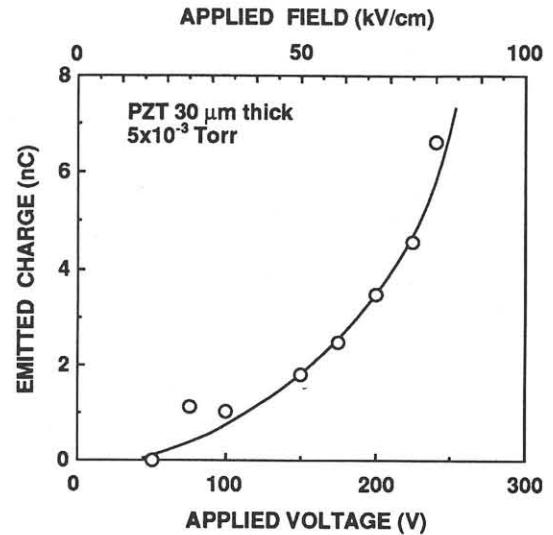


Fig. 5. The emitted charge as a function of the applied pulse voltage.

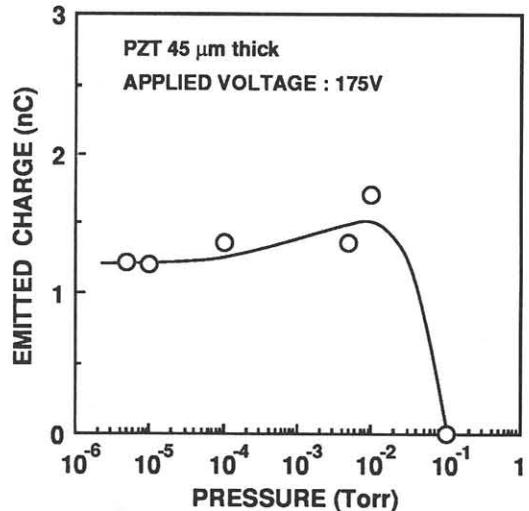


Fig. 6. The emitted charge as a function of the pressure of the vacuum chamber.

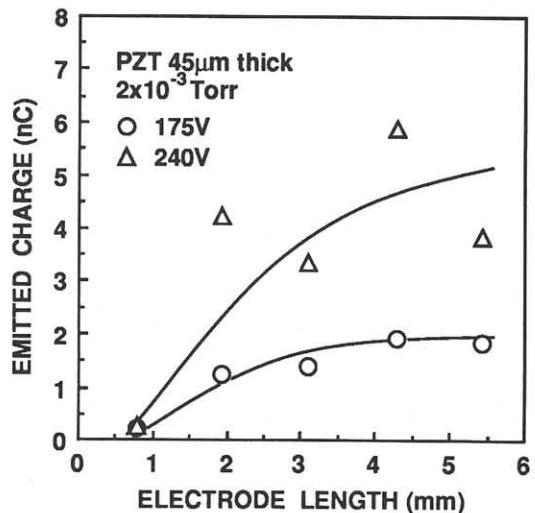


Fig. 7. The emitted charge as a function of the GE electrode length.