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Energy distribution of electron emission from L-α alanine doped TGS single crystals

K. Biedrzycki

Institute of Experimental Physics, University of Wrocław, Max Born 9, 50-204 Wrocław, Poland

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Abstract

Energy distribution measurements for electron emission from L-α alanine doped TGS single crystals which have shown considerable internal bias, induced by a drive ac electric field with an amplitude of 10^3–10^4 V/cm, have been carried out. The energy spectra observed for electron emission produced under negative charging of the emitting sample surface due to switching of the spontaneous electric polarization, differ from that detected for a positive one. The influence of internal bias on these energy spectra is also evidenced.

Keywords: A. Ferroelectrics; D. Electron emission

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1. Introduction

The first experimental results concerning electron emission under pyroelectric conditions (thermally stimulated electron emission) from ferroelectrics into a vacuum were reported in the seventies [1–3]. Under these conditions, electron energies exceeding a few tens of keV and even a hundred of keV have been obtained in single TGS [2,4], $LiNbO_3$ [5] and $LiTaO_3$ [6,7] crystals. The energy of these electrons is gained owing to a potential difference generated between a negatively charged crystal surface and detector. On the basis of this effect, a simple electron and/or X-ray generator can be made by heating (cooling) pyroelectric material in a vacuum, for example, such as $LiNbO_3$ [5] or $CsNO_3$ [8].

Electron emission from ferroelectrics into a vacuum can also be generated under an external electric field excitation. At first, a weak electron emission from $PbGe_3O_{11}$ [9] and TGS [10–12] crystals was observed. Later, an electron emission with a current density about a few A/cm^2 was produced on PLZT ceramic samples [13]. Over the last ten years, many research groups all over the world have investigated these electron emission phenomena because of their potential applications in accelerator technology and vacuum electronics [14]. The so-called ferroelectric cathodes are able to emit electron currents with densities up to a few hundred A/cm^2, operate at MHz repetition rate, produce electron beams involving electrons with energy of the order of 10^2–10^3 eV without any extraction potential, etc.

Up to now, there are only a few literature data known describing detailed kinetic energy distribution measurements for electron emission from ferroelectrics induced by external electric field. These data seem to be very important from the application point of view, for instance, for flat panel display technology. Generally, the energy of electrons depends on experimental conditions such as sample and electrode preparation, magnitude and polarity of driving voltage or mode of sample excitation. It is known, from the available literature that, in the case of electron emission discussed above, two different energy spectra for electrons were observed. For example, the electrons with broad energy spectra were produced on TGS single crystals [15], PLZT ceramics [13] and PZT thin plates [16]; narrow energy spectra on PLZT thin plates [17,18]. Both these broad and narrow energy spectra were obtained in the case of electron emission from L-α alanine doped TGS (LATGS) single crystals [19] and PLZT ceramics [20].

The aim of this paper is to present the recent results of time and energy distribution measurements for electron emission from LATGS single crystals, induced by an ac electric field driving with amplitude of the order of 10^3–10^4 V/cm.

E-mail address: kazmierz@biedrzycki.ifd.uni.wroc.pl (K. Biedrzycki).

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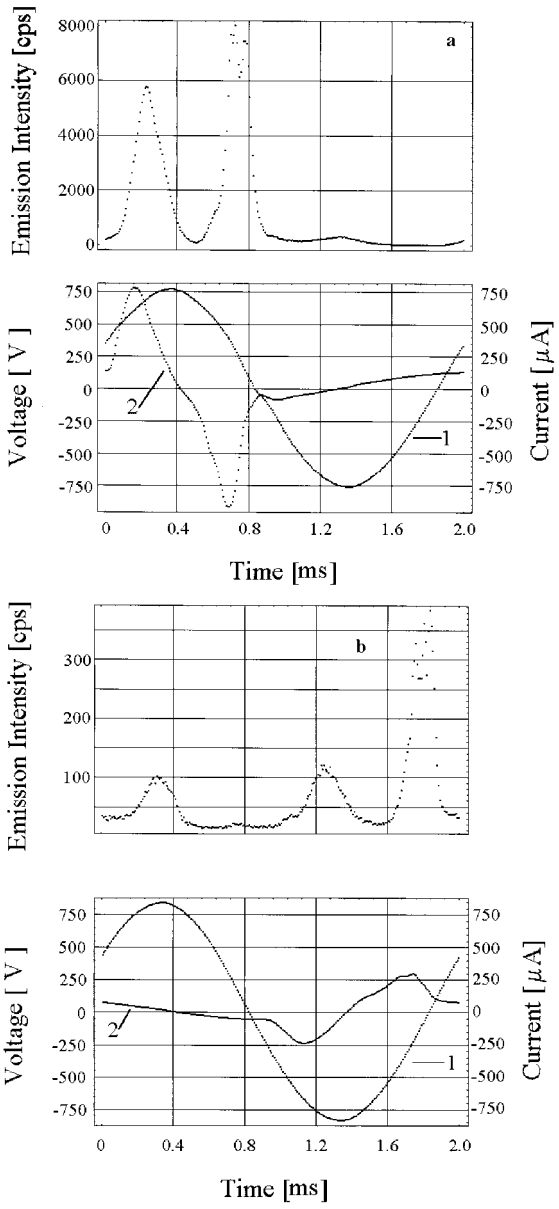

Fig. 1. The waveforms of applied ac electric field and of exciting current (curves 1 and 2 in the lower part of Fig. 1a and b) monitored during a cycle of this field as well as time distribution of the number of charges, integrated over 5×10^5 and 10^6 (upper part of Fig. 1a and b, respectively) field cycles, emitted from LATGS sample. The amplitude of the driving ac field was (a) 7.75×10^3 and (b) 8.56×10^3 V/cm, frequency 500 Hz, temperature of the sample 315 K. The time window (2 ms) is divided into 250 time channels [19].

2. Experimental

The LATGS crystal samples were cut out from a large L-α alanine doped TGS crystal in the plane perpendicular to the ferroelectric *b*-axis. The samples, about 1 mm thick, were supplied with vacuum evaporated Ag electrodes. The upper Ag electrode had a 1 mm diameter bare aperture (bare emitting surface). The bare surface outside the top electrode was covered with an insulating layer. The solid, rear electrode was electrically isolated from the heater surface by a thin Mylar layer.

Before each measurement, the LATGS samples were heated under vacuum conditions up to 353 K, and then slowly cooled down to a chosen measuring temperature. The pressure in the vacuum chamber was about 10^{-4} Pa. The charges (electrons and ions) generated at the bare emitting sample surface were detected by an electron multiplier operating in a pulse detection mode. The top sample electrode and the first grid of a planar three-section energy analyzer were grounded.

The measurements were performed with the use of a PC and suitable data acquisition board. The details are described in Refs. [15,19].

3. Result and discussion

Under ac electric field driving, the LATGS crystal sample can operate as electron or electron and ion emitter. Examples of the temporal relationship between charge emission (top part in Fig. 1a and b) and electric voltage, as well as exciting current (curves 1 and 2 in the lower part of Fig. 1a and b) during a cycle of 500 Hz ac electric field, are shown in Fig. 1a and b for a LATGS sample excited with 7.75×10^3 and 8.56×10^3 V/cm, respectively. The results presented in Fig. 1b were obtained for the same sample turned by an angle of π with regard to its initial orientation (Fig. 1a). It was reported in Ref. [19] that the charges registered under 'negative' switching current (second peak in Fig. 1a and b) contain mainly electrons; the charges detected under 'positive' switching (first peak in Fig. 1a and third in Fig. 1b) as well as during the mere charging of the sample (third peak in Fig. 1a and first in Fig. 1b) include electrons and positive ions. It should be mentioned that, depending on the time scale of the driving ac voltage (Fig. 1), the LATGS sample studied behaves as a ferroelectric or dielectric material.

Three-dimensional time and energy distributions for electron emission processes, produced only during the switching of the spontaneous electric polarization, are given in Fig. 2. The spectra of electron emission corresponding to the negative switching are shown in Fig. 2b and c, the spectra corresponding to the positive one in Fig. 2a and d. When the switching process leads to negative charging of the emitting bare sample surface, the energy of electrons is determined by a transient non-homogeneous negative surface potential. Under these conditions, the electrons can attain energies up to 400 eV (Fig. 2b). If, however, internal bias E_b prevents negative charging of this emitting sample surface (Fig. 1b) only a high energetic part of the energy spectrum is detected (Fig. 2c). When electron emission is accompanied with ion

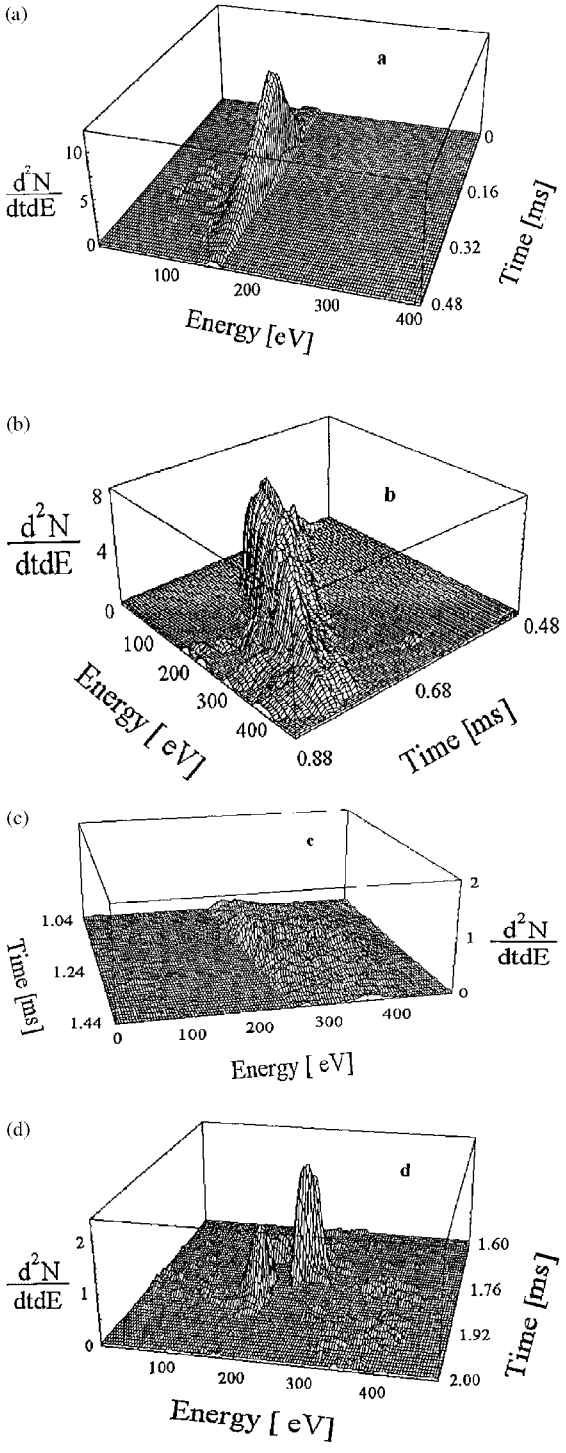

Fig. 2. Time and energy distribution of (b, c) electron emission monitored during negative switching and (a, d) during positive switching process. The LATGS sample was excited by 500 Hz ac electric field with amplitude of (a, b) 7.75×10^3 and (c, d) 8.56×10^3 V/cm. Temperature of the sample was equal to 315 K.

emission (under positive charging of the emitting surface), the electron energies are more focused (Fig. 2a and d). Until now, the mechanism responsible for this energy transfer has been unknown. However, the influence of internal bias on energy spectra shown in Fig. 2a and d is evident. In the case of the result presented in Fig. 2a, the field E_b prevents positive charging of the bare sample surface; in Fig. 2d accelerates this process. In order to understand the presented emission phenomena at the atomic level, the study of the surface processes such as desorption and ionization of residual gas molecules, charge separation, mass spectroscopy, etc., occurring at a charged ferroelectric (dielectric) surface, will be continued.

In conclusion, electron emission from LATGS single crystals is observed during negative as well as positive charging of the emitting sample surface due to switching of the spontaneous electric polarization. When under a negative charging process only electron emission is detected, the electrons have broad energy spectra with energies up to about 400 eV. In the case where the ion emission assists the electron emission (under positive charging), the electrons have more narrow energy spectra focused at about 200 eV. It is also shown that internal bias influences energy spectra for field induced electron emission from LATGS samples studied.

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