EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/PS 92-27 (AR)

# ENHANCEMENT OF LASER-INDUCED ELECTRON EMISSION FROM FERROELECTRICS BY SURFACE CHARGE REFRESHMENT

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ABSTRACT

The emission from ferroelectric material is dominated by surface electrons, which screen a large part of the spontaneous polarization. The surface charge compensation of the polarization can be modified by various methods in certain limits and, hence, also the efficiency of the electron emission. An increase of emitted charge by laser irradiation of more than two orders of magnitude was measured after switching the polarization of polycrystalline lead-lanthanum-zirconium-titanate ceramics (PLZT). An enhancement of electron emission is also observed by pre-illumination with laser light in absence of an extraction voltage compared to regular illumination under a dc extraction field. The laser-induced emission is shown to be dependent on the ferroelectric state and on the full absorption of the laser light in the material.

*Paper submitted to Physics Letters A*

Geneva, Switzerland
February 1992

## 1. Introduction

The emission of electrons as a consequence of spontaneous polarization reversal in ferroelectric materials was first experimentally observed by Rosenman et al. [1]. Submicrosecond polarization switching by high-voltage pulses was applied for the first time by H. Gundel, J. Handerek, H. Riege and K. Zioutas [2-8] with the aim to generate high surface charge densities, which result in the pulsed 'self-emission' of intense electron beams. The easy emission of high current densities seems to be an indication that the electrons originate from the surface, where they screen a large part of the spontaneous electric polarization. High efficiency of electron emission was also demonstrated by irradiation of ferroelectric material with laser light [9]. In the present paper the interaction of laser-induced electron emission from ferroelectrics with field-induced polarization switching and the related electron emission will be described. The experimental results show that the electron emission efficiency can be controlled by modifying the screening surface charge density. This is clearly different from classical photoemission, where quantum efficiency depends mainly on material, surface quality and residual gas pressure.

## 2. Test setup and experimental methods

A ferroelectric, disk-shaped sample is exposed to laser irradiation in a vacuum chamber [9] (see Fig. 1). The illuminated surface of the sample is covered by a grid electrode, the opposite side is fully electroded. The electrodes allow the sample to be pulsed in synchronism with the laser pulse. Submicrosecond high-voltage pulses are generated by capacitor discharges through a fast high voltage, high-current transistor. Electron emission takes place from the grid side of the sample, when the negative voltage pulse amplitude on the rear electrode exceeds a material and thickness dependent threshold value in the range from 0.5 to 4 kV, and/or when the sample is irradiated with laser light, whilst being exposed to a dc extraction field. The emitted electron beam current and charge were measured with an auxiliary grid AG of high (> 90%) optical transparency in front of the emitting surface or by the faraday cup FC (Fig. 1). We mainly applied light pulses from Nd-YAG lasers, which delivered wavelengths of 1064,

532, 355 and 266 nm and pulse energies of a few hundred μJ on the sample surface. The ferroelectric samples were made from different ceramic PLZT materials.

We used the PLZT ceramics 2/95/5, 1/94/6 and 9/65/35, which, by chemical composition, are situated near a phase boundary, and which, hence, contain mixtures of ferroelectric and non-ferroelectric phases, whereas the material PLZT 7/65/35 consists mainly of the rhombohedral, ferroelectric phase [6].

The electron emission was studied by three types of experiments :

- Laser irradiation of the sample, which was kept at a negative extraction potential of several kilovolts.
- Emission by polarization switching of the sample with and without extraction voltage.
- Combined laser and electric field-induced emission under a dc extraction field, where the relative synchronization between the laser and the switching pulse could be varied in steps of ten nanoseconds over a range up to seconds.
- Laser-induced emission with an extraction field after previous laser irradiation without extraction field.

The purely laser-induced electron emission from a prepoled PLZT 9/65/25 sample was investigated during a heating cycle from room temperature beyond the phase transition temperature of 110 °C, where the ferroelectricity disappears. During the experiment the sample support was heated up to 140 °C.

## 3. Results

Figure 2 shows the dependence of emitted electron charge from the 9/65/35 PLZT sample as function of temperature. The sample was irradiated by laser pulses of 12 ns width at a wavelength of 266 nm and subjected to an extraction voltage of 7 kV. At temperatures below 90 °C the emission remained constant and decreased by a factor of three above 110 °C. The reduced emission level is reached at a temperature, at which the prepoled material undergoes a phase transition from the ferroelectric to the paraelectric state. The results were reproduced, when cooling the sample down to room temperature.

Purely laser-induced electron emission under a dc extraction field was demonstrated with a different Nd-YAG laser by irradiating 2/95/5, 2/94.5/5.5, 1/94/6, and 7/65/35 PLZT

ceramics. All materials were strongly emitting at 266 nm wavelength. Whereas 9/65/35 showed significant emission at 308 nm wavelength (Xe-Cl eximer laser), and 7/65/35 even at 355 nm (tripled Nd-YAG), no emission could be observed from any of the other materials at any of the available wavelengths except at 266 nm.

The effect of combining ferroelectric polarization switching pulse with beam-induced electron emission was studied by shifting the laser pulse in time with respect to the polarization switching pulse. A strong amplification of the normal laser-induced emission pulse can be detected during or after the switching pulse. Subsequent emission pulses have decaying amplitudes until the normal laser-induced emission is reached. The amplified amplitudes are independent of the delay elapsed between ferroelectric switching and laser pulse excitation under dc extraction field.

Figure 3 shows the waveforms of subsequently emitted electron beam pulses following a polarization switching pulse together with the waveform (first signal on upper waveforms) obtained under irradiation at 266 nm and under constant extraction voltage of 6 kV without ferroelectric switching. The lower trace shows the waveform of the switching voltage pulse applied to the FE sample. During its rise weak field-excited emission accompanies the switching action. The material was 1/94/6 PLZT. The first current pulse is amplified by up to a factor of 10 independent on the time elapsed after the FE-switching. The diagram of Fig. 4 shows the dependence of current amplification as function of voltage pulse amplitude applied to the 1/94/6 PLZT sample for the first pulse after switching and the two following ones. The total surplus charge generated by one single switching pulse is compared to the charge from a normal laser-induced emission in Fig. 5. The total charge amplification factor is 16.

The emission from a PLZT 7/65/35 sample illuminated with laser light of 355 nm was by almost two orders of magnitude weaker than the emission from PLZT 1/94/6 at 266 nm, but the current amplification by polarization switching reached a factor of 200.

The amplification of laser-induced emission can also be obtained by irradiating a ferroelectric sample for several pulses without extraction voltage and then applying an extraction field. Fig. 6 shows the current amplification of a PLZT 1/94/6 sample irradiated with light of $\lambda$ = 266 nm as function of the number of laser pulses applied without extraction voltage for the first three pulses after extraction potential application.

## 4. Discussion

The efficient emission of electrons from FE surfaces seems to depend on the presence of the ferroelectric phase in the material (Fig. 2). The measurements of the absorption spectra for the two PLZT material groups x/65/35 and y/95/5 [10] suggest, that electron emission can only be observed, when the material is fully absorbing the incident light. The absorption edge of PLZT 7/65/35 is slightly higher (at approximately 400 nm) than that of PLZT 1/94/6 (at 300 nm). Therefore emission occurs from PLZT 7/65/35 at 355nm but not from PLZT 1/94/6. The higher absolute current density from 1/94/6 compared to 7/65/35 may be explained by the larger distance from the absorption edge. The physical mechanisms of photon to electron energy conversion seem to be not fundamentally different from the normal photoeffect, but the liberation of the electrons near the surface appears easier than for the bulk electrons, which must tunnel through or must be pulled over a high energy barrier.

The surface charge density of the electrons screening the spontaneous polarization can be changed, since the screening is partly resulting from internal (space charge) carriers near the surface. The dynamical compensation by internal space charge carriers is a slow process compared to surface charge screening. Hence, surface charge screening is intensified after polarization switching by electrons injected from the grid electrode or drawn from the surface plasma, which accompanies strong emission. A similar effect is observed after surface illumination by laser light pulses without extraction field. The polarization of the surface layer seems to be changed by the thermal and electrical impact of the laser irradiation resulting in a refreshing of surface charge screening, which is apparent after applying an extraction potential together with a laser pulse.

## 5. Conclusions

The electron emission after combined polarization switching and laser irradiation of ferroelectric material is not only an interesting physical effect, but leads to technical applications in all fields, where intense, short electron pulses are required. Depending on material and choice of laser wavelength with respect to the absorption edge of the material charge and current amplification of more than two orders of magnitude have been observed. Promising results may be expected, when robust ferroelectric materials are explored, which fully absorb light in the range of wavelengths, where efficient and cheap lasers exist.

## 6. Acknowledgements

The authors are indebted to Mrs K. Brodacka, University of Katowice, and P. Gaucher, Thomson CSF for preparing the ferroelectric material. We thank D. Boimond for his help with setting up the experiments.

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# List of Figures

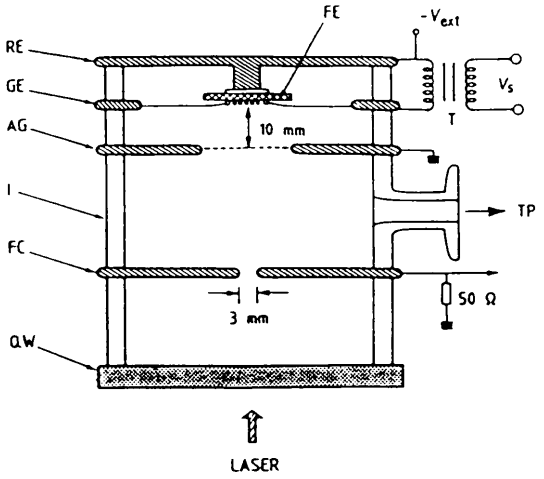


Fig. 1

Laser-induced electron emission from FE.

Scheme of experimental setup :

GE, RE = electrodes ; AG = auxiliary grid ; QW = quartz;

FC = Faraday cup ; I = insulator, T = transformer,

TP = turbo pump.

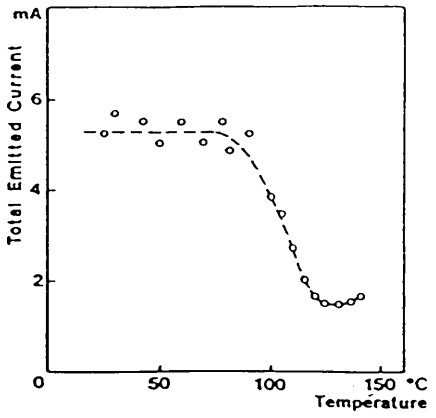


Fig. 2

Temperature dependence of emitted current of a laser-irradiated ($\lambda$ = 266 nm) PLZT 9/65/35 sample:

Phase transition : $T_{pt}$ = 110 °C ;

extraction potential = 8 kV.

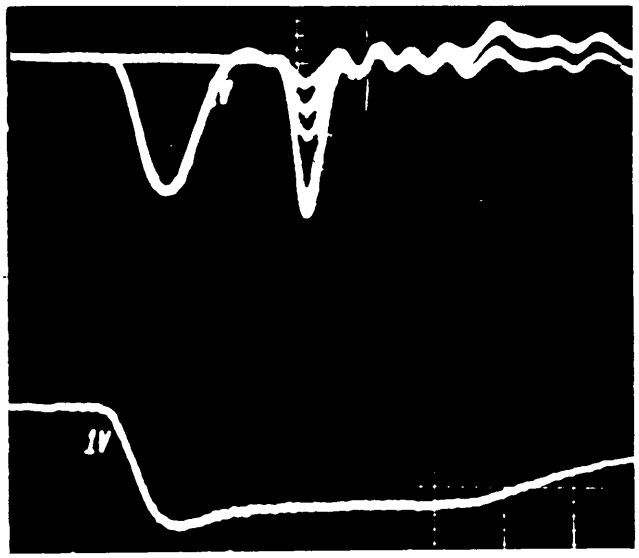


Fig. 3

Enhancement of laser-induced emission from PLZT 1/94/6 by simultaneous polarization switching. The induced surplus charge is exhausted after a few (4 to 5) subsequent laser pulses without P switching. Lower trace: switching voltage wave ($V_s$) form. $V_s$ = 3 kV ;

$V_{ext}$ = 6 kV ; 10 ns/small div.; 20 mA/small div.

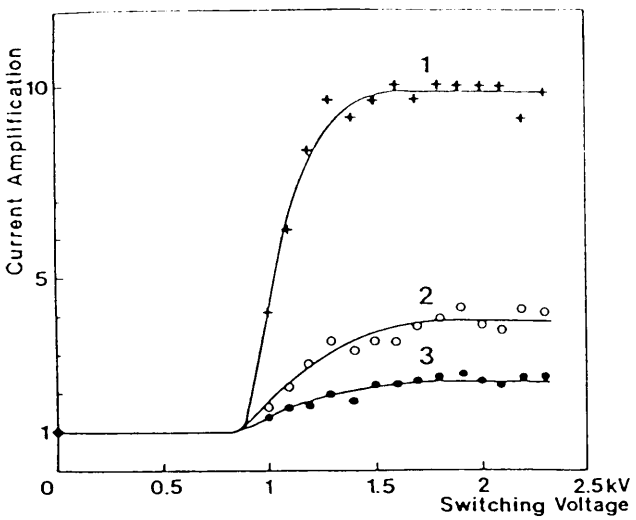


Fig. 4

Current amplification of electron emission after a single polarization switching for three subsequent laser pulses after P switching as function of switching voltage ($V_s$). FE = PLZT 1/94/6; $V_{ext}$ = 6 kV ; laser energy on FE = 440 μJ ; λ = 266 nm; beam diameter= 2 mm.

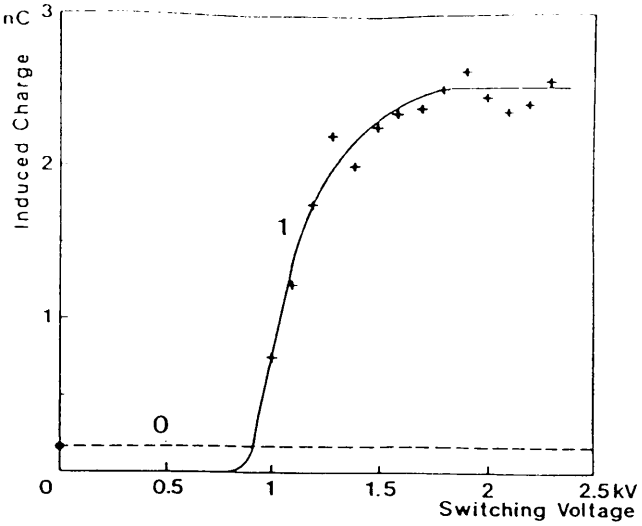


Fig. 5

Total generated surplus charge (1 = sum of the first four laser-induced emissions after one single switching pulse) as function of switching voltage and compared to the charge in one standard laser-induced emission pulse (0). Parameters as in Fig. 4.

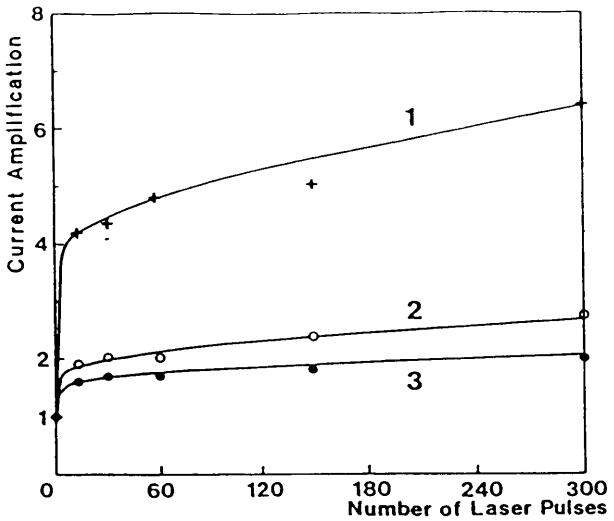


Fig. 6

Amplification of emitted beam current as function of the number of laser pulses applied without extraction voltage and then measured with 6 kV extraction voltage on the first (1), second (2) and third (3) following pulses: PLZT 1/94/6 ; laser energy on FE = 410 μJ ; λ = 266 nm; beam diameter = 2 mm; f = 0.5 Hz.