

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH**HR/AFM****CERN/PS 89-54 (AR)
CLIC NOTE 99****INTENSE LASER-INDUCED ELECTRON EMISSION FROM PREPOLED PLZT CERAMICS**

**K. Geissler, H. Gundel and H. Riege
CERN
CH-1211 Geneva 23, Switzerland**

**J. Handerek
University of Silesia, Institute of Physics,
P-40-007 Katowice, Poland**

Abstract

A sample of lead-lanthanum-zirconium-titanate (PLZT 9/65/35) has been exposed to 6 ns long laser pulses of 266 nm wavelength. The maximum output pulse energy of the laser beam was 300 μJ , the output power density on the sample $5 \cdot 10^5 \text{ W/cm}^2$, and the beam diameter 3 mm. By applying a moderate extraction voltage of several kilovolts, intense electron beam pulses are emitted from the free sample surface. Their time structure corresponds to the time structure of the laser pulse. Electron beam current intensities of up to 0.1 A and 2 A/cm^2 and total charges of 1 nC (corresponding to 20 nC/cm^2) were measured with a simple Faraday cup. In the range where the parameters of laser intensity and of extraction voltage could be varied their influence on the emitted electron beam current amplitude was determined.

Paper to be published in Applied Physics Letters

Geneva, Switzerland
October 1989

1. INTRODUCTION

The main conventional methods of electron emission are the effects of thermionic emission, photoemission and field emission. Electrically conducting materials, such as metals or semiconductors, are mainly used as emitters. A new method of intense electron emission from ferroelectric materials has been reported recently.¹⁻⁵ As indicated in Ref. 1, a photo-effect-like electron emission could also be expected from a ferroelectric, F-center rich material, when illuminating the bare surface with laser light of sufficiently short wavelength. Most of the materials on which ferroelectric emission has been studied belong to the class of perovskite ceramics, or more specifically to the PZT and PLZT ceramics, which usually have a very low electric conductivity. Conventional emitters usually consist of conducting material. Here we report on the emission from a ferroelectric insulator where efficient emission of electrons should be achieved at much lower extraction voltages. Emission from insulators is especially interesting when short pulses are needed.

2. EXPERIMENTAL SET-UP

The principle of the experiment is shown in Fig. 1. The light of a Nd-YAG laser was doubled twice in frequency and the output beam of 3 mm diameter (wavelength $\lambda = 266$ nm) was projected on the surface of a PLZT 9/65/35 sample disk. The laser beam pulse shape and the pulse length of 6 ns were measured with a photodiode in the green light range ($\lambda=532$ nm, fundamental laser frequency doubled once). The uv light output pulse energy was raised to a maximum of 300 μ J.

The PLZT sample, which at room temperature (Curie point near 90°C)

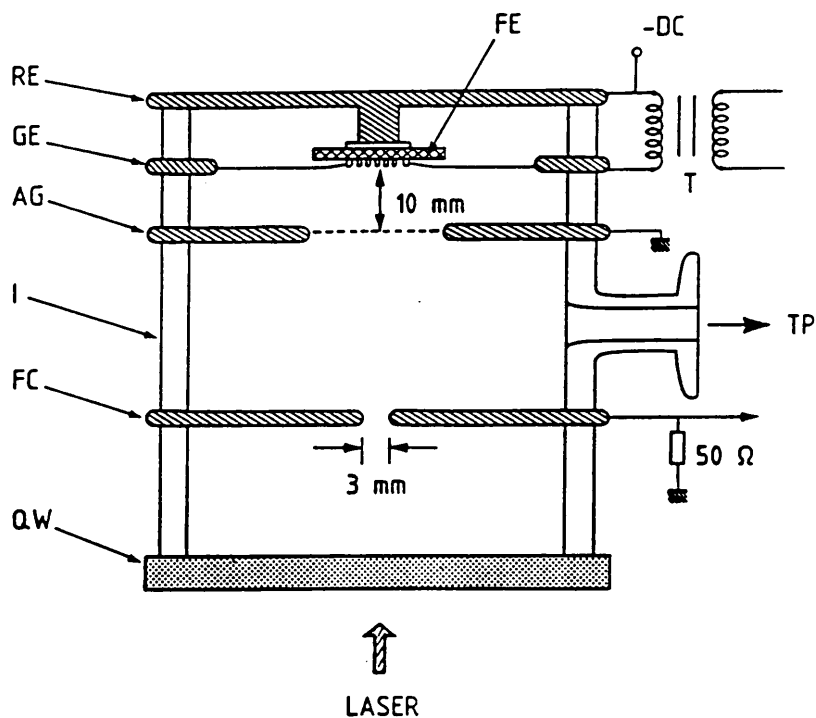


Figure 1 - Scheme of experimental set-up.

FE = PLZT; RE, GE = electrodes; AG = grid; QW = quartz;
 Tp = pump; FC = Faraday cup; T = transformer; I = insulator.

is fully inside the ferroelectric phase, was prepoled prior to illumination for 15 min at 100°C under an electric dc field of 2 kV/cm and subsequently cooled down under the same field to room temperature. The sample face connected to negative potential during prepoling (emitting surface) was covered with a grid electrode GE as described in Ref. 4 (interconnected gold stripes of 200 μm width separated by stripes of bare surface of 200 μm width). The rear sample surface RE was fully electroded. Via a separating transformer T the sample FE of 1.0 mm thickness could be subjected to a HV pulse in order to induce reversal of the spontaneous electric polarization.¹⁻⁵

The space between the gridded sample face GE and the quartz window QW for the laser beam could be evacuated down to a pressure of 10^{-6} mbar. A simple metal disc with a center hole for the passage of the laser beam served as a Faraday cup FC with 50 Ω to ground for measuring

the emitted electron beam current and charge. The sample and the secondary winding of the transformer T were negatively charged against the Faraday cup to a maximum of -10 kV, whereas the protection grid AG between the sample and the Faraday cup was connected directly to ground. The laser and HV pulses were synchronized in time via their specific pulse generators with an electronic delay. Owing to limitations due to geometry, optical path, and sample grid layout, only one quarter of the laser pulse output energy reached the bare sample surface.

3. RESULTS

Illumination with laser light of 2.3 eV photon energy, even with highest possible intensity and at 12 kV extraction voltage, did not lead to the release of an electron current measurable with the 50 Ω Faraday cup. When changing simultaneously the spontaneous polarization with a negative HV pulse to the full (rear) sample electrode RE, normal ferroelectric electron beam emission³⁻⁵ were observed but no laser effect.

The first time the sample was exposed to a laser pulse of $\lambda=266$ nm wavelength (photon energy 4.64 eV), electron emission took place starting from 1 kV extraction voltage corresponding to a field of 1 kV/cm. Figure 2 shows the electron beam current pulse measured on the 50 Ω -Faraday cup at an extraction field of -8 kV/cm and at a temperature of 25°C. The current amplitude was 75 mA and the total emitted charge 0.6 nC. Maximum currents of 0.1 A and emitted charges of 1 nC per pulse were observed at highest extraction voltages (-10 kV/cm) and at highest laser output intensities (300 μ J) corresponding to power densities on the sample of $5 \cdot 10^5$ W/cm². Taking into account the effective emitting

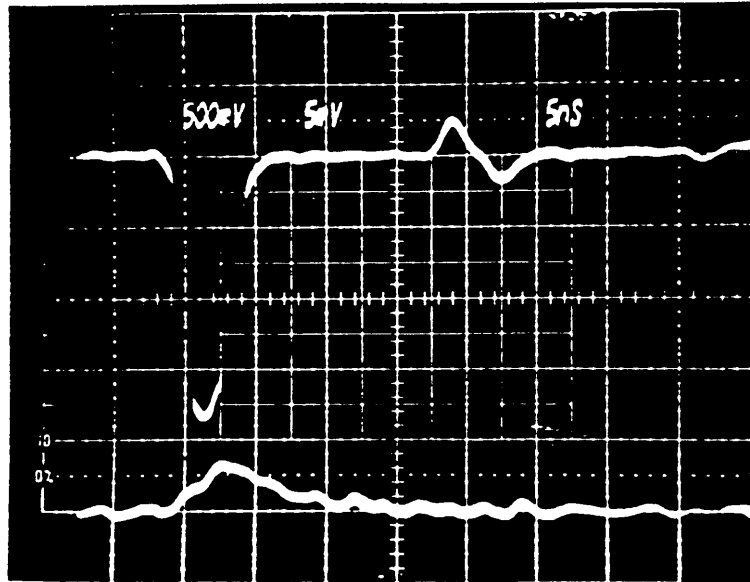


Figure 2 - Laser intensity and emitted electron beam current waveforms for a laser output energy ($\lambda = 266 \text{ nm}$) of $60 \mu\text{J}$ and an extraction field of -8 kV/cm .
 Upper trace: e^- beam current, $10 \text{ mA/small division}$;
 Lower trace: uv laser light intensity.

surface of the sample and the finite transparency of the protection grid AG maximum current densities of 2 A/cm^2 and emitted charge densities of 20 nC/cm^2 are calculated. The lower trace in Fig. 2 is the laser light signal measured with a photodiode in the uv range, where its sensitivity is very poor and a considerable distortion of the laser pulse shape takes place. From the data of laser beam energy and emitted electron charge a quantum efficiency of several 10^{-4} is estimated. Figure 3 shows the emitted electron beam current as a function of extraction field for two different laser pulse output energies.

The simultaneous ferroelectric polarization reversal of the sample was only possible at a very low field strength of 15 kV/cm across the ferroelectric disk. At this level, the ferroelectric emission is quite

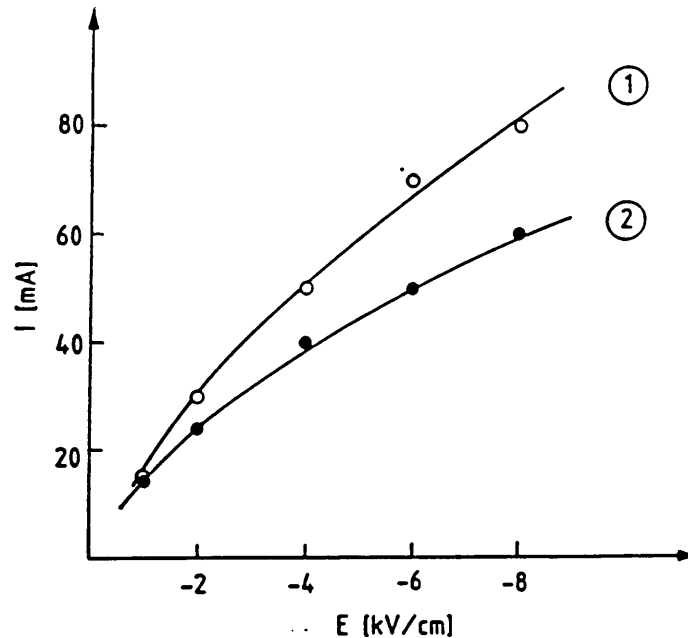


Figure 3 - Emitted electron beam current as a function of dc extraction field for the laser beam energies (at $\lambda = 266$ nm) of 60 and 150 μ J.

small and comparable with the laser induced emission. A linear superposition of both effects was observed but no amplification.

4. DISCUSSION AND OUTLOOK

The laser-induced emission observed from PLZT can be characterized as a large area, photo-effect-like emission which apparently takes place without plasma assistance.⁶ In the experiment it could not be proved, whether the emission is provoked by spontaneous polarization changes of the PLZT sample (e.g. by the pyroelectric effect) or by the liberation of electrons from the oxygen vacancies (F-centers). The fact that green laser light, which was available with much higher intensity than the uv light, did not produce any emission, indicates, however, that the ferroelectric space charge polarization, formed by the concentration of F-centers near the emitting surface layer during prepoling, seems to be the main cause of this type of emission.

Since the time structure of the electron beam pulse is identical to the laser pulse shape, one can predict the creation of very short electron pulses in the picosecond range. Total amplitudes of current and charge are mainly determined by the effective, emitting PLZT surface area, by the laser beam pulse energy, and by the laser beam diameter. Considerably higher electron beam intensities can be expected when materials with very high F-center concentration, and much stronger prepolarizing procedures at elevated temperatures and with strong electric dc fields are applied.

The advantages of the new emission method, compared with the classical schemes of thermionic emission, photoemission and field emission, can be summarized as follows:

- Emission can be achieved with extraction fields as low as 1 kV/cm.
- Easy control of beam current amplitude with laser power, laser beam diameter, and bare sample surface area.
- Arbitrary electron beam cross sections (e.g. hollow and multiple beams) can be obtained by proper choice of emitting area and laser beam cross section.
- Moderate vacuum or even low pressure gas do not inhibit emission.
- The emitter material is rugged ceramics and, as such, much more resistant than most conventional thermionic or photoemitters.

Similarly to the method of electron emission from ferroelectrics by polarization reversal, the laser-induced scheme described in this paper may be useful in many technical systems. Potential applications can be identified as electron beam sources for accelerators, for free electron and gas lasers, for ion beam sources, or for machining purposes, as well as a trigger or preionizer for high-power switches.^{3,6}

ACKNOWLEDGEMENTS

The authors are very grateful to D. Boimond for his help in setting up the experiment and for assisting during the measurements.

REFERENCES

1. H. Gundel, H. Riege, E.J.N. Wilson, J. Handerek and K. Zioutas, "Fast Polarization Changes in Ferroelectrics and their Applications in Accelerators", Nucl. Instrum. Methods, A 280 (1989) 1.
2. H. Gundel, H. Riege, E.J.N. Wilson, J. Handerek and K. Zioutas, "Fast Polarization Changes in PZT Ceramics by High-Voltage Pulses", Ferroelectrics 94 (1989) 337.
3. H. Gundel, J. Handerek, H. Riege and K. Zioutas, "A Low-Pressure Hollow Cathode Switch Triggered by a Pulsed Electron Beam Emitted from Ferroelectrics", Appl. Phys. Lett. 54, 21, (1989) 2071.
4. H. Gundel, J. Handerek, H. Riege, E.J.N. Wilson and K. Zioutas, "Copious Electron Emission from PLZT Ceramics with a High Zirconium Concentration", CERN/PS 89-35 (AR), (1989), to be published in Ferroelectrics.
5. H. Gundel, J. Handerek, H. Riege, E.J.N. Wilson and K. Zioutas, "Pulsed Electron Emission from PLZT Ceramics", CERN/PS 89-47 (AR), presented at the 7th Int. Meeting on Ferroelectricity, Saarbrücken, FRG, (Aug. 1989), and to be published in Ferroelectrics.
6. H. Riege, "New Ways of Electron Emission for Power Switching and Electron Beam Generation", CERN/PS 89-42 (AR), to be published by Plenum Press.