FERROELECTRIC CERAMICS: A NOVEL EFFICIENT AND ROBUST PHOTOCATHODE

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Abstract

Ferroelectric ceramics of the PLZT type, i.e. lead zirconate titanate lanthanum doped, in form of thin disks have been tested as photocathodes. The disc of material, with the back surface only metallized and held in place by a metallic ring, was set in front of a solid anode. The applied accelerating field reached 20 kV/cm and the light pulse was 25 ps long, 532 nm wavelength and its energy arrived up to 6 mJ on an area of about 10 mm^2. The vacuum was very poor. The maximum output charge was 1 nC, but it was clearly limited by space charge. A theoretical explanation of the results is only hinted because the material surface structure is very complicated and various emission mechanism concur.

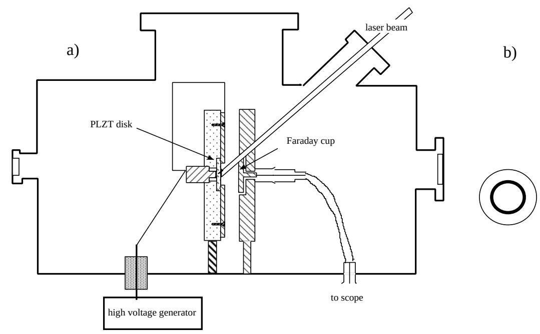

Figure 1: a) Sketch of the experimental apparatus used in the photoemission experiments; b) sketch of the cathode with the ring electrode at the front surface. The passively mode locked Nd-YAG laser provides some mJ of light at λ = 532 nm for a pulse length of 25 ps.

1 INTRODUCTION

The photoemission from ferroelectric material has become interesting after the experiments at CERN [1, 2]. The reasonably good emissivity at wavelength varying from green to UV, coupled to robustness makes this ferroelectric lead zirconate titanate lanthanum doped (referred as PLZT) ceramic a real subject of research for an efficient and robust photo-cathode for induction linac [3], next generation of accelerators [4], FEL, ultrashort x-ray sources.

The problem of the physical interpretation of the photoemission from these materials appeared soon very difficult. In reference [5] a new physical model has been proposed in order to account for the different experimental observations.

An experimental program has been set with the aim to investigate further the physics of the emission. The green light has been chosen because it seemed more suitable for that investigation.

The sketch of the experimental setup is shown in fig. 1.

The experiment has been carried out with PLZT having composition 8/65/35 and 4/95/5, where the numbers refer to lanthanum (in relation to lead), zirconium and titanium relative atom percentage and with lead titanate, PTO_3, sample. The ceramics 8/65/35 and PT are in ferroelectric phase at room temperature, while the 4/95/5 is in antiferroelectric phase, but it undergoes a transition from antiferro to ferroelectric phase under the action of an enough high electric field [6]. These materials have a high density of defects [7], whose activation energy is about 1 eV. The samples were not prepoled. The cathodes are disks of 16 mm diameter and 1 mm thickness, coated by a uniform metallic film at the back surface and by an external ring only at the front surface, see fig. 1 b).

2 EXPERIMENTAL RESULTS

2.1 Experiments on PLZT 8/65/35 with bare front surface.

The results of the emission from a PLZT 8/65/35, fig. 1 b), are given in figures 2 and 3. The emission reached such a level that the saturation effect becomes evident. From the shape of the emitted charge versus the incident laser power, we can see that: there is a threshold and the yield in logarithmic scale increases linearly with an angular coefficient nearby 4. Extrapolating with an accelerating field high enough to avoid saturation effects, the emitted charge at 6 mJ of laser light would be 2 nC. The value of quantum efficiency results around 10^{-6}.

2.2 Experiments on PLZT 4/95/5.

We have investigated the emission from antiferroelectric PLZT 4/95/5 samples. The results are summarized in figures 4, 5 and 6.

The charge emitted increased from some picocoulombs to a couple of hundreds of picocoulombs when the applied field passed from 3.5 kV to 7 kV (equivalent to 20 kV/cm).

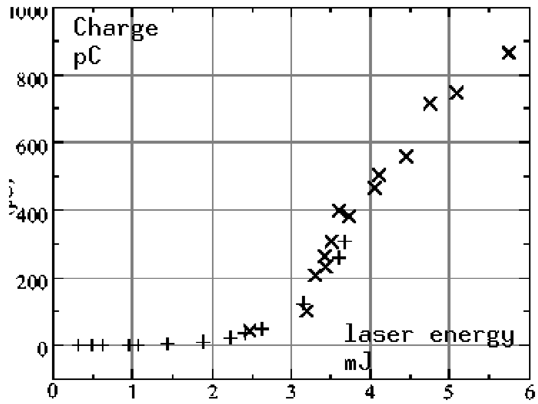

Figure 2: Emitted charge versus laser energy for a PLZT 8/65/35 without the front grid. Notice the clear bending of the curve due to the space charge effect.

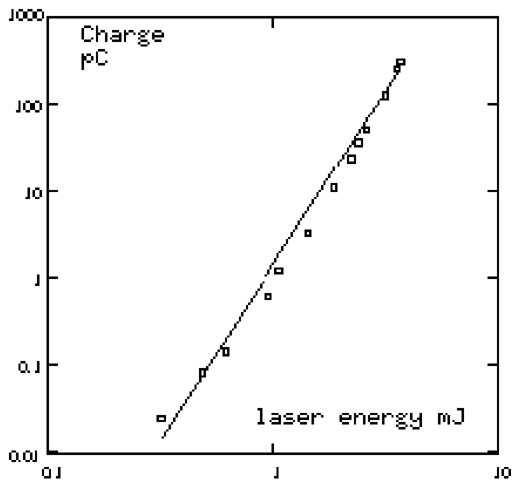

Figure 3: Emitted charge versus laser energy for a PLZT 8/65/35 without the front grid in log-log frame. The continuous line is a fit with $Q\alpha I^4$ scaling law.

In addition the log-log plot of emitted charge as function of laser power changed the slope from about 2 to the higher value around 3.

2.3 *Experiments on PT.*

This lead titanate material is a hard ferroelectric, good absorber of radiation in optical range. It emitted at much lower level as shown in fig. 7. We remark that the emission from this sample follows the two-photon absorption law [8], as the case of 4/95/5 sample at relatively low electric field in the diode gap.

We have, finally, tested the emission with two light pulses separated by 2 ns. The two emissions are substantially stable. The system seems able to provide pulse trains with nanosecond time separation.

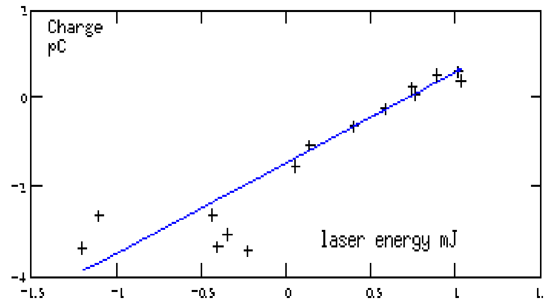

Figure 4: Emitted charge versus laser energy in logarithmic scale for a PLZT 4/95/5 sample when the applied voltage through the gap was 3.5 kV. The continuous line fits with $Q\alpha I^2$ scaling law.

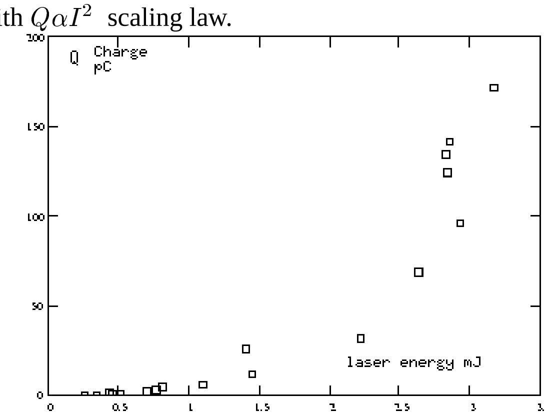

Figure 5: Emission versus laser energy for a PLZT 4/95/5 sample when the applied voltage was 7 kV.

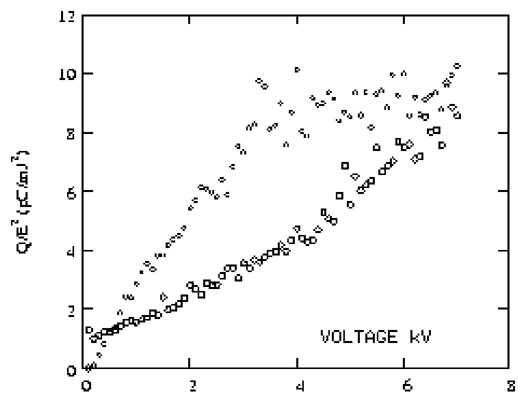

Figure 6: Emitted charge versus laser energy: the lower points are obtained at 7 kV of applied voltage, while the points of the upper curve are obtained in succession but after having reduced the voltage to 3.5 kV. The hysteretic behavior was not observed keeping constant the voltage.

3 DISCUSSION

The two main characteristics of the strong emission are: the almost negligible emission up to a laser intensity of about 1 GW/cm^2 (i.e. 2 mJ) and the high non-linearity starting from that point. In addition to this, the other notable fact is the change of the operational regime for the PLZT 4/95/5

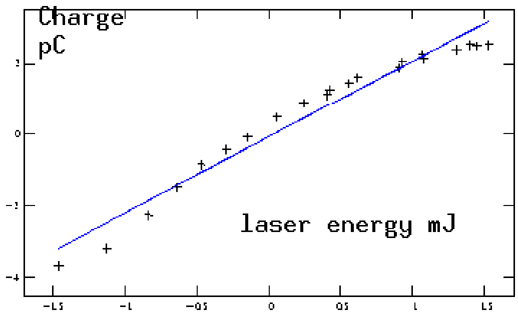

Figure 7: Charge versus laser energy in log-log scale for PT. The continuous line fits with $Q\alpha I^2$ scaling law.

sample when it is immersed in a relatively high electric field. The PT sample has stably two-photon emission.

The generalized Fowler-Dubrige theory [8] cannot explain these results. An average potential barrier higher than 4 eV is estimated in these materials for the electrons of the defect traps. The electron affinity E_a is not well defined because the surface state is un-defined: is like a patchwork of pieces with different physical characteristics, which range from insulating to metallic [9, 10, 11]. That value of the potential barrier is a fairly crude approximation.

Furthermore, our disk is immersed in the electric field applied through the diode gap, hence a counter field is created by the induced polarization. When the crystal is polarized, there is a band bending at the surfaces with a potential well for electrons at the positive side of the polarization, while there is a barrier at the opposite side [12].

The emission at 2.3 eV and its non-linearity with a power equal or greater than 4 would envision the anomalous heating regime [13], cooperating with the Auger effect [5].

More generally, we should have the concurrence of different contributions: one and two-photon emission, thermally assisted and Auger emission.

The increase of the emission of 4/95/5 sample as a function of the applied field, together with the hysteretic behavior of fig. 6 tells that the polarization is very important: when the polarization builds up in the sample, the emission steps up, then the sample remains polarized when the electric field is reduced because of the hysteresis loop. The experiment with PT material says that the polarization by itself is not sufficient for obtaining strong emission, but a strong doping, that is a large number of defects, must be also present.

Assuming that the electron pulse length is strictly correlated to the light pulse length, that is $\approx 25ps$, since the illuminated area is about 10 mm^2, the current density would be higher than 1 kA/cm^2. The laser power is well below the damage threshold.

4 CONCLUSIONS

A new very efficient configuration for ferroelectric photocathodes has been investigated. We got 1nC level of emission only because the charge was limited by space charge effect. Since the damage threshold of a ceramic is relatively high, a large amount of extracted charge can be foreseen.

The emission has shown to be very sensitive to the sample polarization. This fact allows to foresee a large enhancement of the quantum efficiency just increasing the polarization. This polarization increasing occurs naturally with the high electric field that are customary applied in electron guns.

The characteristics of these cathodes, are: a)strong robustness, they work in any kind of vacuum showing a long life; b) they do not require any particular processing; c)they can be operated with green light. In the near future the extracted electron beam will be characterized in terms of time structure. If the electron pulse duration is strictly related to the laser pulse duration, these cathodes promise to deliver current densities larger than 1 KA/cm^2 and to be valid competitors of both metallic and alkali cathodes.

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