EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH



CERN AT / 92-20 (DI)

# HIGH-CURRENT ELECTRON AND ION SOURCES BASED ON FERROELECTRICS SWITCHING

D. Boimond, F. Dothan, K. Geissler, J. Handerek, J. Kuipers,
A. Meinecke, H. Riege, and G. Schröder

*Presented at the XVth International Conference on High Energy Accelerators*
*July 20-24, 1992, Hamburg, Germany*

Geneva, Switzerland
July, 1992

# HIGH-CURRENT ELECTRON AND ION SOURCES BASED ON FERROELECTRICS SWITCHING

D. Boimond, F. Dothan, K. Geissler, J. Handerek,
J. Kuipers, A. Meinecke, H. Riege, and G. Schröder
*CERN, CH-1211 Geneva 23, Switzerland*

**Abstract**

Fast submicrosecond switching of the spontaneous electric polarization of ferroelectric (FE) material by electric field excitation (FEEE) leads to a strong pulsed emission of electron beams. Laser-induced electron emission, combined with field-excited electron beam emission, offers high spatial and temporal flexibility for the application to intense electron beam sources needed in accelerators, and to the generation of microwave power. The strong electron emission from FE material can also be applied to the indirect production of intense pulsed ion beams. The results of basic experiments, which demonstrate the capabilities of FE emission for its use in particle sources, are reported. Specific developments which have been started in this field are described.

Strong electron emission can be induced by rapid changes of temperature, pressure, by polarization switching with electric field, or by laser illumination. The experimental investigations and the developments of pulsed electron and ion sources described in this paper are mainly concerned with the two latter modes of excitation. The switching of FE polarization with fast-rising high-voltage pulses may be accompanied by electron emission with current densities exceeding 100 A/cm$^2$. This effect has been demonstrated with different FE materials, such as triglycine-sulphate crystals and especially ceramic FE perovskites, such as lead-lanthanum-zirconium-titanate (PLZT) and lanthanum-doped barium-strontium-titanate [1]-[5]. The FEEE very much resembles the electron emission from insulators induced by charge separation due to friction. The charge separation in ferroelectrics is achieved by changing the spontaneous electric polarization $P_s$. After $P_s$ change the polarization charge and the screening charge may appear on the surface. The surface fields due to the FE polarization may enhance the emission of electron currents exceeding the Langmuir-Child limit by several orders of magnitude[6]. The emission can even take place without applying any extraction voltage. This feature, the robustness of the FE ceramics and its insensitivity to the presence of low-pressure gas or even plasma are the main advantages of FE emitters compared with other cathode materials. Most data of the FEEE have been obtained with disk-shaped FE samples mounted with a gridded electrode towards the vacuum of a small test chamber. The HV excitation pulses were generated by a capacitor discharge through a fast transistor switch. The emitted intensity increases when switching is faster and when higher excitation and/or extraction voltages are applied. Figure 1 shows switching with 2 MHz repetition rate. The emission excited by 500 A/3 kV HV pulses occurs with 35% duty cycle[4].

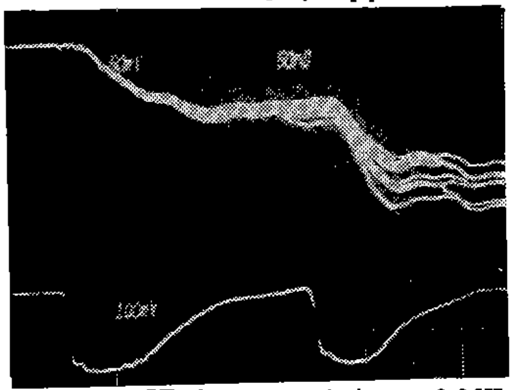


Figure 1: FE electron emission at 2 MHz.
Top: emitted charge, 5 nC/small div (sd).
Bottom: HV pulse (1 kV/sd); 50 ns/sd

The speed of polarization change depends on the resistivity and on the switching properties of the FE material, which seem to depend on the coexistence of two (or more) phases and on the fast transformation of one phase into the other. The fast emission is followed generally by an equally fast depolarization and recharging of the sample without any resetting action.

Significant electron emission by laser irradiation (LIEE) of a FE sample has been reported in[3]. The

LIEE from FE cathodes differs greatly from normal photoemission by the easy control of emission efficiency through variation of the surface fields and of the surface charge density induced by FE polarization switching, or by other surface treatments, such as laser irradiation without extraction voltage[7]. In Fig. 2 the emitted current amplification of the first three LIEE pulses after one FE switching pulse is plotted as a function of excitation voltage pulse amplitude. An important requirement for LIEE is the full absorption of the incident photon energy by the FE material.

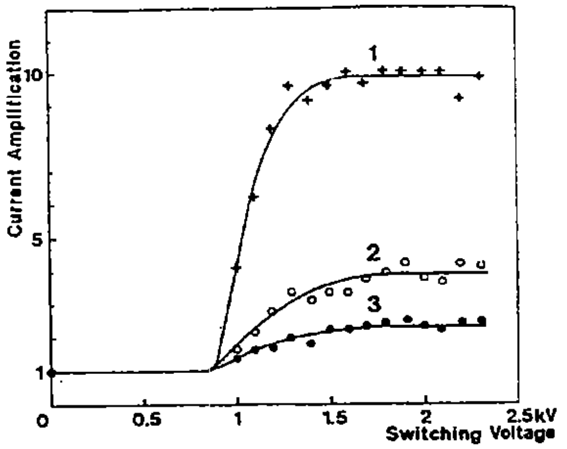



Figure 2: Current amplification of electron emission after one FEEE switching for three subsequent laser pulses as a function of switching voltage. FE=PLZT 1/94/6; V ext=6 kV; laser energy=440 $\mu$J; $\lambda$=266nm.

The high efficiency of the FEEE and the flexibility in controlling the geometrical and temporal boundary conditions of the emission, including the electron surface charge density, allow the construction of electron sources for high-intensity, high repetition rate and high average power beams required in the electron guns of future high-intensity electron linacs. The FE emission is well suited for the generation of axial, hollow or multiple electron beams. The FE emission can be easily combined and amplified with the strong beam generation from a diffuse vacuum discharge (DVD)[8]. The direct field-induced emission of short-pulse trains from FE cathodes may be pushed towards higher rf and repetition frequencies by combining LIEE with fast FE polarization switching. A quite successful application of FEEE is the development of a high-power, low-pressure gas switch (35 kV, 30 kA) with one or two HV gaps and independent FE electron beam triggers for the future pulse generators of the CERN LHC beam dumping system[9]. The FE electron beam trigger can emit beam currents of 1 to 100 A, which ignite the main switch with 100% efficiency and nanosecond precision in a dynamic anode voltage range of more than 1:100 at constant gas pressure (Fig. 3). The FE emitters have demonstrated very high reliability (several $10^5$ shots at 10 kJ switched energy per pulse) in a heavy-duty environment of electrode erosion and metal vapour deposition. Short-pulse sources can be made with laser-driven FE photocathodes. At the moment a test with switchable FE cathodes is being performed in the CERN CLIC dc test stand, the results of which will be reported elsewhere.

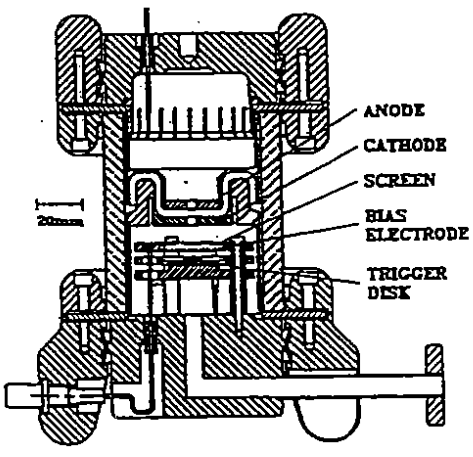



Figure 3: Design of hollow cathode, high power switch (one-gap version)

The intense electron beams from FE cathodes may be applied to the generation of strong ion beams. Figure 4 shows a vacuum chamber with a perforated FE sample, that directs a strong electron beam onto a target.

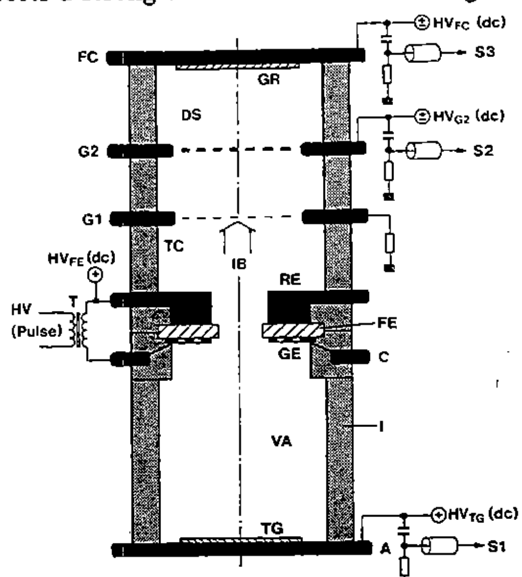
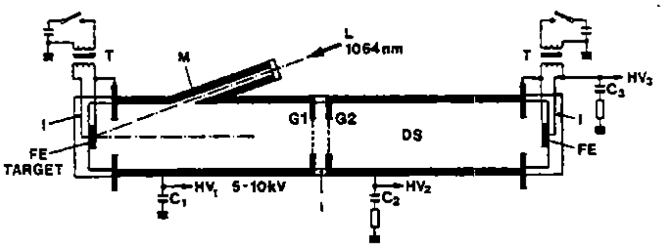


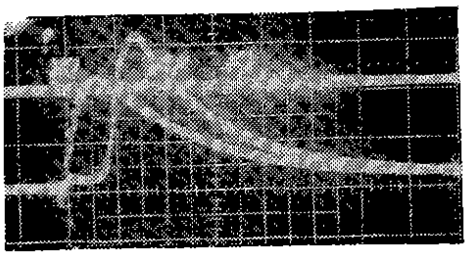

Figure 4: Scheme of set-up for a DVD, based ion-beam source with passive neutralization. Legend: FE = PLZT; GE = grid electrode; RE = rear electrode; G1 = grid 1; G2 = grid 2; FC = Faraday cup; GR = graphite; TG = target; A = anode; C = cathode; DS = drift space; $HV_{FE,G1,G2,TG}$ = d.c. potentials; T = transformer; I = insulator; VA = vacuum; TC = transport channel; IB = ion beam; S1, S2, S3 = signals.

After sputtering, a complete vacuum breakdown (DVD) is initiated, which produces an intense ion beam through the hole of the FE[8] provided the ions repeatedly hit metallic grids between short drift spaces. The electrons sputtered from these grids are accelerated back into the source, thus neutralizing and enhancing the counter-moving ion beam.

The ion source plasma can be also generated by intense laser illumination[10]. The enhancement of the extracted ion beam from such a laser-ion source can be achieved by neutralizing the ions with an electron beam generated by high-repetition rate FEEE and directing the electrons either in the opposite or in the same direction as the ions (Fig. 5a,b). As in ECR or EBIS ion sources one may consider the mutual interaction of separate high-intensity, low-charge ion beams with strong, wiggling FE electron beams[11], which leads to an average increase of charge state.




a)



b)

Figure 5

a): Laser-ion source with active neutralization. M = ion chamber; I = insulator; ES = drift space.

b): Ion beam current enhancement by neutralization with an FEEE pulse. Top trace: trigger pulse for laser and FE switching; bottom: charge (50 nC/sd) measured on DS with (first) and without (second trace) FE emission. 10× enhancement of ion current

FE cathodes are well suited for high-peak and average intensity electron beam sources, since FE emitters are simple and easy to handle, efficient, consist of robust material, and can operate in modest vacuum, low-pressure gas or plasma with high repetition and fast recharging rates. Space-charge neutralization of ion beams with FEEE generated kA electron beams may be envisaged as an efficient way to enhance the yield of ion sources by orders of magnitude.

## References

[1] H. Gundel, H. Riege, E. J. N. Wilson, J. Handerek, K. Zioutas, *Nucl. Instrum. Methods,* **A280** (1989) 1.

[2] H. Gundel, H. Riege, E.J.N. Wilson, J. Handerek, *Ferroelectrics* **100** (1989) 1.

[3] K. Geissler, H. Gundel, H. Riege, J. Handerek, *Appl. Phys. Lett.* **56** (1990) 895.

[4] H. Gundel, J. Handerek, H. Riege, *J. Appl. Phys.* **69** (1991) 975.

[5] J. Handerek and H. Riege, *Ferroelectrics* **128** (1992) 1663.

[6] J.D. Ivers, G. Kerslick, J.A. Nation, L. Schachter, *Enhanced Electron Emission from Ferroelectric Cathodes in Vacuum Diodes*, Cornell Univ. Unpublished Note (1992).

[7] K. Geissler, A. Meinecke, H. Riege, J. Handerek, H. Granzer, and D. Suchland, *Phys. Lett.* **A166** (1992) 84.

[8] H. Gundel, and H. Riege, *Appl. Phys. Lett.* **56** (1990) 1532.

[9] L. Courtois, P. Faure, J. Handerek, H. Riege, and G. Schröder, *Development of the High Power Switches for the LHC Beam Dumping Pulser*, in Proc. European Particle Accelerator Conf. (EPAC 92), Berlin (1992).

[10] H. Riege, Proc. Interdisc. Conf. on Dielectrics, Properties, Characterization, Applications, ed. by Société Française du Vide, Antibes (1992) p. 190.

[11] F. Dothan, H. Riege, *Feasibity of Increasing the Charge State of Ions in a Plasma by Electrons from Ferroelectric Sources,* Note CERN PS/HI 92-01 (1992).