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A LOW-PRESSURE HOLLOW CATHODE SWITCH TRIGGERED BY A PULSED ELECTRON BEAM EMITTED FROM FERROELECTRICS

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

J. Handerek
University of Silesia, Institute of Physics,
P-40007 Katowice, Poland

K. Zioutas,
University of Thessaloniki, Nuclear and Elementary Particle
Physics Section, GR-54006 Thessaloniki

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A new type of low-pressure gas switch is described. The switch is triggered by an electron beam that is emitted from the surface of a ferroelectric sample. The electron beam is generated within the hollow cathode and ejected through a hole of arbitrary shape into the main gap of the switch. The beam current is so high and the electron energy can be chosen such that instantaneous breakdown is achieved with very small jitter. The switch with its ferroelectric trigger requires neither heating nor an auxiliary gas discharge. The fast spontaneous polarization change $\Delta \vec{P}_S$, which is the cause of electron emission, is induced by a high-voltage pulse from an electronic switching circuit.

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High-power gas switches are widely used in pulsed power devices, such as in modulators for radar, in laser systems, or in pulsed magnet systems of accelerators. Conventional switches, such as thyratrons or high-pressure spark gaps, are sometimes the limiting elements in these systems owing to factors such as maximum current density, precision, voltage hold-off capability, or erosion. Recently, a new class of low-pressure gas switches[1,2] were introduced, which significantly improve on current density compared to thyratrons, on precision compared to ignitrons, and on erosion compared to high-pressure spark gaps.

In this paper the authors report on a new type of low-pressure gas switch which is characterized by the direct firing of a high-voltage gap with a high density, low-energy electron beam of short duration. This switch needs neither a heated cathode nor a permanent glow discharge for triggering. The breakdown initialization is direct in the sense that the initial number density of electrons is sufficiently high and no additional charge carrier multiplication process is required to commute the switch resistance from an infinite to a small value in a short time.

The electron beam is emitted from the surface of a ferroelectric material. In order to obtain such an emission the macroscopic spontaneous polarization $\vec{P}_S$ of the sample must be changed in a short time interval (nanosecond range)[3,4] by a fast, high-voltage pulse applied to the sample via partially perforated electrodes.

In Fig. 1 the scheme of an experimental switch is shown, which is used to study the electron beam production from a $(Pb_{0.93}La_{0.07})(Zr_{0.65}Ti_{0.35})O_3$ sample (PLZT), and the breakdown initialization of the main gap. The PLZT sample is placed inside the hollow cathode C_S of the switch between two plane electrodes GE and RE. The whole assembly is filled with a low-pressure gas such that the breakdown behaviour is characterized by the left-hand branch of the Paschen curve. The sample electrode GE facing the main switch cathode C_S is partially perforated (grid or sieve). Between the main cathode and the sample another metallic grid AG of high transparency can be charged with a modest dc potential (±10 to ±200 V) to accelerate or decelerate the emitted electrons and to raise or lower the main breakdown voltage.[1] In the experimental switch of Fig. 1 the auxiliary grid serves also as the main diagnostic tool for determining the features of the emitted electron beam.[5]

Pulse length, current density and energy of the electron beam are controlled by the polarity, rise time and duration of the high-voltage pulse, and by the dc potential applied to the auxiliary grid AG. It is also important to which electrode of the sample the HV pulse is applied. Figure 2a shows electron emission measured on AG, at the end of a positive pulse applied to the grid electrode GE of the sample, whereas Fig.2b demonstrates emission at the start of a negative pulse applied to the rear electrode RE of the sample. Whenever the potential difference between GE and RE reaches a threshold value, $\vec{P}_S$ is rapidly changed and emission takes place. The electron-beam emission can only start from free parts of the ferroelectric surface. When the HV pulse is over, $\vec{P}_S$ in part of the domains and grains reverses back to the original state induced by depolarization fields and mechanical stresses inside the sample. The next HV pulse can be repeated shortly afterwards. The maximum charge $\Delta q_S = \Delta\vec{P}_S \cdot F_0$ that can be emitted during one emission cycle, is limited by the value of spontaneous polarization change $\Delta\vec{P}_S$ and by the non-electroded surface area F_0. In order to enable fast polarization changes the HV_F pulse must have a sufficiently high electric field amplitude. The HV_F pulse must also be generated in a low-impedance circuit to provide a high current amplitude, preferably of the order of 100 A or more, in order to remove or restore compensation changes via the electrodes. For the experimental switch a thyristor pulse generator of 0.2 to 1.3 kV amplitude, 100 ns rise time and 4 to 20 A current amplitude, was used. The whole assembly was operated in air at atmospheric pressure, whereas the discharge volume and the ferroelectric sample were under nitrogen pressure ranging from 0.1 to 100 Pa. The main switch voltage HV_S was limited to a few kilovolts.

The experimental results show that the main discharge of the switch starts when the electron emission takes place (Figs. 2a and 2b). There is evidence that the switch is fired directly by the electron beam. The maximum energy of the emitted electrons depends on the sample thickness d and is of the order of $\Delta\vec{P}_S \cdot d/\varepsilon$, where $\varepsilon = \varepsilon_r \cdot \varepsilon_0$ is the permittivity of the ferroelectric material. The average energy of the emitted electrons should be chosen such that the maximum ionization cross section for the given low-pressure gas atmosphere (typically around 100 eV for most gases) is achieved. If every electron has to perform several ionization acts on its way to the main anode of the switch, starting energies of the order of keV are needed. These are also the maximum electron energies obtained in the experiments described.

The delay and the jitter of the main switch depend mainly on the reproducibility and the jitter of the primary trigger pulse. The electron transport (Figs. 2a, 2b) is controlled by the potential distribution between the rear and the front electrode (RE and GE) of the ferroelectric sample, the auxiliary grid AG, and the main cathode C_S. The most favourable condition is to generate a modest accelerating potential between GE and AG at the moment when the electrons are produced on the ferroelectric surface (Fig. 2b).

The new method of large-volume ionization by electron emission from a ferroelectric medium is ideally suited for precisely switching high voltages and high currents at high-power levels. High-voltage closing switches profit from the absence of heated electrodes, auxiliary glow discharges, or the intermediate stage of laser illumination to produce enough charge carriers for breakdown. The high-density electron beam allows arbitrary discharge cross sections to be chosen, such as multiple channels or ring-shaped discharges. Very low-inductance switches can be built with hollow beams. Also the erosion of the main electrodes will be reduced accordingly. The beam energy, the gas pressure and the discharge geometry can be chosen such that optimum ionization rates are obtained. One can envisage using this effect also for closing-opening switches where a large volume discharge is controlled by the presence of an electron beam. Gas amplification has to be avoided by choosing a mixture of attaching and non-attaching gases.[6]

Adaptation to a large range of power-switching situations can be achieved through the control of the electron beam by such factors as material, geometry and electrodes of the sample, HV pulse characteristics and circuit impedance, auxiliary grid potential and gas pressure.

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FIGURE CAPTIONS

Fig. 1 Scheme of electron-beam-triggered hollow cathode switch. A_S = switch anode; C_S = switch cathode; HV_S = switch charging voltage; Z,R = charging cable impedance and matching resistor; I = insulators, AG = auxiliary grid; GE = grid electrode; RE = rear sample electrode; FE = ferroelectric sample; HV_F = HV pulse for polarization reversal of FE; e^- = electron beam.

Fig. 2 Wave forms of current on AG (top), voltage on A_S (middle) and voltage on GE (bottom) measured with a positive HV_F pulse on GE (a) or with a negative HV_F pulse on RE (b) of the switch shown in Fig. 1. The dc potential of the AG is zero in both cases.

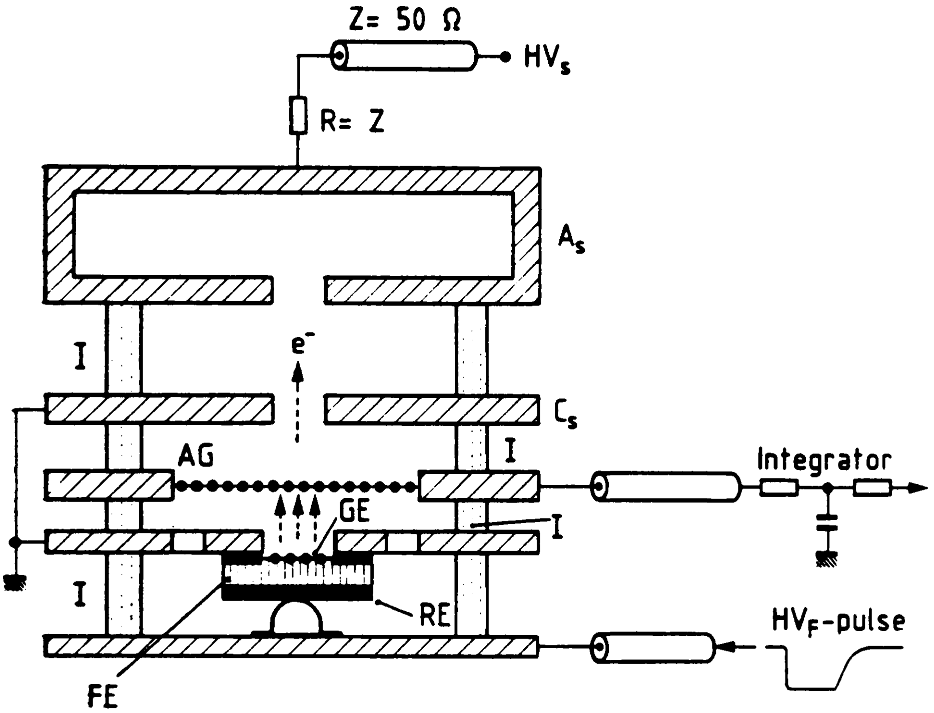
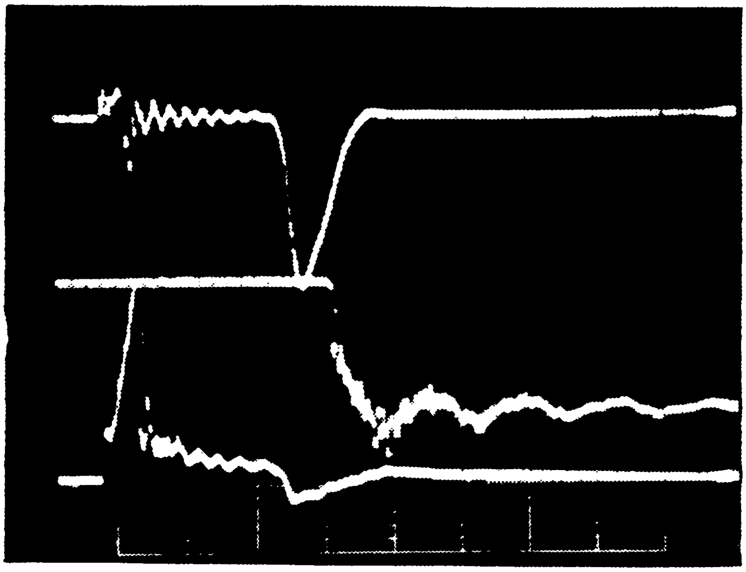


Figure 1



0.1 A/div

200 ns/div

500 V/div

100 V/div

a

0.25 A/div

100 ns/div

500 V/div

200 V/div

b

Figure 2