Profile Measurements on a Pulsed Ferroelectric Electron Beam

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Abstract

Pulsed electron emission from ferroelectrics can be induced by short high voltage pulses being applied via a gridded electrode. The electrons are emitted from the bare part of the ceramic surface. Provided the field across the sample is homogeneous an almost arbitrary geometry of the emitter should be feasible. This can be of particular interest in order to reduce beam emittance or to adjust the emitter to different applications. First beam profile measurements have been performed with emitting areas up to 8 mm in diameter. The dependence of the beam divergence on the total emitted charge has been investigated.

1. INTRODUCTION

Recently a new electron beam source has been introduced, which is based on a fast switching of the spontaneous polarization inside of a ferroelectric material. Besides others, this may be achieved by fast-rising voltage pulses and results in pulsed electron emission with current densities of the order of 10 A/cm^2. Even higher currents seem to be feasible [1-5]. Due to some striking new properties of the "Ferroelectric Electron Beam Source", several applications were proposed [6-8] and an use as an injection source for future accelerators is being discussed [1,9]. Main features of a source suited for this purpose are very high currents and a low emittance of the beam. In comparison with conventional sources, electron emission from ferroelectrics may benefit from the fact that large area cathodes (with reduced current density) and emission into low-pressure gas (where space charge compensation may be achieved) are possible. Both properties are likely to reduce the transversal space charge forces within the beam and hence reduce the beam emittance.

2. EXPERIMENTAL SET-UP

Electron emission has been induced by voltage pulses of negative polarity which were applied to the insulated rear side of the ferroelectric sample. The grid structure of the emitting front side is kept at zero potential. A comprehensive description of a ferroelectric source with its grid electrode, the electrical pulse circuit, and the mechanical set-up may be found in Ref. 3 and 5. The experiment has been performed with a $(Pb_{98}, La_2)(Zr_{95}, Ti_5)O_3$ ceramics of 18 mm diameter and of 1 mm thickness. In order to achieve emission, voltages up to 4 kV with a duration of about 120 ns were applied. A typical pulse wave form is shown in Fig. 1 at the lower trace.

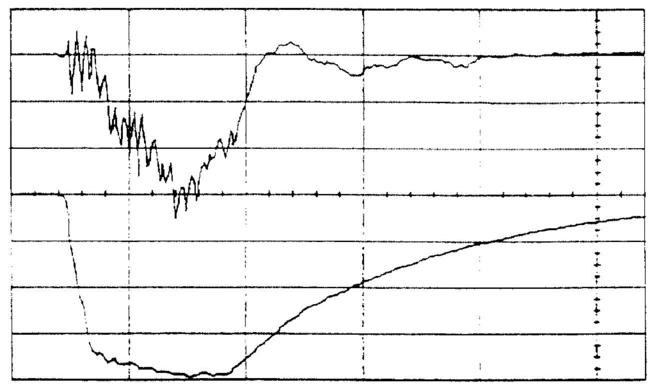

Figure 1. Voltage pulse applied to the ferroelectrics (lower trace, 1 kV/div) correlated to the emitted electron beam current (upper trace, 1mA/div). The time scale is 100 ns/div.

Emission has been investigated in vacuum (1 x 10^{-4} Pa) without any post-acceleration of the electrons. The emitting area of the ferroelectric had about 8 mm diameter. A 50 Ω Faraday Cup of 1 mm in diameter has been used to establish a transversal scan of the electron beam at different distances to the source. The total emitted charge could be measured with a large Faraday Cup which has been placed near the ferroelectrics, capable to integrate all over the emitting surface.

3. RESULTS

In Fig. 1 the emitted electron beam current (upper trace) is shown which was measured with the Faraday Cup (F.C.) described above, time correlated to the applied voltage pulse (lower trace).

In order to measure the total emitted charge, the signals were passively integrated at a proper condensor. Thus, by moving the F.C. transversally to beam propagation direction, 1-dimensional beam profiles were obtained. The charge density distribution measured at different distances z to the source (z = 26 mm, 49 mm, 65 mm) is shown in Fig. 2. It has been normalized to the sensitive area of the Faraday Cup. The value of half-maximum is marked by arrows and the full-width-half-maximum (FWHM) is indicated. Here the

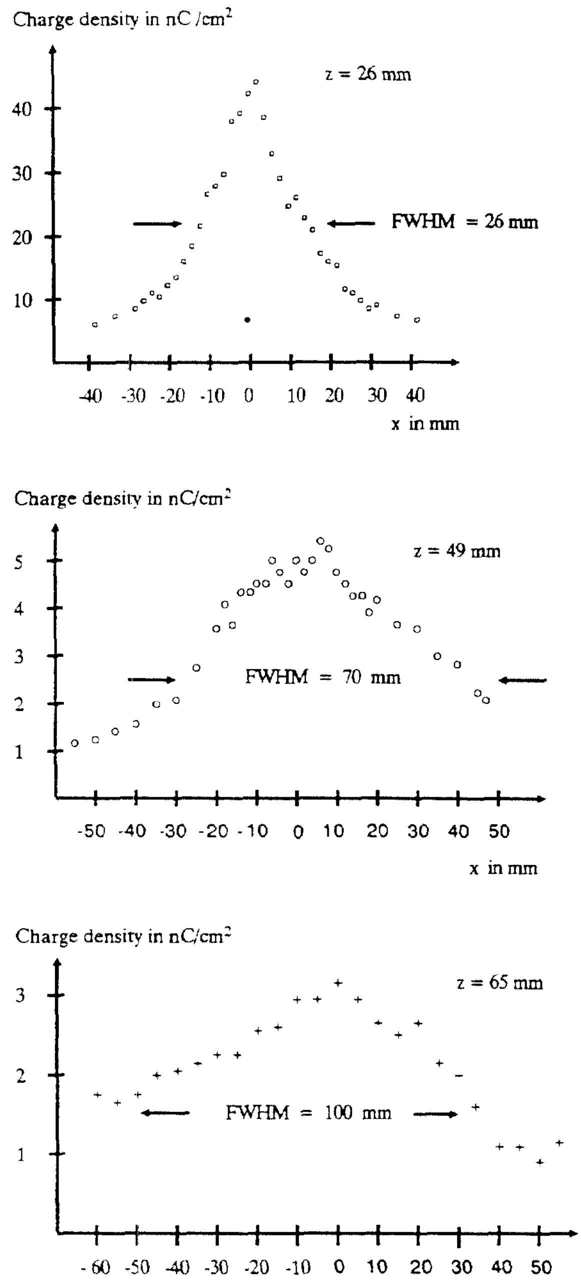

Figure 2. One-dimensional distribution of the emitted charge density at different distances z from the cathode.

position x = 0 corresponds to the beam axis. The distorted symmetry in the charge distribution, visible for z = 65 mm, is mainly due to a non-symmetric propagation tube.

Provided that the beam has a cylinder symmetry, the total emitted charge may be calculated by integrating the profile. Within 10% error, the charge resulting from each profile is 250 nC and is in accordance to the value measured with the F.C. of large area. This corresponds to a charge density of 1 $\mu C/cm^2$ with respect to the emitting area of the source.

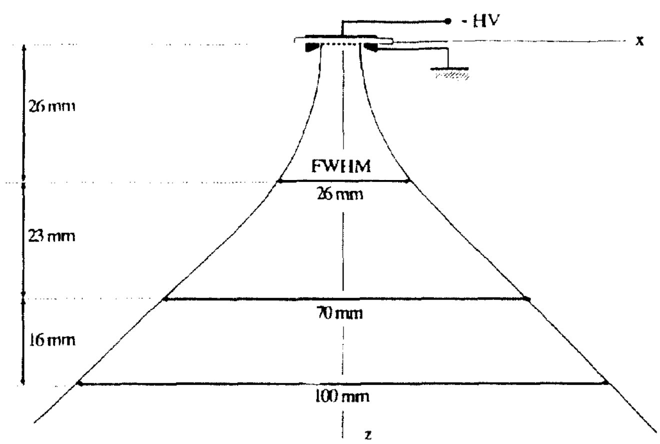

Figure 3. Schematic beam profile for a total emitted charge of 250 nC.

In Fig. 3 the blow up of the electron beam can be seen. Here the FWHM of the charge distributions from Fig. 2 are shown. After a fast initial expansion near to the source, the motion of the electrons is nearly linear for greater distances with an opening angle of 44 degrees.

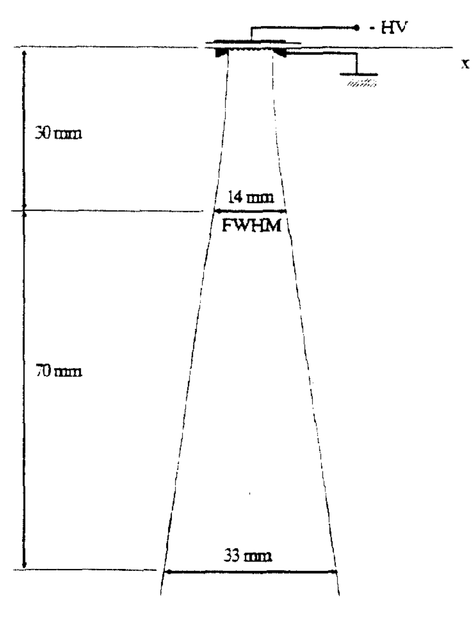

Figure 4. Schematic beam profile for a total emitted charge of 2.5 nC.

The beam divergence of an electron pulse with 2.5 nC total charge, two orders of magnitude lower than described before, is shown in Fig.4. The much lower intensity has been achieved by slightly reducing the applied voltage near the threshold value of the emission effect. An opening angle of about 8 degrees has been determined for this case.

4. DISCUSSION

Profile measurements showed, that there is a strong dependence of the tranversal beam divergence on the total emitted charge. This is in accordance to the assumption that the transversal motion is mainly caused by the repulsive forces of the space charge of the beam itself. The motion of electrons in the direction of propagation is governed by the repulsing forces resulting from the emission mechanism superposed by the influence of the increasing space charge cloud. Since the initial electron energy, originating from the emission process, has been determined to be inhomogeneous [2,3], a quantitative description of the beam is difficult and the beam emittance has not been calculated.

Qualitatively the divergence is characterized by the total emitted charge and the initial electron energy. In case of the 2.5 nC pulse the beam divergence is small. For the 250 nC pulse the transversal forces are much stronger and the divergence is increased as well. In both cases the initial energy distribution was about the same. Nevertheless, there is a region of 10 to 20 mm from the emitting surface, where the electron beam could be focussed before it blows up. This is of practical importance. Additionally, a high-gradient electric field should be used to accelerate the electrons directly from the surface of the ferroelectrics. This will enhance the emitted current (space charge limitation) and will reduce the relative longitudinal energy spread. Furthermore the transversal emittance of the beam should be reduced.

5. ACKNOLEDGEMENT

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6. REFERENCES

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