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HIGH VOLTAGE DISCHARGES AS ELECTRON BEAM SOURCE FOR CALIBRATION MEASUREMENTS

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Abstract. *We have characterized two high voltage glow discharge configurations, with planar cathode and hollow cathode respectively, as electron beam sources. Electron beams having currents between several mA and tens of mA, energy values close to the applied voltage and variable pulse duration between hundreds ns and a few ms were obtained. The simplicity, compactness and unpretentious vacuum operation conditions recommend these electron beam sources for in situ testing and calibration of diagnostic devices.*

Key words: *high voltage glow discharge, electron beams.*

1. INTRODUCTION

In order to calibrate diagnostic devices, such as magnetic energy analysers, X-ray detectors, a pulsed electron source based on a high voltage glow discharge [1], [2], [3] was developed and characterized. The compactness of the electron source is a big advantage, allowing in situ calibration. The electron beam energy depends on the applied voltage (up to 20 kV). Beam currents between several mA and tens of mA were obtained. The pulse duration varies between hundreds of ns and few ms, depending on the external circuit, applied voltage and gas pressure.

2. EXPERIMENTAL SET-UP

Two experimental configurations were used, differing by the cathode type: hollow or planar cathode. In the hollow cathode geometry, a cylindrical, 6 mm inner diameter

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cathode was used, while in the other case the cathode is a planar aluminium plate.

Figure 1a shows the planar cathode discharge geometry. The cathode consists of an aluminium plate. We selected aluminium for the cathode material because it is known that by oxidation the secondary emission coefficient at the cathode surface increases significantly, therefore increasing the electron beam generation efficiency and also the current density. The active region of the cathode is limited by an insulator (Ins) with a 6 mm in diameter central aperture.

Figure 1b shows the hollow cathode configuration. A 6 mm in diameter cylindrical cathode was employed.

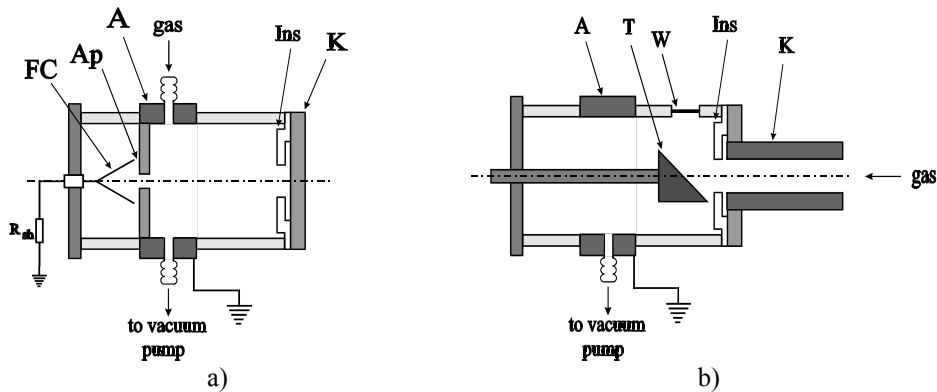


Fig. 1. Experimental set-up:

- a) planar cathode configuration for total electron beam current measurements;
- b) hollow cathode configuration for X-ray measurements;

In both discharge geometries the anode consist of a 30 mm in diameter cylindrical piece, which can be placed at various distances from the cathode. The position of the anode does not have any influence on the electron beam characteristics as long as the distance between electrodes is kept longer than the cathode dark space [2].

The discharge was operated in air at typical pressure values in the range 0.02 - 0.1 Torr.

The X-ray signal produced by the electron beam interaction with a copper target (T) shown in Fig. 1b was measured by a scintillator-optic fiber-photomultiplier chain after passing through a 0.2 mm thick mylar window (W).

Pulsed electron beams are generated by discharging the capacitor C ($C = 0.5$ nF or 3 nF) between the cathode and the grounded anode, through the resistance R_3 ($R_3 = 280 \Omega$), by means of a rotary spark-gap (RSG). The electrical circuit is illustrated in Fig. 2. The electron beam current was measured by means of a shunt resistance (R_{sh}) connected to a Faraday cup (FC) and the discharge voltage was measured by a 1000:1 Tektronix voltage divider.

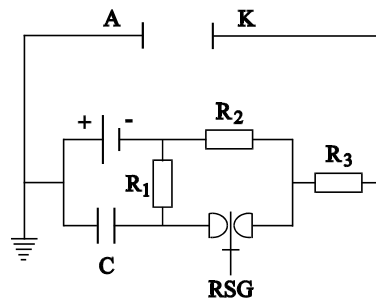


Fig. 2. Electrical circuit.

The fluctuations in the beam current from one shot to another and also the transitions from the high impedance mode of operation to the low impedance regime were greatly diminished by the addition of a small continuous current discharge. This significantly improved the reproducibility of the high voltage glow discharge and of the electron beam parameters [4]. The low current discharge (approx. 100 μA) was produced by using a resistance R_2 ($R_2 = 30 \text{ M}\Omega$) that by-passes the spark-gap switch.

The electron beam energy spectrum was determined with a magnetic analyser placed behind the anode (Fig. 3). The electrons enter the transverse magnetic field (B) through a 0.5 mm on-axis aperture (EA); the 0.5 mm exit slit (ES) is placed 10 mm off axis. The energy resolution of the analyser was estimated at 10%.

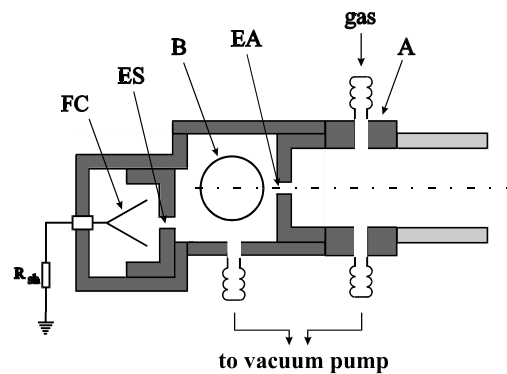


Fig. 3. Magnetic analyser.

3. RESULTS AND DISCUSSIONS

The device is operating in a high voltage abnormal glow discharge regime.

We measured the total electron beam current, the X-ray signal and the energy spectrum both in the planar cathode and in the hollow cathode discharge geometries.

3.1. Total electron beam current measurements

The electron beam current varies with gas pressure p and discharge voltage V , increasing sharply as p and V increase. The maximum values for p and V at which the discharge can be operated are limited by the occurrence of transitions from the high impedance to the low impedance mode of operation.

Typical oscillograms of the electron beam current and discharge voltage are presented in Fig. 4. The electron beam current was measured with the Faraday cup placed on axis at 65 mm from the planar cathode, through a 2 mm diameter aperture. The oscillations observed in the beginning of the voltage characteristic are thought to be due to the capacitor stray inductance [1].

The beam current dependence on the discharge voltage can be closely approximated by the following law:

$$I = a \cdot f(p) \cdot U^m$$

where a and m are constants, and $f(p)$ is a function of pressure. The current-voltage characteristic for a working pressure value of $p = 0.04$ Torr is shown in Fig. 5.

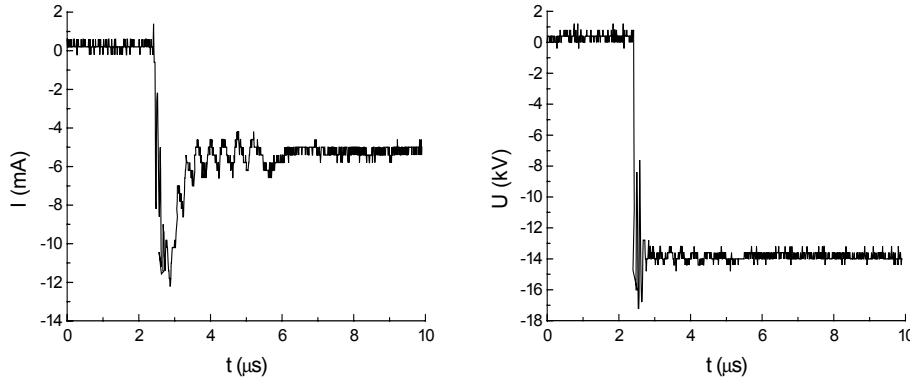


Fig. 4. Electron beam current (left) and discharge voltage (right), in the planar cathode discharge geometry, using $C = 3$ nF, $p = 4 \times 10^{-2}$ Torr

Over the range of these measurements a value of approximately 1.5 was obtained for the m parameter. For the hollow cathode configuration a similar value for m is obtained.

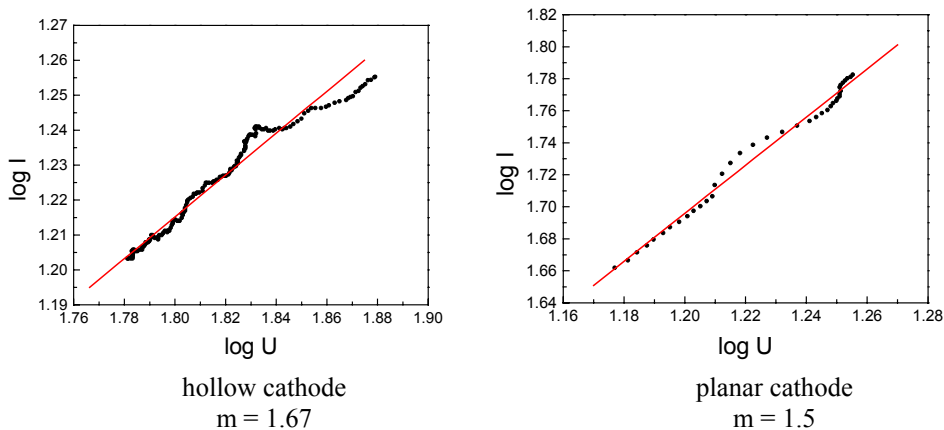


Fig. 5. Electron beam current vs. applied voltage.

3.2. Electron beam energy spectra measurements

The electron beam energy spectra for the planar and hollow cathode geometries respectively, at 14 kV discharge voltage are presented in Fig. 6. The data were measured with the energy analyser shown in Fig. 3, in the plateau region of the beam current (see Fig. 4). For the absolute energy calibration a 2.3 μm thick plastic foil, playing the role of an energy filter, was placed in front of the Faraday cup. The mean energy threshold of the foil is approximately 11.5 keV. Although the relative measurements are very

accurate, for the absolute calibration the precision is lower due to the rather high straggling in energy (range) for the electrons passing through the foil.

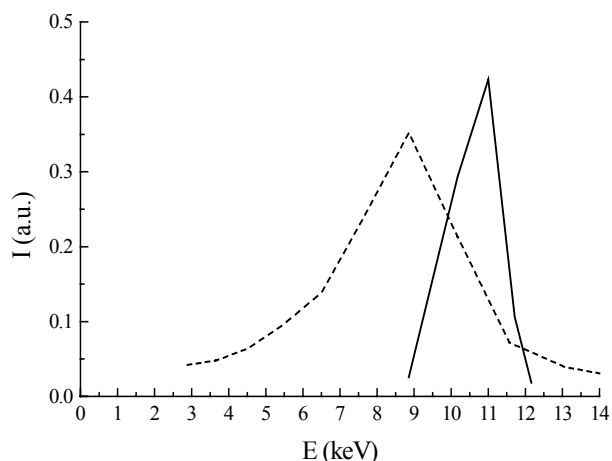


Fig. 6. Electron beam energy spectra
(planar cathode - continuous line, hollow cathode - dashed line)

In the planar cathode configuration, the energy spectrum is narrower (FWHM less than 2 keV) than in the hollow cathode geometry (FWHM - 4 keV).

In the planar cathode geometry, after the initiation of the discharge, the plasma which is formed in the discharge tube plays the role of a virtual anode. Practically the entire discharge voltage is concentrated in front of the cathode, in the cathode fall. The electrons are generated from the cathode surface by secondary emission due to energetic ions and fast neutrals bombardment. These electrons are accelerated in the potential drop in front of the cathode and form an electron beam. The net ionization probability per electron is so small that the electrons extracted from the cathode move through the cathode fall region almost without collision, which can explain the quasi-monoenergetic character of the beam. Most of the ionizing processes take place very close to the cathode surface, where the electron energies are rather low and the ionization cross-section has a significant value.

In the hollow cathode configuration the electron source is the plasma generated inside the cathode. The discharge voltage is divided between an internal voltage drop and the voltage drop in front of the cathode. Electrons emitted by the internal walls of the cathode, as a result of ions bombardment and photoelectric emission, are accelerated through the internal voltage drop and lose most of their energy in ionizing and exciting collisions that sustain the internal plasma. The electrons forming the beam are extracted from this internal plasma and accelerated axially only through a part of the total applied voltage, which can explain the shift of the spectrum maximum towards lower energies.

Lower energy electrons are generated in ionizing collisions of the positive ions from

the plasma which occur throughout the cathode dark space. These electrons are accelerated only through a part of the cathode fall. We measured total electron currents several times larger than the high energy electron current, as predicted in [3].

Taking into account the energy resolution of the magnetic analyser which is approx. 10%, the 2 keV value for the FWHM of the high energy electron beam energy spectrum is a maximal value in the planar cathode configuration. Consequently, this simple and compact discharge configuration is recommended as electron source for in situ calibration measurements, for example in pseudospark-like discharges [5].

3.3. X-ray signal measurements

In Fig. 7 the X-ray signal produced in the hollow cathode geometry by the electron beam interaction with a copper target (7a) and the discharge voltage (7b) are presented. The target was placed at approximately 7 mm from the hollow cathode at an angle of 45° with respect to the electron beam propagation direction.

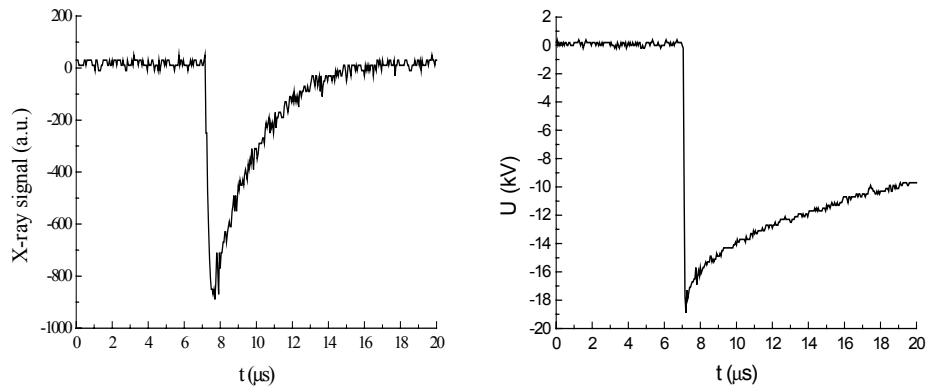


Fig. 7. X-ray signal (left) and discharge voltage (right), in the hollow cathode discharge geometry, using $C = 500$ pF, $p = 4 \times 10^{-2}$ Torr

The abrupt decrease in the X-ray signal compared to the voltage decrease is due to the dependence of the X-ray intensity both with the square of the voltage and with the current intensity. The X-ray attenuation in the mylar window as a function of energy should be also considered.

By varying the gas pressure and discharge voltage the dimensions of the plasma inside the cathode can be modified, therefore a variable diameter of the electron beam and implicitly of the X-ray source can be obtained. By proper adjustment of the pressure and discharge voltage, a point-like X-ray source (less than 1 mm diameter) was obtained, as revealed by the dimension of the beam-target interaction region. The X-ray source parameters make it suitable for different applications, a big advantage over the well-known X-ray tubes being the unpretentious vacuum operation conditions.

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VISOKONAPONSKO PRAŽNJENJE KAO IZVOR ELEKTRONSKOG SNOPA ZA KALIBRACIONA MERENJA

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Opisali smo dve konfiguracije visokonaponskog luminiscentnog pražnjenja kao izvore elektronskog snopa, jednu sa planarnom a drugu sa šupljom katodom. Dobijeni su elektronski snopovi sa strujom napona od nekoliko mA do nekoliko desetina mA, vrednosti energije približne primenjenom naponu i varijabilno trajanje impulsa od nekoliko stotina ns do nekoliko ms. Jednostavnost, kompaktnost i nepretenciozni uslovi za vakuumske operacije daju preporuku ovim izvorima elektronskog snopa za testiranje in situ i kalibraciju dijagnostičkih aparata.

Ključne reči: visokonaponsko luminiscentno pražnjenje, elektronski snopovi

