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Behavior of photocathodes on superficial modification by electrical breakdown

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Abstract

In this work, we present the experimental study and a theoretical approach of the photoemission of rough and smooth photocathodes. The cathode was made of pure yttrium while its surface was morphologically modified. The cathode surface was irradiated by a KrF excimer at normal incidence. The measurements were performed after electric breakdowns between anode and cathode. For the rough cathode the maximum output current was 10.5 A, with a maximum quantum efficiency value of 1.3×10^{-4}. Instead, the smooth cathode provided an output current of 8.4 A with a maximum quantum efficiency value of 7.0×10^{-5}. In this process, the plasma production and the Schottky effect play a fundamental role.
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1. Introduction

New accelerators offer the possibility to realize sophisticated devices for industrial [1] and scientific applications [2–4]. Electron beams can be obtained by different processes. The thermionic process is the most known but the photoelectric one seems to be very promising for getting easily electron beams of high current of low emittance [5,6]. Consequently, these characteristics should promise the best background in helping high brightness electron beams. Metallic photocathodes have a long life time and need only a DC high voltage applied to the cathode to produce electron bunches of the same time duration of laser beam.

Cathodes of high efficiency are also made by heteroepitaxial semiconductors but their manipulation is very complex [7].

The disadvantage of all conventional electron sources is their maximum current, which is dependent on $V^{3/2}$, with V the accelerating voltage. High voltages can not be applied because it is known that they are responsible of the arcs. We also found that the output current generates plasma, which favours discharges. Therefore, to get high extracted currents it is necessary to improve the cathode characteristics in order to avoid plasma in the accelerating gap and to apply high voltage values.

2. Theory

The modified Fowler–DuBridge equation governs the photoemission processes [8]. It contains only two terms for $h\nu > \varphi$, with $h\nu$ the photon energy and φ the work function. The thermionic component is:

$$J_0 = AT^2 \exp(-\varphi/kT), \tag{1}$$

while the 1-photon process component is:

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$$J_1 \cong a_1 A I(t) T^2 (1 - R) \times \left[\frac{1}{2} \left(\frac{h\nu - \varphi}{kT} \right)^2 + \frac{\pi^2}{6} \right]. \tag{2}$$

In the above equations I is the incident laser intensity, R is the target optical reflection, $A = 120\ \mathrm{A/(K^2\ cm^2)}$ is Richardson constant, T is the target temperature, a_1 is the quantum coefficient and φ is the target work function.

In this experiment, the thermionic component is neglected due to the low temperature value. Besides, the emittance is dependent on spot radius and on $h\nu - \varphi$ term [9].

3. Experimental results

The laser beam was led on the cathode surface by a 100 cm focal length lens (L), Fig. 1. A fast photodiode (Ph) was employed to record the laser waveforms. Measurements of the photo-extracted current were performed in a stainless-steel chamber in which vacuum was performed up to 10^{-7} mbar. The utilized cathodes were pure Y disks by 3.1 eV work function.

By a grinder/polisher and a sand-blasting machine two superficial morphologies for targets were produced: smooth and rough, respectively. The anode was made of a stainless-steel grid with 4 meshes per mm^2 having an optical transmittance of 64%. The anode–cathode distance was 5 mm and the maximum applied accelerating voltage was 25 kV.

To diagnostic the current, it was necessary to simulate the cathode stem together with the chamber accessories as a transmission line approximately of 100 Ω characteristic impedance. So, to avoid signal reflections, the extremity of the cathode support was connected to a load resistor of 100 Ω. Picking up the signal of the load resistor, we recorded the electron waveform.

The experiments were performed by a KrF laser of 5 eV. The KrF pulse time duration at FWHM and laser spot were 23 ns and 50 mm^2, respectively.

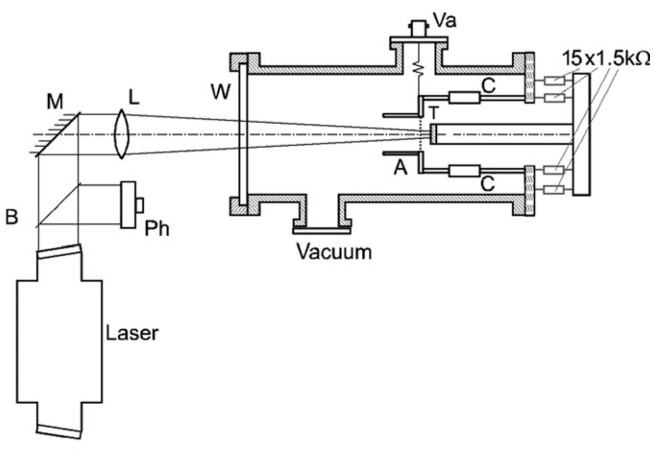

Fig. 1. Experimental apparatus. B: beam splitter; M: totally reflective mirror; Ph: photodiode; L: convergent lens; W: quartz window; Va: high voltage; T: target (cathode); A: anode; C: capacitor.

4. Results

For both utilized cathodes we performed measurements after having operated the vacuum for almost two days. Afterwards, we applied electric breakdowns. By the breakdowns the surfaces become rougher. Generally during the electron extraction the roughness decreases. Fig. 2 shows the experimental results for the rough cathode: peak current is shown as a function of the accelerating voltage, at 12 mJ laser energy. The maximum output current was 10.5 A, reached at 25 kV accelerating voltage. The maximum quantum efficiency (MQE) was calculated by the following formula:

$$\eta_{\mathrm{TQE}}(t) = \frac{J(t) h\nu}{e I(t)}, \tag{3}$$

where $J(t)$ and $I(t)$ are the output current density and the incident laser intensity, respectively. The MQE value was 1.5×10^{-4}. Fig. 3 shows similar results for the smooth cathode in the same conditions of the previous measurements. The maximum output current was 8.4 A, reached at 25 kV and the MQE value was 9.5×10^{-5}, a lower value than the one obtained with the rough cathode.

By means of Figs. 2 and 3, it is possible to see that in the presence of the space charge effect ($0 \div 15$ kV accelerating voltage), the electron emission was higher than the one expected by the Child–Langmuir law. This fact is due to the plasma formation onto the cathode surface that introduced an impedance in the acceleration gap and decreased the effective anode–cathode distance. This behavior allowed the current to overcome the Child–Langmuir curve [10].

In saturation regime ($15 \div 25$ kV accelerating voltage) the electron emission increased with accelerating voltage, owing to the plasma formation and to the Schottky effect. In fact, due to the high electric field on the rough surface, the metal work function decreases, according to the expression:

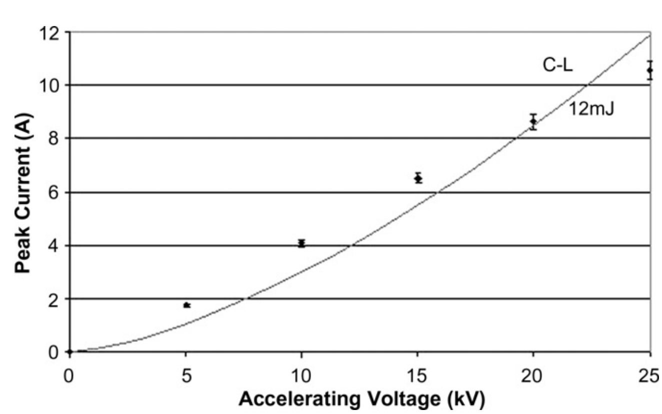

Fig. 2. Experimental results for rough cathode. Dots represent the experimental values, whereas, the line represents the Child–Langmuir law results.

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