EMITTANCE MEASUREMENTS OF ELECTRON BEAMS GENERATED FROM Cu AND DIAMOND PHOTOCATHODES

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Abstract

In this paper the measurements of current, emittance and brightness of the electron beams photoextracted from Cu (1mm thick) and diamond film (4 μm thick) cathodes are reported. Two excimer lasers, Kr-Cl and Xe-Cl working at 222nm (5,6eV) and 308nm (4,02eV), were used to illuminate the cathodes. In order to estimate the beam emittance a slit-slit system was developed. This system allows to value the electron beam distribution function in a transversal trace plane. The laser beams were focused in a 4mm^2 spot on the extraction surfaces, while their energy were fixed at 0,5mJ and 2,5mJ for the Kr-Cl and Xe-Cl lasers, respectively. For both cathodes the highest current was obtained with the lowest laser wavelength, 370mA and 410mA for Cu and diamond cathodes, respectively. The corresponding emittance values resulted to be 18 [π mm mrad] and 27 [π mm mrad]. From these current and emittance values, the normalized brightness beams resulted equal to 4.6x10^{9}A[π m rad]$^{-2}$ for the Cu cathode and 2.3x10^{9}A[π m rad]$^{-2}$ for the diamond film. To obtain a more larger intensity electron beam from Cu cathode, we fixed the Kr-Cl laser spot at 70mm^2 while its energy was increased. In this way, the maximum extracted current was 16,4A at 36mJ laser energy.

1. INTRODUCTION

In order to obtain electron beams of low emittance and high current intensity, metal photocathodes are used. With the excimer lasers, tanks their high photon energy values, the one-photon photoelectric emission from all metal cathodes is possible. Furthermore, the emittance values of the photoextracted electron beams are lower than the thermionic ones[1]. The technique of photoextraction allows to obtain higher quality electron beam than the thermionic one. The particle beams with emittance values equal to zero, namely laminar beams, represent the ideal situations. In actual beams thermal velocities at the source, plasma generation and surface imperfections, always, give rise to no laminar behavior. Then, an important parameter to quantify the beam quality is the beam-emittance [BE].

We define the *x*-plane emittance ε_x as $1/\pi$ times the area A_x in xx' trace-plane [TP] occupied by the points represented by the beam particles at a given value of *z*

$$\varepsilon_x = \frac{A_x}{\pi}, \tag{1}$$

where x' is equal to:

$$x'(z) = \frac{dx}{dz}, \tag{2}$$

analogously for the *y*-plane emittance ε_y.

Let us denote the density function $f_2^0 = f_2^0(x, p_x)$ in the phase-plane [PP] Γ_{2x}. The area occupied by the electron beam in this particular PP satisfying the condition $f_2^0 \neq 0$ is[5] :

$$A_x^0 = \iint_{f_2^0 \neq 0} dx dp_x = p_z A_x, \tag{3}$$

where p_z is particle invariant.
Substituting $p_z = m_0 c\beta\gamma$ in the Eq. (3) we have

$$A_x^0 = m_0 c\beta\gamma A_x, \tag{4}$$

where m_0 is the electron rest mass, $\beta = v/c$ with v the longitudinal electron speed, c the light speed and

$$\gamma = 1\Big/\sqrt{1-\beta^2}. \tag{5}$$

The emittance values have an important property which can be deduced from Liouville's theorem in the PP xp_x with p_x the canonical momentum corresponding to x position coordinates. The areas occupied by the electron beam in PP are invariant quantities and the emittances vary in inverse proportion to p_z, therefore if the beam is not accelerated (p_z = constant) the emittance is also invariant quantity. Commonly the beam is accelerated, p_z is not constant, and it is possible to define an invariant quantity ε_{nx}, nominated «normalized emittance», defined as:

$$\varepsilon_{nx} = \beta\gamma\varepsilon_x. \tag{6}$$

Analogously, is possible to define the BE and the normalized BE in the *y* transversal direction.

The beam-brightness [BB] is defined by the following formula:

$$B = \frac{I}{\varepsilon_x \varepsilon_y}, \tag{7a}$$

while the normalized BB is defined by:

$$B_n = \frac{I}{\varepsilon_{nx}\varepsilon_{ny}}. \tag{7b}$$

This is another beam motion invariant quantity that for axial symmetry beams, $\varepsilon_{nx}=\varepsilon_{ny}=\varepsilon_n$, is equal to:

$$B_n = \frac{I}{\varepsilon_n^2}. \tag{8}$$

The characteristics of the extracted electron beam can be determined valuing the current direction distributions of the selected beamlets.

To analyze the current intensity Faraday cups and/or Rogowski coils are used while the slit-slit method[2] can provided the beamlets direction spreads which are utilized to estimate the emittance value.

To measure the beamlet divergence on x direction the two slits must be parallel to the y axis and to move along the x direction. The first slit, at the x position, allows to pass those electrons having the same x coordinate, while the second one allows to value the distribution function $f_2(x,x')$ in the x' dimension. For an ideal beam and slits of d width, the beam distribution function has the triangular shape with the base equal to $2d$, while it ought to be d at FWHM. Comparing these last parameters with the experimental ones, we can determine the beamlet angular spread. By plotting the distribution function on xx' plane the BE ε_x can be valued.

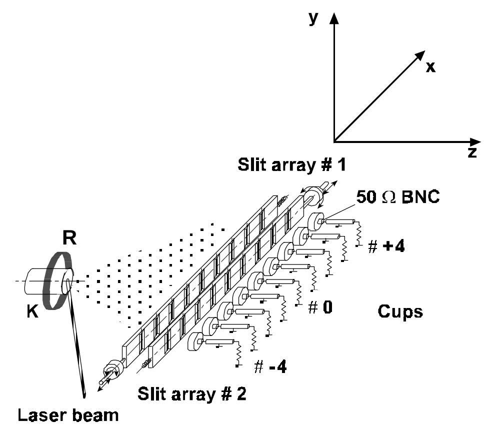

Fig.1: Emittance meter: K cathode; EB: electron beam; R: Rogowski coil.

2. EXPERIMENTAL SET-UP

The UV light was generated by two home made excimer lasers utilizing an Xe-Cl and a Kr-Cl mixture having photon energy 4.02 and 5.6 eV, respectively. These energy values are close to the work function of copper (4.5 eV). The excimer laser utilized was home-made and its characteristics were described in a previous paper[3]. The emittance meter is composed by a horizontal array of small Faraday cups and two arrays of slits made of stainless steel and 20mm distant each other, how the Fig. 1 shows.

The first slit array is placed at 160mm from the cathode while the second one is placed at about 1 mm from the cup flange. All cups are inserted into the grounded flange, insulated and connected coaxially to a 50 Ω BNC. So, the cups are able to detect only the electron current and they are not subject to the electromagnetic noise. The cups are 9 mm in diameter and 11.5 mm distant from each other, and each one corresponds to a slit of the first slit array and to a slit of the second slit array. This facility allows to record nine different currents on laser shot. In order to overcome the limit on the lowest detectable current imposed by the noise oscilloscope level, the slit width have to be appropriately large 1mm. Another requirement on the slit width was also dictated by the mechanical step advance of the movable slit array, which fixed the tolerance of the slit width. Being 0.127 mm the lower mechanical step advance, the slit sides have to present a lower tolerance. So, the slit dimensions were analyzed by a HeNe laser illuminating two corresponding slits. Substantial diffraction phenomenon were obtained when two corresponding slits were positioned in such an way that the diffraction conditions were satisfied. By the diffraction patterns the slit dimension resulted 1 ± 0.02mm. In this case the uncertainty provided by the slits in the x' value was 1 mrad.

An -HV power supplier fed the cathode. The accelerating voltage can vary up to 50 kV. A Rogowski coil[8], having an attenuation factor of 14.8 A/V, allowed to record the total output current.

The UV laser beam was focused on the cathode by a 30cm focal length lens at a grazing incident angle of 20^o. A Dove prism along the laser beam path and near to the output laser beam coupler was used to turn the beam by 90^o in order to reach a low horizontal divergence of the laser beam and as a consequence to impress a circular focused beam on the target. In this way the minimum laser spot area used on the cathode was small less than 4 mm^2. A turbo-molecular pump evacuated the chamber down to 10^{-7} Torr.

3. RESULT DISCUSSION

The cathodes used in this experiment were a 1 mm thick Cu and a 4 μm thick diamond film. To determinate the beam emittance the beam spot was fixed at 4 mm^2 large and the laser energy was 0.5 and 2.5 mJ for the KrCl and XeCl laser, respectively. Under these conditions short-circuits due to the plasma formation were avoided.

For the Cu cathode, with the maximum accelerating voltage applied (50kV), the output current was 370 and 70 mA with the KrCl and XeCl laser, respectively. This values resulted larger than the Child-Langmuir law calculates[4-6]. The higher value current was obtained with KrCl laser. This result can be ascribed to the high photon energy (5.6 eV) of this laser that applied the one-photon photoelectric process, while, with the XeCl laser (4.02 eV) the two-photon photoelectric process was necessary. When the KrCl laser was used the output current pulse was as wide as the laser pulse duration, while when the XeCl laser was used the output current resulted about 85% narrower than the laser one. These behaviors point out that the photoextracted current with the KrCl laser was due mainly to the one-photon photoelectric process, while the photoextracted current with the XeCl laser can be expressed by an order higher than 1 on the laser intensity, implying that a multi-photon mechanism took place[7].

Analyzing the electron beams having the higher current (KrCl laser) we can observe, that the beam was in saturation regime for accelerating voltage major of 40 kV. The output current obtained with the XeCl laser was very low and the electron beam was not affect by the space charge for accelerating voltage higher than about 10 kV. For investigating the BE at 50% of the peak density, we consider the beamlet width at 50% of maximum current recorded. The BE value, utilizing the KrCl laser and 50 kV accelerating voltage, was 18 [π mm mrad] and the corresponding BB was 1.14×10^9 A[π m rad]$^{-2}$. Applying the Eqs. (6) and (8) the normalized BE and the normalized BB values resulted 9 [π mm mrad] and 4.6×10^9 A[π m rad]$^{-2}$, respectively. In order to estimate the bending due to the space charge of the only beamlet, we considered the influence due to maximum current density on electron directions. In this way the maximum bending was estimate to be 50 μrad. This value is two orders lower than that obtained by the uncertainty of the slits and we can say that the beamlet transversal propagation was not influenced by space charge effects. The BE value, utilizing the XeCl laser and 50 kV accelerating voltage, was 29 [π mm mrad] while the BB value was 0.08×10^9 A[π m rad]$^{-2}$. Also in this case, applying the Eqs. (6) and (8) the normalized BE and the normalized BB resulted 15 [π mm mrad] and 0.34×10^9 A[π m rad]$^{-2}$, respectively. Analyzing the electron beams obtained with KrCl laser on the accelerating voltage the BE decreased versus the accelerating voltage while the BB increased, how preview theoretically. The corresponding normalized BE and BB values versus the accelerating voltage were not constants contrary to the theory. These behaviors can be ascribed to the space charge regime at low accelerating voltage, to no-paraxial approximation of the beam and to no-monoenergetic particles that contributed to increase the transversal electron temperature.

Analogously we determined the electron BE and BB values using the diamond film and the two lasers. Also in this case the BE value decreased versus the accelerating voltage, while the extracted current and BB values increased. At the maximum accelerating voltage (50 kV) and using KrCl laser the BE and BB values, were 27 [π mm mrad] and 0.56 $\times 10^9$ A[π m rad]$^{-2}$ respectively while with the XeCl laser these values were 32 [π mm mrad] and 0.1 $\times 10^9$ A[π m rad]$^{-2}$. Applying the Eqs. (6) and (8) the normalized BE and BB values resulted 13 [π mm mrad] and $2{,}3 \times 10^9$ A[π m rad]$^{-2}$ for the KrCl, while using the XeCl laser these values were 16 [π mm mrad] and 0.39×10^9 A[π m rad]$^{-2}$.

In order to obtained electron beams of larger intensity from the Cu cathode, we fixed the KrCl spot laser at 70 mm^2 and the accelerating voltage at 50 kV. Figure 2 shows the photoextracted current versus the laser energy. The maximum extracted current, 16.4 A, was obtained at 36 mJ laser energy.

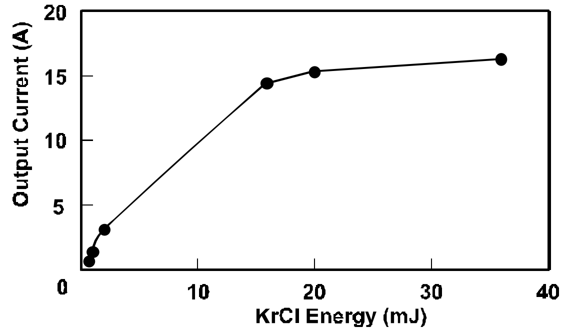

Fig.2 Current extracted from the Cu cathode with 70mm^2 laser spot and 50 kV accelerating voltage.

By the Fig. 2 we deduce that the quantum efficiency is not a constant but it decreases as laser density increases. It seems that the space charge effects, which are present also at highest accelerating voltage, contributed to decrease the quantum efficiency. The total extracted charge was about 200 nC.

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