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EMISSION AND EMITTANCE MEASUREMENTS OF ELECTRON BEAMS GENERATED FROM CU AND DIAMOND PHOTOCATHODES

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Abstract

We report on the electron emission from Cu and diamond film cathodes irradiated with UV excimer laser beams. The beam emittance values utilizing a new experimental setup composed by two movable slit arrays and 9 small cups also are presented. The phase space areas occupied by the electron beam was determined measuring the electron current on beamlet direction by the small cups and the slit arrays. With a 4 mm2 beam spot and 0.5 mJ KrCl laser energy the maximum currents from the Cu and diamond film cathode was 370 and 200 mA, respectively. The corresponding emittances were 18 and 50 [p mm mrad]. From these values the normalized beam brightness were estimated to be 4x109 A[π m rad]$^{-2}$ for Cu cathode and 0.33x10^9 A[π m rad]$^{-2}$ for diamond cathode.

I – INTRODUCTION

New electron sources utilizing metal photocathodes have demonstrated the possibility of getting emittances much lower than those provided by thermionic ones[1] and electron currents also more larger than those calculated by the Child-Langmuir law[2,3]. Due to high photon energy, UV light allows to extract electrons from metal cathodes applying the one-photon photoelectric process.

The quality of the extracted electron beam was determined by current and divergence measurements. Generally in this experiments Faraday cups and/or Rogowski coils are used to detect the output current while the beam propagation can be determinate by the beamlet divergence measurements using the slit-slit method[4]. This method provides the beamlet spread and then the emittance value.

The electron beam distribution function, for a beam propagating along the z direction, is dependent on the x and y coordinates and on the p_x and p_y momenta. By assuming a constant p_z greater than p_x and p_y, the electron beam distribution function, $f(x,x',y,y')$, in the xx'

phase space, is:

$$f(x,x') = \iint f(x,x',y,y')dydy' \quad (1)$$

with $x' = p_x / p_z$.

The emittance is:

$$\varepsilon_x = A_x / \pi \quad (2)$$

where A_x is the phase space area occupied by the electron beam in the xx' plane corresponding to $f(x,x') \neq 0$. The normalized emittance on x direction is:

$$\varepsilon_{xn} = \varepsilon_x \beta\gamma \quad (3)$$

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

$$\gamma = 1 \big/ \sqrt{1-\beta^2} \quad (4)$$

The normalized beam brightness, by assuming $\varepsilon_x = \varepsilon_y$, is calculated by the following formula

$$B = \frac{I}{\varepsilon_{xn}^2} \quad (5)$$

where I is the electron current.

When two small slits separated by a fixed axial distance are utilized to measure the beamlet divergence on x direction, they must be parallel to the y axis and to move along the x axis. The first slit allows to pass those electrons having the same x position of the slit, while the second slit scans the distribution function $f(x,x')$ on the x' dimension. From theoretical considerations, supposing a paraxial beam and slits of d width, the beam distribution function width ought to be $2d$ at 0% its intensity, while it ought to be d at FWHM. Comparing these last parameters to the experimental width values one can determine the beamlet angular spread on the x position. Plotting the distribution function on xx' space the area occupied by the $f(x,x')$ determines the beam emittance.

II – EXPERIMENTAL SET-UP

The UV light was generated by two home made excimer lasers utilizing a Xe-Cl and a Kr-Cl mixture. The laser characteristics were described in a previous paper[5]. The laser photon energy was 4.02 eV for the XeCl and 5.6 eV for the KrCl. These energy values are close to the work function of copper (4.5 eV) and of natural diamond (5.5 eV).

In Fgure 1 the sketch the experimental setup containing also the acceleration chamber is shown. Fig. 2. shows a detailed of the emittance meter composed by an horizontal array of small Faraday cups and two arrays of slits. The first slit array is placed at 160 mm from the cathode while the second one is placed near the cup array. Each cup was 9 mm in diameter and 11.5 mm distant from the center of the neighboring cup. 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 are not subject to the electromagnetic noise. Each slit array have got 9 slits in correspondig of the cups. This facility allows to record nine different current 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 is also dictated by the mechanical step advance of the movable slit array, which fixes the slit width upper limit. The cathode is 20 mm in diameter and is fixed at about 180 mm apart the cup array as well as the distance between the slit arrays. The slits supports were made of stainless steel. The slit dimension were analyzed by a HeNe laser in order to measure the slit shape quality. 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 edge dimensions of the slits was estimated to be 1 ± 0.02 mm. In this case the uncertainty provided by the slits on the x' was 1 mrad. An HV power supplier fed the cathode. The accelerating voltage can vary up to 50 kV. A Rogowski coil[6], having an attenuation factor of 14.8 A/V allowed to recorded the total output current.

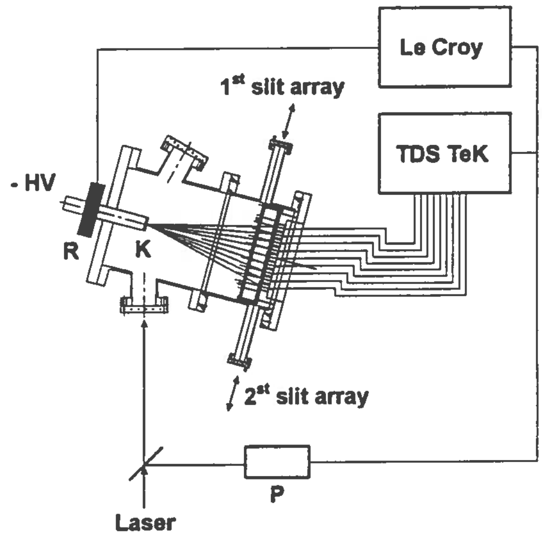

Fig. 1 – Experimental set-up of the accelerating chamber: -HV: Negative high voltage; R: Rogowski coil; K: Cathode; P: Photodiode.

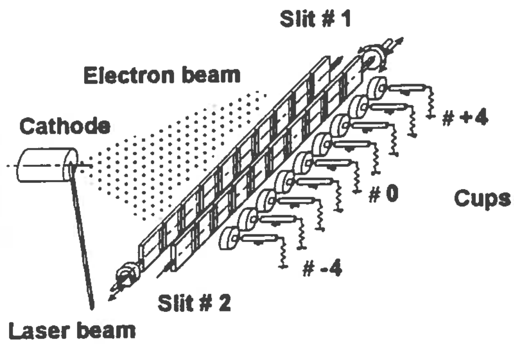

Fig. 2 – Emittance meter.

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

III – RESULT DISCUSSION

The cathodes used in this experiment were a 4 microns thick diamond film and a 20 mm in diameter Cu disc. The diamond film was grown on Si(100) substrate by the well-established arc-discharge plasma chemical vapor deposition procedure from methane-hydrogen mixture. The concentration of methane was 4% and the total gas pressure was 100 Torr. The substrate temperature was about 800 °C.

In this experiment plasma on the cathode was generated which modified the beam propagation for space-charge dominated electron beams[7] and in order to avoid short-circuit due to the plasma and to reduce the thermionic emission, mechanically polished mirror-like surfaces were used for Cu cathodes eliminating the surface microtips, while for diamond cathodes before photoemission processes an set of laser pulses (10^2-10^3 pulses) was applied to remove impurities/adsorbed layers and to stabilize the photocurrent signals.

To determinate the beam emittance the laser spot was 4 mm^2 large and the laser energy 0.5 mJ. This value was limited owing to the short-circuits due to the plasma formation. At the maximum accelerating voltage applied the output current obtained from Cu cathode were 370 and 30 mA with the KrCl and XeCl laser, respectively, while for the diamond cathode under the same experimental conditions the output current were 200 and 100 mA for the KrCl and the XeCl laser, respectively. The higher current values were obtained with the KrCl laser and this behavior can be ascribed to the higher photon energy of this laser which applies in almost all cases the one-photon photoelectric process, while with the XeCl laser the two-photon potoelectric process is necessary to get electron emission.

The emittance investigations were done particularly to the electron beam having a high current.

Fig. 3 shows the cup currents obtained fixing the first slit and moving the second one for the Cu cathode with 50 kV accelerating voltage. At the maximum current density the bending of the beam due to the space charge of the only beamlet was estimate to be 50 μ rad. This value is very little and we can consider the beamlet was not affected during the interaction with the first slit. The phase space for the electron beam generated with KrCl laser are showed in Fig. 4 for Cu cathode 50kV accelereting voltage. The emittance values at 50 kV accelerating voltage were 18 and 50 [π mm mrad] for the Cu and the diamond cathodes, respectively. and the corresponding normalized beam brightness were 4×10^9 A[π m rad]$^{-2}$ and 0.33×10^9 A[π m rad]$^{-2}$.

One can note that the beam generated from Cu cathode have a higher intensity and a lower emittance value than those of the diamond cathode. The low emittance value obtained with the Cu cathode could be due to its mirror-like surface which allows to accelerate the electrons along the electric field lines while the diamond surface was not mechanically worked and its surface was not mirror-like. The Cu work function is lower than the one of diamond and the one-photon photoelectric process generate electrons with an high initial energy from Cu cathode in spite to the electrons generated from diamond but this energy discrepancy did not affect the transversal temperature of Cu electron beam.

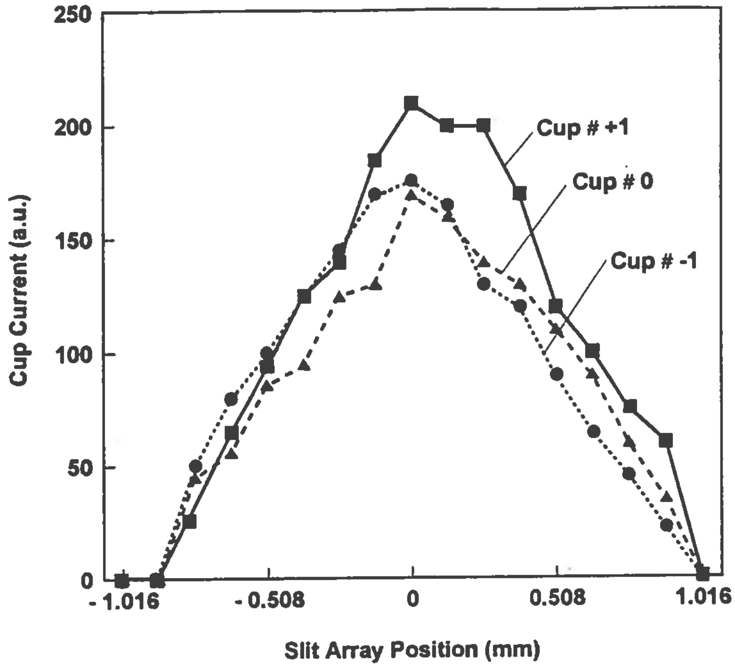

Fig. 3 – Typical beamlet profile of the slit-slit measurement for the Cu cathode at 50 kV accelerating voltage.

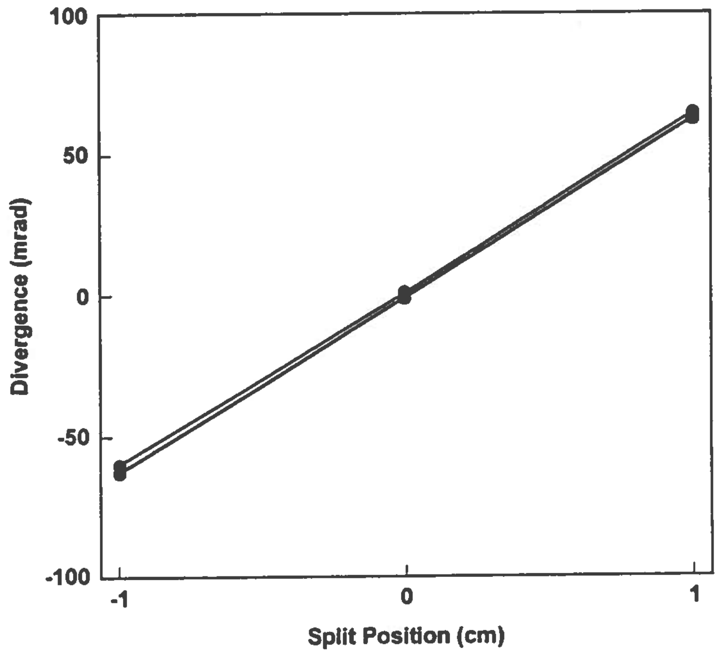

Fig. 4 – Phase space diagram of the e-beam generated from the Cu cathode at 50 kV accelerating voltage.

In order to investigate the maximum current we have increased the spot laser on the cathode (70 mm^2) detecting the output current as a function of the KrCl laser energy from the copper cathode. Fig. 5 shows the output current versus the laser energy. In this experiments the output current waveform is similar to the laser one. In fact the current pulse width is very near to the one of the laser. Fig. 6 shows the waveforms relative to current and to the laser pulse. This behavior is very interesting to produce electron beam of time duration similar to that of the laser.

The maximum current extracted from Cu cathode was 15.4 A. The total extracted charge was 185 nC and the photon efficiency was 5.2×10^{-5}.

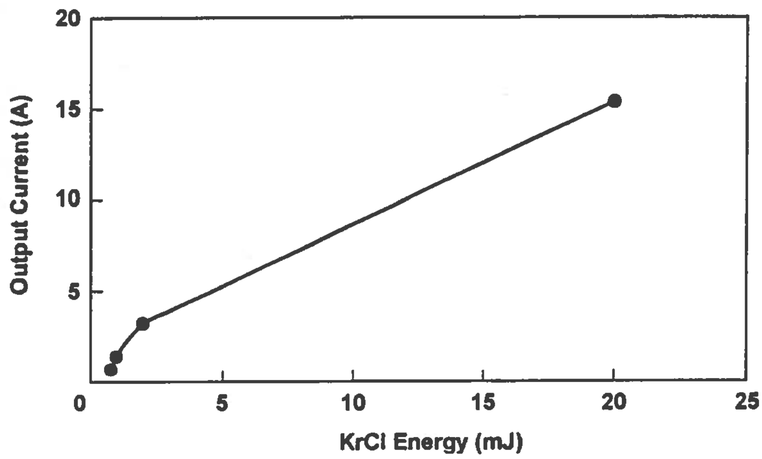

Fig. 5 – Output current on the KrCl laser energy for a Cu cathode having a 70 mm^2 at 50 kV accelerating voltage.

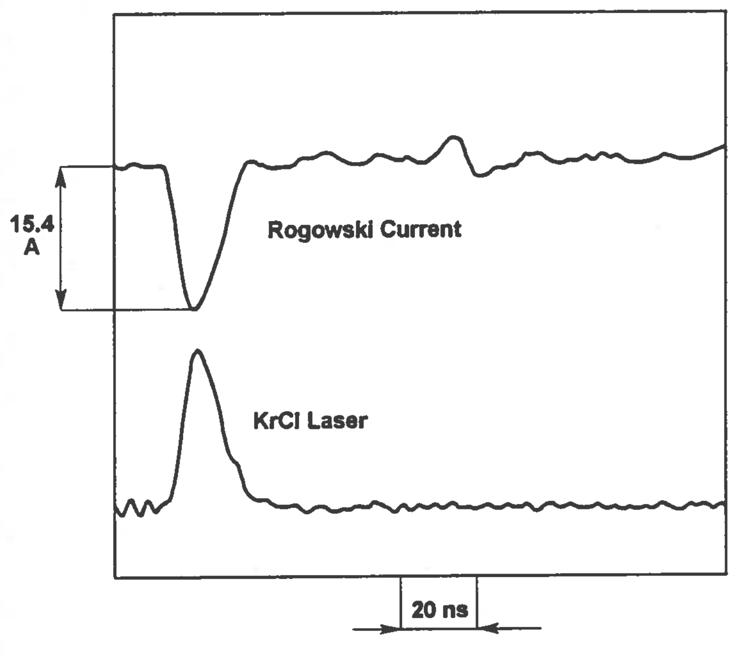

Fig. 6 – Waveforms of the Rogowski coil and KrCl laser pulse relative to the 70 mm^2 Cu and 20 mJ laser energy.

IV – CONCLUSION REMARKS

We have analyzed the electron generation from a Cu cathode and a diamond film cathode illuminated by two excimer laser. The KrCl excimer laser produced a total current higher than that obtained with the XeCl laser. This result can be ascribed to the high photon energy of the KrCl, which applied the one-photon photoelectric process.

Measurements of the beam emittance were performed with the slit-slit method which was able to measure the beam energy spread on x position. With a 4 mm^2 beam spot the maximum current from the Cu cathode was 370 mA while from the diamond cathode was 200 mA. The corresponding emittance values were 18 and 50 [π mm mrad] for the Cu and the diamond cathode, respectively. Considering the normalized beam brightness, $4x10^9$ A[π m rad]$^{-2}$ for Cu cathode and $0.33x10^9$ A[π m rad]$^{-2}$ for diamond cathode, we conclude that electron beam generated from Cu cathode present the better beam quality.

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