Experimental Characterisations of the Electron Beams Induced by Excimer Lasers on Al Targets

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Abstract

This work compares the experimental results relative to electron beam emittance and current photo-extracted from aluminium targets utilising an XeCl (308 nm) and a KrCl (222 nm) excimer laser. The maximum laser energies utilised were limited by the plasma density on the cathode which short-circuits the diode. The output current was higher with KrCl laser than with the XeCl laser while the lower emittance was obtained with the XeCl. These results can be ascribed mainly to the difference between laser photon energy and the target work function. The lower normalised transverse emittance was 24 π mm mrad for a current density of 8 A/cm^2 and the higher current density value reached was 30.6 A/cm^2. By computer simulation we found an output current of only 6.4 A/cm^2 and then also a lower emittance, (20 π mm mrad). The higher experimental output current can be attributed to the plasma formed on the cathode which modifies the Child-Langmuir law conditions.

1. INTRODUCTION

The new electron accelerators need high brightness electron beam injectors in order to increase the beam luminosity. These devices can be realised using RF photocathode guns which have confirmed the possibility of getting emittances very lower than those provided by thermionic cathodes [1]. In particular metal photocathodes seem to be very promising especially when excimer lasers are used to irradiate their surface [2] and they seem also to provide beam emittances much lower than those provide by thermionic ones [3].

Excimer lasers allow the application of one-photon photoelectric processes even with metal targets because of their high photon energy which is comparable to the metal work function. This condition is interesting for extracting electron beam of low emittance, even if space charge effects and target increasing temperature degrade the beam quality.

The emittance due to the potential distribution and to space charge effects can be easily calculated by computer simulation while the contribute on the emittance due to the source quality can be only measured.

We report here on the output current and beam emittance experimental results for an Al photocathode irradiated with two different excimer lasers; the XeCl working at 308 nm and the KrCl working at 222 nm. Because the Al work function is 4.2 eV, the Richardson equations for XeCl photons are [4],:

$$J_{308} = a_{308}\ T^2 I \exp[(4.02 - \varphi)/kT] \qquad (1)$$

while for KrCl photons:

$$J_{222} = a_{222}\ I(5.6 - \varphi)^2/2k^2 \qquad (2)$$

where a_{308} and a_{222} are the Richardson coefficients respectively for XeCl and KrCl laser, I is the laser intensity, T is the target temperature and k is the Boltzmann constant.

2. EXPERIMENTAL SETUP

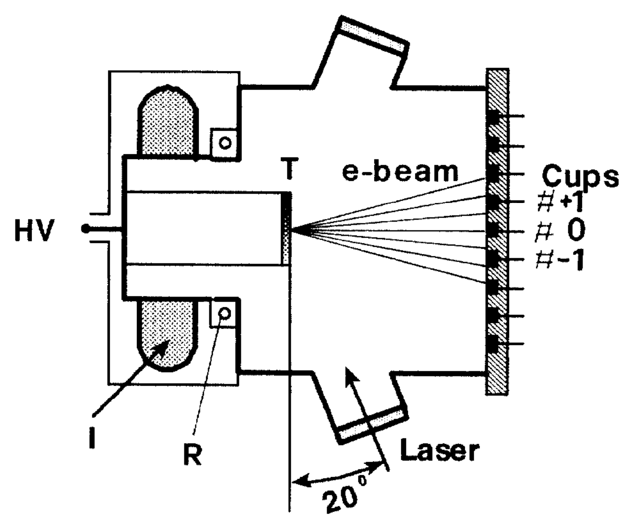

Figure 1. Accelerating chamber: T: target; I: insulator; HV voltage supplier, R Rogowski coil.

Fig. 1 shows the experimental setup formed by an accelerating chamber having two symmetric quartz windows and an array of small Faraday cups in front the cathode. Each cup is 9 mm in diameter and 11.5 mm distant each other. All cups are placed into the grounded flange by an insulator and connected to a 50Ω BNC. In this way the cups are able to measure only the electron beam current and to prevent the electromagnetic noise.

A rod, connected to the power supplier, supports the cathode (T).The accelerating voltage varied from 5 to 20 kV. A Rogowski coil and an insulator ring connected the rod to the chamber. The laser beam was focused on the cathode by an 30 cm focal length lens at a grazing incident angle of 70^{0}.

During the experiment the chamber was evacuated up 10^{-7} mbar by a turbo-molecular pump.

In order to reduce the thermionic emission and the plasma formation on the cathode, mechanically polished samples, mirror-like, having a high reflectivity (60% at 308 nm and 36% at 222 nm) were used.

During the experiments two digitising oscilloscopes a Tek. 540 (1Gs/s) and a Tek. 620 (2GS/s) recorded the waveforms.

3. EXPERIMENTAL RESULTS

We fixed the laser spot on the cathode at 2 mm in diameter and the laser energies utilised were chosen in order to achieved the maximum electron intensity without plasma emission. For the XeCl laser the incident energy was 5.6 mJ while for the KrCl laser it was of 3.8 mJ. These values are dependent on chemical-physical proprieties of targets.

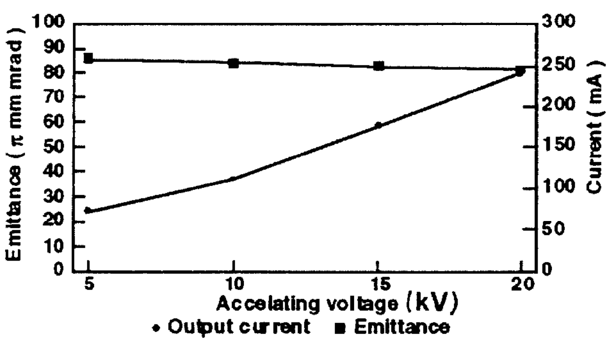

Figure 2. Output current and emittance as a function of the accelerating voltage utilizing the XeCl laser. The laser energy was 5.6 mJ.

Fig. 2 shows the output current and the emittance values as a function of the accelerating voltage for the XeCl laser. The XeCl photon energy is lower than the Al work function but electrons can be extracted as can confirmed by Eq.(1).

From Fig. 2, can be seen that as the voltage increases as the output current increases while the emittance decreases. The beam is space charge dominate and its normalised transverse emittance at 20 kV is 24 π mm mrad.

Fig. 3 shows the output current and the emittance as a function of the accelerating voltage obtained with the KrCl laser. In this case the emittance and the output current values are higher than those obtained with the XeCl laser but their behaviour is similar to that obtained with the XeCl laser. At 20 kV of accelerating voltage, an output current intensities of 960 mA and with a transverse emittance of 39 π mm mrad have been achieved.

In both cases the electron beams show a strong dependence on accelerating voltage indicating that it is dominated by space charge effects.

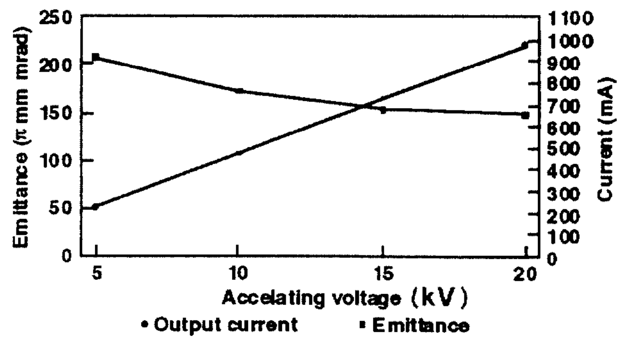

Figure 3. Output current and emittance as a function of the accelerating voltage utilising the KrCl laser. The laser energy was 3.8 mJ.

Fig. 4 shows the waveforms of the output current detected by the Rogowski coil I_R, by the cup # 0, # 1, and # -1. The time duration of the output current measured by the cup # 0 is larger than those measured by the cups # 1 and -1, while the time durations of these two last cups are larger than that recorded by the Rogowsky coil which is similar to the laser pulse time duration. From these results we can infer that the central part of the electron beam is strongly affected by space charge.

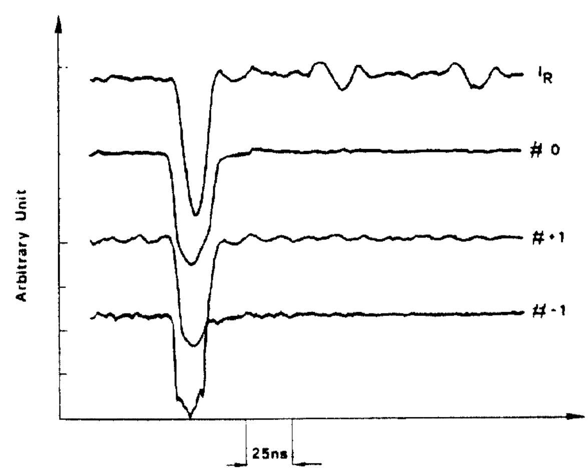

Figure 4.Waveforms of output current detected: IR by Rogowski coil, by the cup # 0, # +1 and # -1.

The applied voltage favours the output current and, although the large current obtained by KrCl laser irradiation, we cannot reach the saturation regime.

Increasing the applied voltage, and consequently the output current, it seems that the physical condition in the anode-cathode region are changed, due to the presence of a plasma

The normalised peak brightness, defined as

$$B = I_e/\varepsilon_n^2 \qquad (3)$$

where I_e is the electron current and ε_n is the normalised emittance, has a value of 0.43 10^9 A[π m rad]$^{-2}$ for XeCl laser and 0.63 10^9 A[π m rad]$^{-2}$ for KrCl laser. Therefore, although the KrCl laser produces electron beams with higher emittance, the brightness becomes higher than that provided by XeCl laser due to the large current extracted. This last one is much larger than that theoretically calculated by EGUN code. The maximum current density extracted in this work is 30.6 A/cm^2 against 6.4 A/cm^2 provided by code. The large discrepancy between the experimental result and the theoretical calculation has been found also by other authors [5] and we considered to be due to the plasma formation on the sample surface. By the computer simulation we found a space charge limited output current of 200 mA. The data are shown in Fig. 5. From this figure we can estimates that the theoretical emittance is 71 (π mm mrad). The simulation data can be easily compared with XeCl experimental data. The experimental beam emittance is higher than the theoretical one, this can be due to the higher experimental output current and to the target surface quality.

With the KrCl laser the output current is much higher and, of course, we expect an higher space charge effect.

4. CONCLUSIONS

Irradiating an Al target by a KrCl excimer laser, with a photon energy of 5.6 eV, an output current density of 30.6 A/cm^2 has been obtained.

The quantum efficiency is calculated to be 1.8 x10^{-5}

5. REFERENCES:

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