ELECTRON EMISSION FROM A NIOBIUM PHOTOCATHODE

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Abstract

We report on the experimental results of a niobium photocathode illuminated by two different wavelength lasers operating at 308 and 222nm.The output current was recorded by a fast Rogowski coil while the beam angular distributions by small Faraday cups placed in front the beam. For λ=308nm the quantum efficiencies were 1.0×10^{-6} and 2.1×10^{-6} for p and s-polarisation, respectively. When the 222nm light was used they were 1.6×10^{-5} for p-polarisation and 5.3×10^{-5} for s-polarisation. In both cases the s-polarisation got efficiency higher.

The maximum output current was 1.25A, τ=10ns; this value was obtained utilising the shortest wavelength laser, 4.9 mJ and 20 kV accelerating voltage. By the electron beam angular divergence, we determined the upper limit normalised emittance. The shortest value found of upper limit emittance was 7 [π mm mrad], achieved by the s-polarised radiation, at λ=308nm.

1 INTRODUCTION

Electron beams of good geometric quality can be generated from metal photocathodes[1]. They are very promising and efficient particularly if stimulated by pulsed ultraviolet lasers. These photocathodes can also generate electron beam pulses of the same time duration of laser pulse with a fast rise time. The cathode materials are inexpensive, have a long live time and operate at modest vacuum values.

The electron photoemission is dependent on the incident radiation polarization on the target and its intensity. In this work we studied the generation of an electron beam induced by a p-polarised and a s-polarised light. In this way we can study the electron beam characteristics due to volume (p-polarisation) and surface (s-polarisation) photoextraction, respectively[2].

Particularly, we investigated the quantum efficiency for the volume and surface electron generation considering the polarization of the light and the incident angle. The experimental values were compared to the values obtained with a KrF laser[3]. Besides, we determined the upper limit emittance values and the corresponding brightness of the electron beam.

2 THEORY

To explain the selective features of the electron photoemission one has to resort to the quantum theory. We limit ourselves to give an explanation of the dependency of the photoemission on the light polarisation state. Our treatment is based on the ideas reported in Ref.4, taking into account both volume and surface effects in the process. On the other hand, we deal in the single particle approximation for the so-called primary electrons, i.e. those coming out from a light scattering process in the bulk and/or the surface of the metal plate. Furthermore, the emission is sketched in the following three sub-processes: 1) the optical excitation of the initial state, 2) the diffusion in the bulk and the crossing of the surface, 3) the outgoing final state.

The initial and outgoing states in steps 1) and 3) are described by the wavefunctions $|i\rangle$, bounded in the lattice, and $|f\rangle$, an unbounded state extending out of the metal. For the treatment of the step 2), we introduce two energy dependent coefficients. The probability $D(E)$ that an electron gets the surface, if it has been excited into an optical absorption length ~$\frac{1}{\alpha}$ and its mean free path is s(E), is estimated by;

$$D(E) = \frac{\alpha\, s(E)}{1+\alpha\, s(E)} \qquad (1)$$

The transition coefficient of the surface barrier is roughly approximated by a step function

$$T(E) = u\,(\frac{k_{\perp}^2\hbar^2}{2m} - \phi) \qquad (2)$$

where $k_{\perp}$ is the orthogonal wavevector component to the surface and ϕ is the work function of the material. For the laser frequency ω, the corresponding photocurrent takes the form:

$$I(\hbar\omega, E) = \frac{2\pi e}{\hbar}(\frac{e}{mc})^2 \sum_{i,f} \left|M_{f,i}\right|^2 D(E)T(E)\delta(E_f - E_i - \hbar\omega)\delta(E - E_f) \qquad (3)$$

where the summations is extended to all final electron states of energy E, excited by all possible initial states by absorbing $\hbar\omega$. By a perturbative computation in the Bethe-Salpeter approximation[4], the matrix elements $M_{i,f}$ are given by

$$M_{i,f} = -i\hbar\langle f|\frac{\partial A}{\partial z}|i\rangle - \frac{i}{\omega}\langle f|\vec{A}\cdot\nabla V_B|i\rangle - \frac{i}{\omega}\langle f|\vec{A}\cdot\nabla V_S|i\rangle \quad (4)$$

where the first term comes from the changes of the electromagnetic field through the interface (the surface optical effect), the second and the third one takes into account the volume V_B (volume photoemission) and the surface V_S (surface photoemission) potential drift effects.

In the above formula for the photocurrent the volume photoemission contribution becomes dominant typically for s(E) ≥ 10 Å. On the contrary, for s(E)≤ 5 Å the surface contributions are the most important. But in this case the first and last terms in (4) have a dependency on the incident angle, roughly proportional to $\sin^2\vartheta$. Furthermore, since s(E) has to be small enough also in comparison with the plasma length, the surface effects are relevant when the photons have energy less than the plasma energy.

The study of the surface photoemission gives information about the local density of the outermost states. Finally we remark that an exact theoretical analysis of the surface photoemission is far to be complete.

3 EXPERIMENTAL SETUP

The laser beam was focused on the niobium target by a 30cm focal length convergent lens. To polarise the beam we utilised a polarising cube for the 308 nm, while a straight of four quartz windows tilted at 56° for the 222 nm. The beam laser illumined the cathode with an angle of 70°, respect to the longitudinal axis of the vacuum chamber. In the vacuum chamber the distance anode/cathode was 8cm. A negative voltage (up to 50kV) was applied. The vacuum chamber was evacuated to 10^{-7} Torr by a rotative and a turbomolecular pump. In Fig. 1 the experimental set-up is shown. The current pulse was measured by a fast Rogowski coil inserted on cathode rod. During the experimental measurements the electromagnetic noise did not disturb the picked up signals. In front the cathode we arrange an array of nine Faraday cups, and we measured the angular distribution of the electron beam in the (x,y) plane assuming that the beam propagation is directed on the z axis.

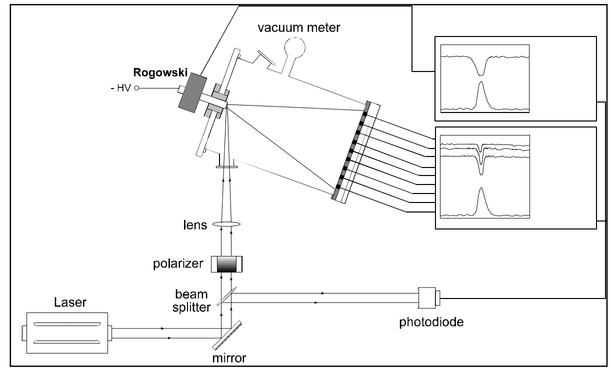

Fig. 1: Experimental setup

4 RESULTS AND DISCUSSION

We investigated the quantum efficiency for surface and volume photoextraction considering the incident light electric field components on the cathode surface. We define the quantum efficiency η as the relationship between the issued electron number and the incident photon number:

$$\eta = \frac{Issued\ electron\ number}{Incident\ \ photon\ number} \quad (5)$$

The upper limit emittance is defined like[2]:

$$\varepsilon_0 = \frac{r\Delta\phi}{\pi} \quad [\pi\ mm\ mrad] \quad (6)$$

where *r* it is the ray of the spot characterised from the laser beam on the target of niobium and Δϕ the angular divergence of the electron beam. Multiplying for $\beta\gamma$ we obtain the normalised emittance. Knowing the emittance value, the brightness is evaluated by:

$$B_0 = \frac{I_{\max}}{\varepsilon_0^2} \quad (7)$$

where I_{max} represents the maximum value of current

In all experiments the maximum energy applied was 0.6mJ while the maximum accelerating voltage was 50 and 20 kV for the XeCl and KrCl laser, respectively. Under these experimental conditions we got emission without plasma generation and as a consequence avoiding short circuits.

4.1 XeCl results

In this experiment the time evolution of the current pulse is very near to the laser one indicating a photoemission from metal without any contributes by the plasma. With polarised light the electron emission efficiency was different dependent on polarisation direction.

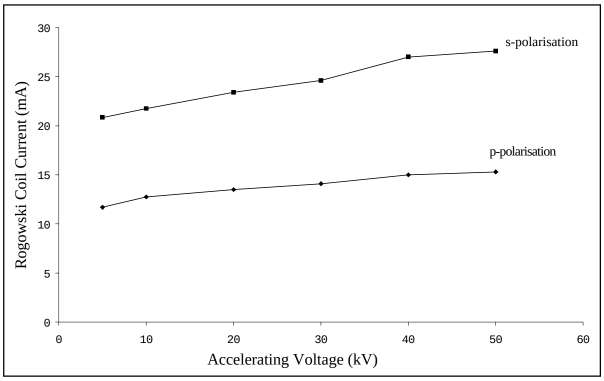

Fig. 2 - Current peaks for the s and p-polarization for XeCl laser

The current values are plotted in Fig. 2 for the s- and p-polarisation. The values obtained with s-polarised beam were 200% higher than the p-polarised ones and the quantum efficiencies were $1.0x10^{-6}$ and $2.1x10^{-6}$ for the p and the s-polarised light, respectively. Recording the angular current distribution, we estimated also the upper limit emittance and the brightness. Table I reports the experimental results obtained with the XeCl laser.

Table I: Electron beam characteristics induced by the XeCl laser

	p.pol	**s-pol**
XeCl Energy [mJ]	0.6	0.6
I_{max} [mA]	15.5	25.7
$\gamma\beta\varepsilon_0$ [π mm mrad]	11	7
B [A(π m rad)$^{-2}$]	1.1×10^6	5.8×10^6

4.2 KrCl results

During the experiment with the KrCl the waveform of the current was wider than the laser one due to the plasma formation, even if the energy was very low. The current

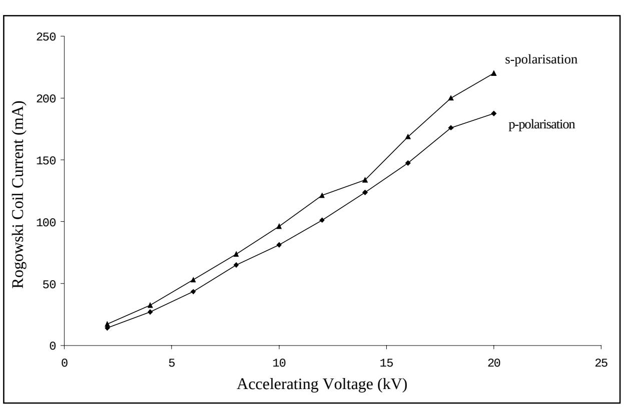

Fig. 3 - Current peaks for the s and p-polarization for KrCl laser

width was 100% larger than the laser one. In this case the output currents were higher than the XeCl ones. The maximum value of current obtained with polarised radiation of type p and type s is equal to 187 and 220mA, respectively. The current values are plotted in Fig. 3 for the s- and p-polarisation versus the accelerating voltage. The corresponding quantum efficiency is equal to 1.6×10^{-5} and 5.3×10^{-5}. These values are very close the ones obtained by the KrF laser[3]. We have estimated also the upper limit normalised emittance value for p-polarisation, 80 [π mm mrad], and for s-polarisation, 76 [π mm mrad]. Generally, when the current increases the corresponding emittance increases too.

Likely, in this case the discrepancy of the emittance values found with p-polarisation and s-polarisation light are not due only to the space charge, but also to the extraction process. Table II reports the experimental results obtained with the KrCl laser. The maximum current obtained was 1.25 A with 4.9 mJ.

Table II: Electron beam characteristics induced by the KrCl laser

	p-pol.	**s-pol.**
KrCl Energy [mJ]	0.6	0.6
I_{max} [mA]	187	220
$\gamma\beta\varepsilon_0$ [π mm mrad]	80	76
B [A(π m rad)$^{-2}$]	2.3×10^6	2.3×10^6

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