ULTRASHORT HIGH CURRENT DENSITY PRODUCED BY LASER FROM METALS

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Abstract

New experimental results on N-photon photoelectric emission from pure metals (Au, Cu and W) in subpicosecond time regime, are reported. All these ones confirm the nonlinear increasing of the photoelectric sensitivity versus the laser peak intensity. In every case, the crossing of the single- and 2-photon photoelectric sensitivities proves that metals can offer in femtosecond range photoelectric performances similar to that ones generally observed with semiconductor photocathodes. Moreover, metals offer advantage to support much higher laser intensity.

1. INTRODUCTION

Our object is to produce very high density electron beams by laser action on a solid target. Such electron beams find their applications in different domains as Free Electron Laser (F.E.L), ultrashort X-ray sources, nonlinear Compton scattering, high-power klystron, and rf-Linac.

High-current photocathodes yielding current densities larger than 1 to 10 kA/cm^2 have several advantages over conventional thermal field emitters : (1) the electron beam intensity can be modulated by modulation of the light source ; (2) the beam can be shaped by patterning the photocathode ; (3) the energy spread of the electron beam can be reduced by selecting the wavelenght of the incident light ; (4) as radiation sources can operate at high average power, it is then possible that beams show high luminosity ($B_n > 10^{10}$ Am^{-2}rad^{-2}). The following factors have to be considered in the utilization of a photoelectronsource : cathode life,operation environment, performance of the cathode and cathode replacement. From this point of view, metallic photocathodes are good candidates.

laser irradiation using a pulse duration shorter than the electron-phonon energy relaxation time of the material may lead to high electronic temperature T_e without significant heating of the lattice [1], while the heating of the lattice could degrade the emittance and elongate the electron bunch [2]. Another advantage compared to the picosecond range situation, is that the laser damage threshold of the surface is improved by a factor of 100 typically, i.e., $I_D \cong$ 200-300 GW/cm^2.

2. EXPERIMENTAL DETAILS

In our experimental arrangement, the source was a lambda-physik femtosecond excimer pumped dye laser [3] emitting pulses at 248 nm (5 eV) and 496 nm (2.5 eV) with 450 fs duration. The laser beam was linearly polarized and the maximum laser energy per pulse at 496 nm was only 53 μJ and 8 mJ at 248 nm. The laser energy E_ω on the photocathode was adjusted by varying the aperture of a circular diaphragm located at the laser output. The laser beam at 496 nm was circular with a spot diameter of 6 mm and a full divergence angle lower than 0.1 mrad; it was focused on the photocathde surface by a biconvex silica lens, with 16.9 cm focal lenght. The angle of incidence Θ on the photocathode could be changed in a short range : 74° to 85°, with a precision of 0.2°. Our experimental arrangement did not permit to make valuabe measurement at lower incidence angles for which we suppose from the Vectoriel Photoemission Theory (VPT) [4] that the sensitivity would be much higher. A set of mirrors were used to achieve p-polarization of the laser beam on the photocathode. As observed with Au [4] in *Figure1*, the photoemission efficiency of W and Cu for s-polarized incident radiation was much lower than for p-polarized laser beam, so we consider here only p-polarization.

The photocathodes consisted of a flat, high purity, polycristalline gold, copper and tungsten. We calculated that electrons were emitted promptly with a temporal spread over the irradiating laser pulse less than few femtoseconds. The work functions (4.7 - 4.9 eV for gold, 4.5 eV for copper and 4.5 eV for tungsten) are twice the photon energy at 496 nm .

The photocathodes were mounted in a vacuum chamber maintained at 4 x 10^{-8} mbar. The electrodes gap was fixed to 5 mm. The stainless steel anode was biased at a high voltage V_A varying continuously from 0 to 30 kV. The total charge Q_K leaving the photocathode was collected by a 2 m-long 50 Ω transmission line to a Tektronix 7904A oscilloscope. The amplitude of electron pulse V_e, recorded on 3000 ASA Polaroïd film, was directly proportional to the ratio Q_K/C_S ,where $C_S \approx$ 20 pF is the input capacitance of the oscilloscope [5]. Before any measurements, each

photocathode was fully activated for 5 minutes irradiation with 248 nm femtosecond laser pulses transporting an energy density of about 0.5 mJ/cm^2, able to get rid the surface of all hydrocarbon contaminations and oxides.

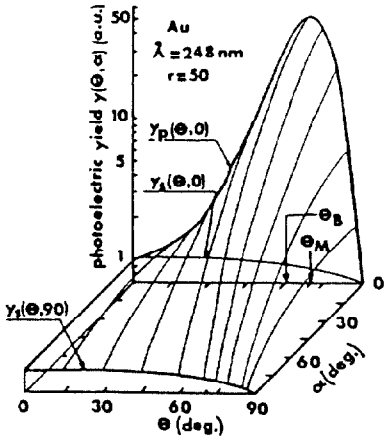
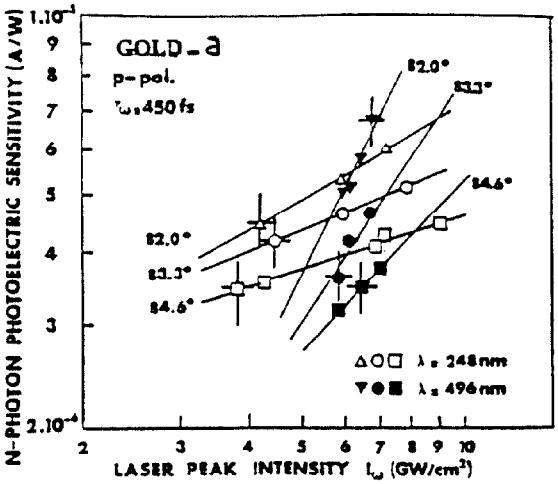
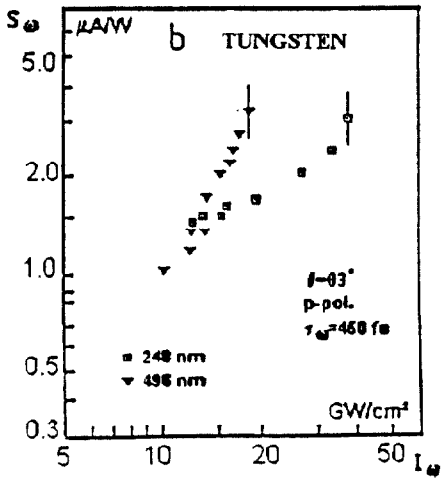


Figure 1- Theoritical variations of the photoelectric yields y_p and y_s from gold versus angle of incidence Θ and the polarization α of laser beam at 248 nm, with a constant intensity.

3. EXPERIMENTAL RESULTS

The photoelectric process is characterized by the sensitivity $S_\omega = Q_K/E_\omega$. In agreement with our model [6] and previous experiments [7], our work confirms that femtosecond photoelectric sensitivity of metals varies as $S_\omega \propto I_\omega^{k-1}$,where k>N. N and k are the linear and nonlinear photoelectric emission process order, respectively. k is depending on the energy and the duration of the laser pulse. This nonlinear behavior, first observed from Au and W [8] (*Figure 2 a,b*) was confirmed later from Cu (*Figure 2 c*). We think that the nonlinearity is a direct consequence of the thermal non-equilibrium between the electron gas and the lattice at the photocathode surface. We also show a new fundamental property of metals in the femtosecond range resulting from comparaison of their single- and 2-photon photoelectric sensitivities. For relatively low laser intensity, we observe that the 2-photon sensitivity $S_{\omega 2}$ is always lower than the single-photon one $S_{\omega 1}$. This property is currently observed from any solid material according to the probability of N-photon photoelectric emission is always lower than the one of any lower -order photoelectric process. On the contrary, when I_ω is sufficiently high, the 2-photon sensitivity is higher than the single-photon one, but such situation is only possible in femtosecond range to do not damage the surface. We present for example the data of Au (*Figure 2a*) corresponding to a laser intensity from 3 GW/cm^2 to about 10 GW/cm^2 and the angles of incidence Θ = 82°, 83.3° and 84.6°. From these graphs it is evident that $S_{\omega 2}$ at 496 nm can be higher than





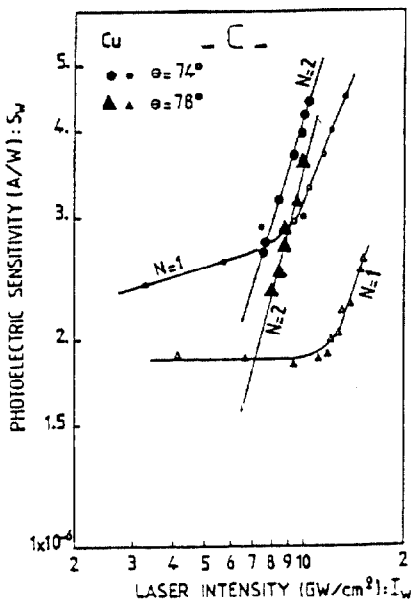


Figure 2- Crossing of single- and 2- photon sensitivities of : (a) gold, (b) tungsten and (c) copper versus the peak intensity of polarized laser beams at 248 nm and 496 nm with 450 fs pulse duration for various incident angles.

$S_{\omega 1}$ measured at 248 nm. The amplitudes S_G of the respective crossing points are : 5.5 10^{-6} A/W, 5 10^{-6} A/W and 4.5 10^{-6} A/W.

4. CONCLUSION

Our observations in Au, W and Cu confirm our hypothesis of an inversion of femtosecond photoelectric sensitivities in the most of metals. This inversion is consequently a dynamical effect. It depends on the typical laser pulse parameters and on the photoelectric cross-sections. It is possible only during a pulse duration shorter than the electron-phonon relaxation time in the metal, i.e. few picoseconds. This situation constitutes a real advantage for the production of very high current densities from metallic photocathodes. Another advantage is that laser radiations with longer wavelenghts are then more suitable, and the photoelectron production could be possible with an efficiency comparable to the one observed in longer temporal regime with semiconductors.

5. AKNOWLEDGMENT

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