THERMAL EMITTANCE ESTIMATION USING A TIME-OF-FLIGHT SPECTROMETER

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Abstract

The so called thermal emittance of photoemitted electron beams is an important parameter for the new generation of high brightness RF photoinjectors. At the LASA Laboratory of INFN Milano, an angle resolved Time-Of-Flight electron spectrometer has been developed. This apparatus allows measuring the energy distribution of photoemitted electrons (at energies below 5 eV) from a variety of photocathode materials. From the energy distribution measurements it is possible to provide an estimation of the thermal emittance of the electron beam. First measurements, together with simulation results, are presented in this paper.

1 INTRODUCTION

The request of high brightness sources has been growing in the last years due to the development of FELs (Free Electron Laser). Moreover the success of the TTF-FEL, operating in the SASE (Self Amplified Spontaneous Emission) regime [1], has pushed this topic further. To reach short wavelengths it is necessary to use very small transverse emittance since the wavelength λ scales as:

$$\lambda > \frac{\varepsilon \cdot 4\pi}{\gamma}$$

The electron sources used for the generation of high quality electron beam are RF guns, where a laser shines a photocathode placed in a RF cavity. The minimum final emittance is limited by the emittance at the source, mainly the initial distribution in phase space of the photoemitted electrons (the so called thermal emittance). The r.m.s. thermal emittance in the x plane is:

$$\varepsilon_{th} = \frac{1}{m \cdot c} \cdot \sqrt{\left\langle x^2 \right\rangle \cdot \left\langle {p_x}^2 \right\rangle - \left\langle x \cdot p_x \right\rangle^2}$$

where m is the electron mass, c the speed of light, x the particle position, p_x the momentum. The brackets mean r.m.s. values.

In order to study the initial distribution of the photoemitted electrons, an experiment is in progress at LASA, the aim being the measurement of electron velocity distribution using a Time Of Flight (TOF) spectrometer. This device allows to achieve an angular resolution of 0.0013 srad sampling the distribution with a step of 5°. In the following section we give a briefly report on the experimental apparatus. A first test of the spectrometer and the acquired spectra are presented in the third section. In parallel to the experimental activity, simulations are performed to validate the obtained data and as a guideline for future developments. In section 4 we will discuss the results obtained so far on Cs_2Te photocathodes, presently used in different labs as emissive materials for RF guns.

2 EXPERIMENTAL SETUP

2.1 General description

The experimental apparatus is composed mainly by a complex UHV system and a Nd:glass laser. The main parts of the UHV system are a cathode preparation chamber, an Auger electron spectroscopy (AES) analyzer equipped with an ion gun for samples cleaning and a chamber for photoemission studies, where the low energy TOF electron spectrometer is installed. The solid-state laser produces very short pulses with wavelengths from the fundamental to UV by harmonic generation (τ = 500 fs, λ = 264 nm). Figure 1 shows a sketch of the experimental apparatus.

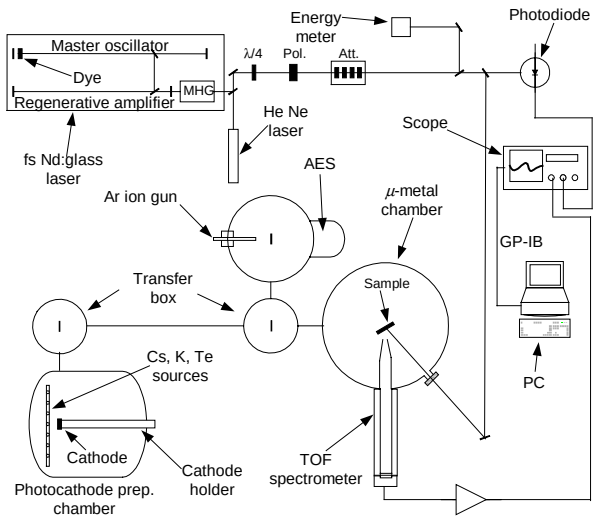

Figure 1: Schematic view of the experimental set-up.

2.2 Energy analyser: general aspects

The TOF analyser apparatus consists of a μ-metal UHV chamber (base pressure in the low 10^{-10} mbar range), a drift tube and the readout electronics. An UHV transfer

system moves photocatodes from the preparation chamber to the TOF analyser. A high precision longitudinal and rotational translator enables to move the sample in front of the detector and to change the relative angle between the sample and the analyser.

The TOF analyser technique is based on the measurement of the required time for the electrons to travel a fixed path (L = 439 mm in our set-up). A pair of microchannel plates (diameter = 40 mm) in chevron configuration (typical gain: 10^6) collects the electrons. The obtained signal, after amplification, is analysed using a PC based acquisition system.

The kinetic energy of electrons is calculated from the measured time of flight T using the following relation:

$$E = \frac{m}{2}\left(\frac{L}{T}\right)^2$$

Particular care has been dedicated to study perturbing effects on the electron time of flight because of the importance of electron distribution at different angles for the thermal emittance reconstruction. These effects mainly arise from magnetic and electric residual fields. The former is due to the unperfect shielding effectiveness of the chamber and the latter to the presence of contact potential (Volta effect) between the sample and the analyser. In order to minimise the residual magnetic field inside the apparatus, the entire system has been manufactured with a high magnetic permeability material (μ-metal). The maximum residual magnetic field measured on the drift tube axis is at present 25 mG (compared to 10 mG in the radial direction). Simulations performed using a measured magnetic field map show that the electron trajectories and the collection efficiency are only slightly affected. The main effect is on the velocity transversal component of the slowest electrons.

The contact potential is due to different values of the Fermi levels between the sample and the source. A bias voltage $\Delta\Phi$ is applied to eliminate the resulting electrostatic field, using a low noise voltage source. As for the magnetic field, a study of the electrostatic influence on electron trajectories has been performed. The electrostatic field plays an important role on the electron spectra deformations, mainly increasing the collection of low energy electrons.

Moreover to avoid the effect of possible charge accumulation, the drift tube has been electroplated with a gold alloy.

3 EXPERIMENTAL RESULTS

The aim of these preliminary measurements is to test the sensitivity of the analyser using a known material. We used a polycrystalline silver sample. The sample has been cleaned by Ar^+ ion sputtering and then characterised by AES. All the measurements are collected under the same experimental configuration: the incidence angle of the laser on the sample is 50^0 and the sample is normal to the analyser axis.

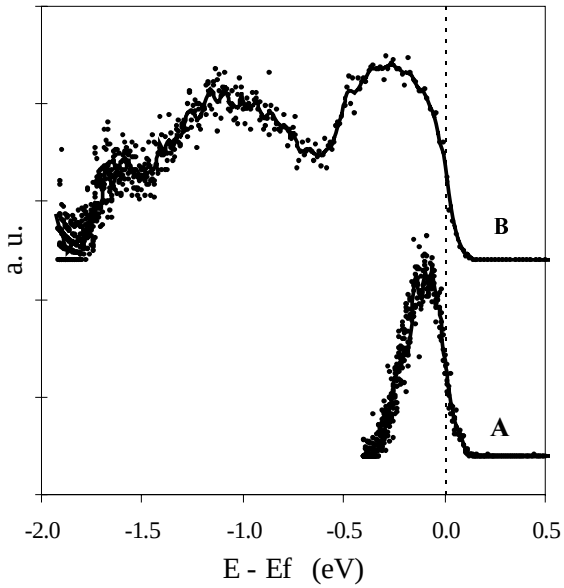

Figure 2: Energy spectra: A) Ag sample; B) cesiated Ag sample. The work function changes from 4.25 eV to 2.9 eV.

The first Ag parameter we have measured is the Fermi level, which is the last occupied level in the electron energy distribution. In Figure 2 the bottom spectrum (A) is the one obtained after balancing the contact potential.

The measured Fermi level is 4.25 eV to be compared to 4.3 eV value reported in literature [2]. The density of the available electronic states (DOS) in the metal can be deduced from the spectrum shape. Since the photon energy is 4.7 eV, the width of the spectrum is just 0.45 eV: therefore only information on the Fermi edge are deducible.

To acquire more information on the silver DOS, we have decreased the Ag sample work function covering its surface with Cs. After the deposition of 1 monolayer of Cs, the work function decreases from 4.25 eV to 2.9 eV and a broader spectrum can be measured. Spectra obtained for cleaned and cesiated silver (B), are compared in Figure 2.

To test the sensitivity of the analyser, we have exposed a cesiated silver sample to nitrogen to measure the change in the work function. Performing measurements on the same sample at different time delays after the start of the calibrated gas flow, we have observed that the work function gradually grows towards the not cesiated silver value. In Figure 3 we report the spectra measured with $\Delta\Phi$ = 1.5 V at different time delays. Work functions are calculated subtracting the width of the spectrum to the photon energy. Since the relevant parameter is the width of the spectrum and not the shape, we have balanced the Volta effect only for spectrum A.

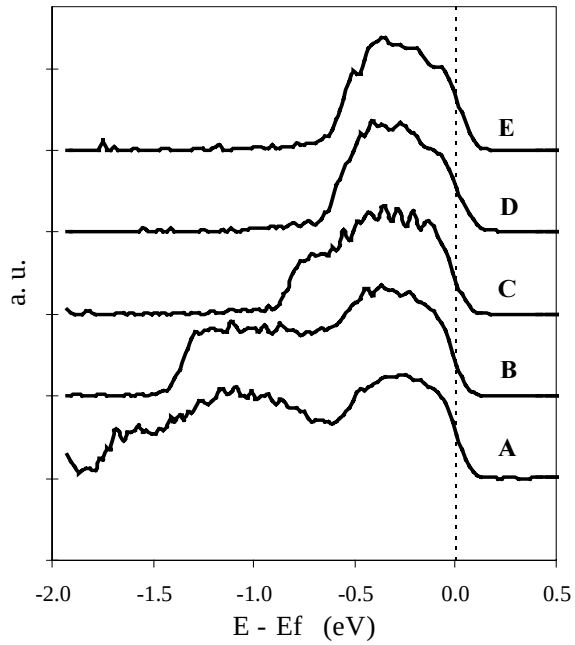

Figure 3: Influence of nitrogen exposition on Ag spectra: A) just after Cs deposition; B) 32 h; C) 104 h; D) 145 h; E) 200 h.

4 Cs_2Te SIMULATIONS

The Cs_2Te has been extensively used as a photocathode material for solar blind photomultiplier since the twenties. Nevertheless there is a lack of information about its properties, if we exclude some important but dedicated exceptions [3], [4]. Our group has already applied the "three step model" to polycrystalline Cs_2Te [5]. In this model, the photoemission process is divided in three separated steps: photoelectron production, photoelectron transport through the material and emission in vacuum [6]. We present here the results so far obtained using data [7] measured directly on the cathode presently used as photoemissive source at DESY. These data, assuming no correlation between position and momentum, give a beam divergence of 0.68 mrad for the photoemitted electrons.

The aforementioned lack of information about Cs_2Te implies some limitations to the model. The model assumes a scattering of the electrons with the lattice during their propagation to the surface but, at present, the scattering mean free path (m.f.p.) is assumed to be independent from the electron energy. Since the scattering m.f.p. is typically longer for lower energy electrons, we underestimate their contribution. Moreover no information on the DOS is included in the electron generation since the data available from Powell are not complete. This is important for the electron generation since it introduces more probable transitions and hence structures in the electron energy distribution. For these reasons, we expect that our numerical model is not conclusive but, nevertheless, can give indications of general trends. In Figure 4, we present as an example the beam divergence for different values of the Electron Affinity (EA) that is the parameter easily affected by poisoning during operation in the gun. The growth of EA decreases both the divergence and the Quantum Efficiency: QE varies by two orders of magnitude while the divergence is only halved. However this correlation suggest a possible way to control the beam emittance changing the photocathode EA.

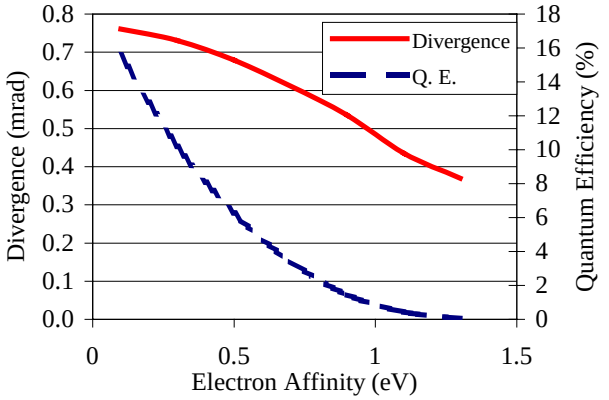

Figure 4: Beam divergence and Quantum Efficiency vs. Electron Affinity.

The task of the experimental activity on Cs_2Te is both to measure the missing parameters necessary to the simulations and to validate the Cs_2Te photoemission model used. In the future, simulations of the electron generation will be used to study the involved mechanisms, which play an important role in the thermal emittance growth.

5 CONCLUSIONS

Being the measure of the Cs_2Te thermal emittance our goal, measurements performed on Ag have given us only preliminary information on the properties of our TOF. To complete the calibration of the analyser, we are now measuring the photoemission spectra of Nb and Cu. Next step will be the measurement of Cs_2Te photocathode electronic distribution. Measurements will be done varying the angle between the sample and the analyser to obtain additional information on the photoelectron distribution spectra.

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