FIRST ENERGY SPECTRA OBTAINED WITH A TIME-OF-FLIGHT (TOF) ELECTRON SPECTROMETER ON Cs_2TE PHOTOCATHODES

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Abstract

The first electron energy spectra obtained from a Cs_2Te photocathode using a Time-of-Flight (TOF) spectrometer are presented and discussed in this paper. The high-resolution angle resolved TOF electron spectrometer has been developed at INFN Milano-LASA (theoretical resolution: 2 meV at 5 eV). The system has been designed for the investigation of the electron beam thermal emittance that is a key parameter for future generation FEL based high brilliance photon sources. The excitation light source is a short pulse solid-state Nd:glass laser (4^{th} harmonic, τ= 400 fs, λ= 264 nm). In this paper the spectrometer is presented together with first measurements on different metals and Cs_2Te.

1 INTRODUCTION

Since some years, an interest on high brilliance sources is growing due to the FEL (Free Electron Laser) development pushed by the achievements reached at Tesla Test Facility, TTF-FEL [1]. One of the key parameters in reaching very short wavelengths is a very small beam transverse emittance at the source [2].

The sources used to generate the electron beam for the FEL are mainly RF-guns, where a laser shines on a photoemissive material and the emitted electrons are immediately accelerated to overcome space-charge effect.

In our lab in Milano since few years we have an R&D activity devoted to the study of the energy distribution, angle resolved, of electrons emitted from different materials. We use an electron spectrometer based on the Time of Flight technique with the possibility to change the angle between sample and analyzer. Up to now we have performed measurements on silver and cesiated silver to check the performance of the spectrometer. In the last months we have investigated cesium telluride, the photocathode used at TTF. The angular resolved energy spectra are used to reconstruct the momentum distribution of the photoemitted electrons. From the distribution, we calculate the momentum r.m.s. value in the transverse plane. This value is then used in the r.m.s. definition of thermal emittance

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

where m and c are respectively the electron mass and the speed of light and the terms in brackets are the r.m.s value of the corresponding quantities.

In this paper we report on the experimental apparatus, on the operational principle of the spectrometer and the results obtained on cesiated silver and cesium telluride.

2 TIME OF FLIGHT SPECTROMETER

General aspects

The TOF spectrometer is connected to an UHV (Ultra High Vacuum) μ-metal chamber. The vacuum chamber has six Suprasil viewports for laser light at 10° step between 30° and 80°. A turnable sample-holder allows changing the sample-analyzer angle. The system is connected, keeping UHV condition, to the photocathode preparation system and to an AES (Auger Electron Spectroscopy) apparatus equipped with an Ar^+ ion gun. The AES spectrometer is used to check the sample surface cleanness before performing TOF analysis.

The TOF spectrometer consist of a drift tube (L=439 mm) where the photoemitted electron fly with low electric and magnetic field influence. A pair of MCPs (Micro Channel Plates), used in Chevron configuration, detect the electrons that reach the end of the drift tube. Two amplification stages increase the output signal to noise ratio. The acquisition system detects the flight time of the electrons with respect to the start signal given by the photons.

The light source used to excite photoemission from the sample is a femtosecond (τ= 400 fs) Nd:glass laser with two stages of doubling crystal to produce green (λ= 532 nm) and UV (λ= 264 nm) light.

Fig. 1 show a schematic layout of the experimental apparatus.

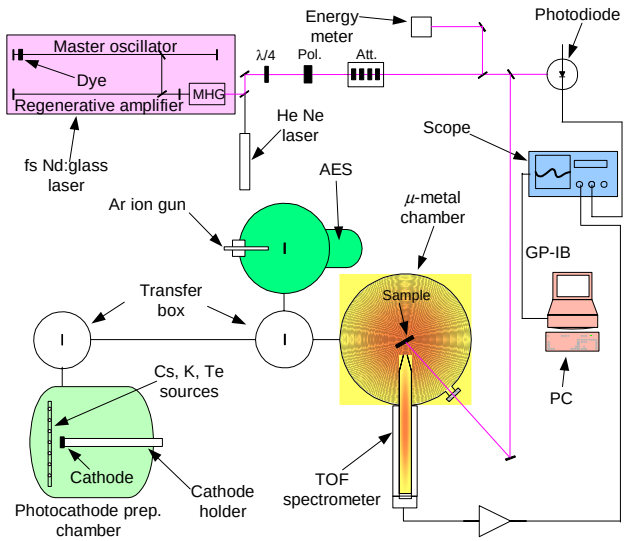

Fig 1. Sketch of the TOF system, including the photocathode preparation chamber, the AES spectrometer and laser system.

The kinetic energy of the electron is given by

$$E_{kin} = \frac{1}{2} \cdot m \cdot \left(\frac{L}{T} \right)^2$$

where T is the electron flight time, L the drift space and m the electron mass.

The influence of residual magnetic field as well as of electric field has to be minimized to reduce the effect on the time of flight and on the angular resolution. All the hardware components around the spectrometer are in μ-metal to shield the magnetic field present in the lab. The maximum magnetic field measured along the drift tube axis is 25 mG. Sources of residual electric fields are contact potential between the sample and the surrounding components and building up of charge of components due to dielectric layers. The contact potential is balanced applying a proper voltage between sample and spectrometer (the nearest components). All critical surfaces (spectrometer tube, drift tube, grid) have been gold plated.

Spectrometer energy resolution

The energy resolution of a TOF spectrometer is given from the following relation

$$\frac{\Delta E}{E} = 2 \cdot \sqrt{\left(\frac{\Delta T}{T} \right)^2 + \left(\frac{\Delta L}{L} \right)^2}$$

We have measured the energy resolution acquiring a spectrum from cesiated silver and comparing it with the convolution of a gaussian distribution with the Fermi distribution at 300 K. The standard deviation of the gaussian distribution gives the energy resolution.
In Fig. 2 the data for the resolution measurement at 1.9 eV are reported.

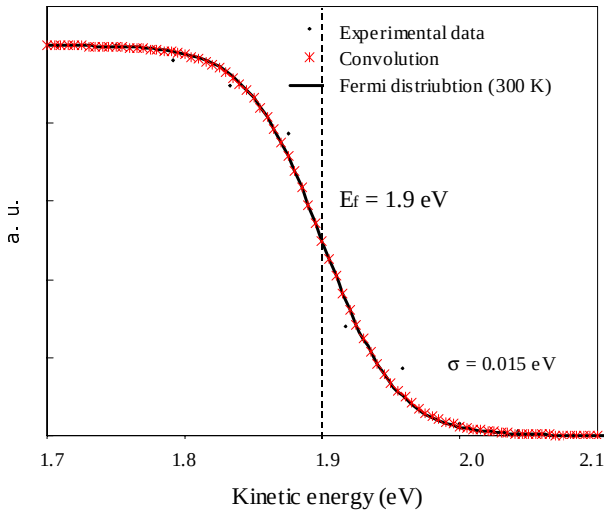

Fig.2. Measurement of the spectrometer energy resolution using a cesiated silver sample. See text for a description of the procedure used.

The value obtained of 15 meV is in very good agreement with the expected value of 14 meV calculated from the previous formula assuming the major contribution given by time uncertainty of 2 ns due to the acquisition system. At lower energy, we measured a larger value of energy resolution mainly due to the effect of the residual magnetic field (25 meV @ 0.4 eV).

3 CESIATED SILVER

To test our apparatus, we chose a well-known material like cesiated silver. Silver has been studied since the sixties [3] and the cesiation process (covering of the Ag sample with less than a monolayer of Cs) allows lowering the Fermi edge from 4.25 eV to 2.9 eV [4]. In this way it is possible to probe, with photons, deeper in the energy band of silver. The measured spectrum is reported in Fig. 3 (blue line). The contact potential is balanced applying a proper voltage to the sample. In the analysis of the spectrum we have to include not only the effect of the electron transport in the material after laser excitation but also the influence of the residual magnetic field along the drift tube. The result of the calculation of the electron propagation in the material (including electron-electron scattering, electron-phonon scattering and Auger process) and of the flight in the drift tube (taking into account the residual magnetic field previously mapped) is also shown in Fig. 3 (red line) for comparison.

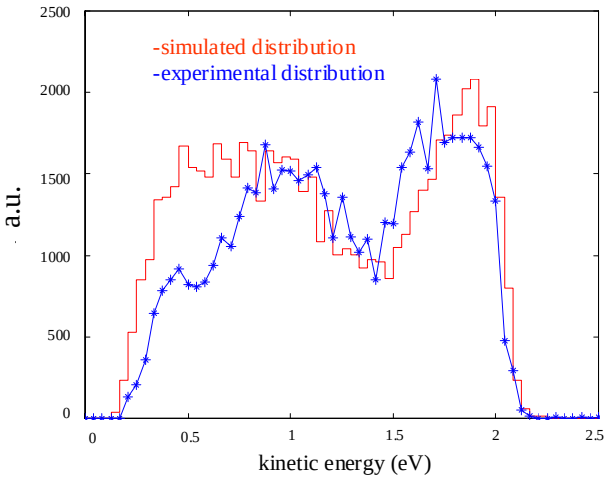

Fig 3. Energy spectrum of cesiated silver (see text for explanation).

The good agreement between the experimental data and the theoretical calculation is a promising validation of the model used for the electron propagation in the material and for the magnetic field influence calculation. Especially the latter is important for understanding the spectra that will be present in the next section.

4 CESIUM TELLURIDE

The key points in the reconstruction of the thermal emittance of electron emitted from a photocathode are the energy spectra acquired at different angles and the number of electron collected at each angle for proper normalization of the spectra one to the other. In view of this goal, in the last months we have acquired different

spectra of Cs_2Te with sample normal to the analyser and laser light at 50° with respect to the sample normal. This choice allows us to compare the spectrum obtained with the measurement done by Powell in the seventies [5].

A typical spectrum is shown in Fig. 4. We have acquired a spectrum with a slightly accelerating field in order to estimate its width and then we have applied the proper counter field to balance the contact potential.

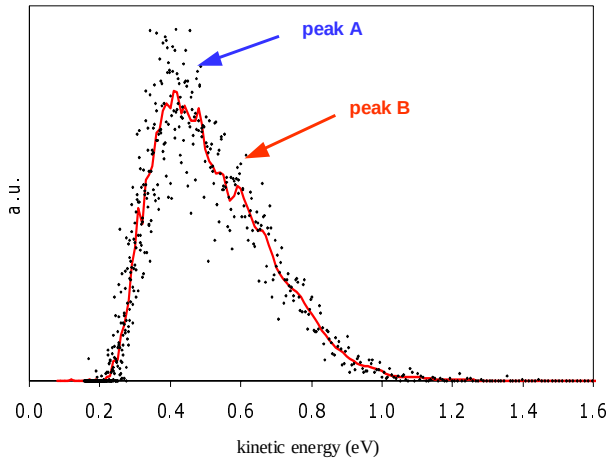

Fig. 4. Energy spectrum of electron photoemitted from a Cs_2Te sample collected with sample normal to the analyser and with the laser light at 50° with respect to the sample normal. The two peaks are transitions between maxima in the valence and conduction band.

The first feature in the spectrum is the lower energy cut at 0.25 eV. This is due to the residual magnetic field in the drift tube. At high energy, we observe electrons up to E_{MAX}= 1.2 eV. Since the photon energy is 4.8 eV, the value of $h\nu\text{-}E_{MAX} = E_A+E_G$ = 3.6 eV where E_A is the electron affinity and E_G the energy gap. The values reported in literature for E_A and E_G are respectively 0.2 eV and 3.3 eV [6].

The structure present in the spectrum gives information about the band structure of Cs_2Te. The first attempt to derive the band structure of Cs_2Te from electron spectra was done by Powell [5]. He suggested the presence of two maxima in the density of state in the Valence Band (VB) located respectively 0.7 eV and 1.4 eV below the top of the VB. Moreover he identified one maximum in the Conduction Band (CB) at 0.75 eV above the bottom of the CB. Starting from this observations, we identify the two peaks in the spectrum as two of possible transitions between VB and CB. Peak A is a transition from the top of the VB to the maximum in the CB. The second peak (B) is a transition from the first maximum in the VB to the maximum in the CB. Powell did not resolve this transition in his measurement done at the same energy but only at higher photon energies. The better resolution of our apparatus allow us to highlight this transition and also to locate the position of the maximum at 0.6 eV below VB.

5 CONCLUSION

The results so far obtained with the time of flight spectrometer are promising. A cesiated silver sample has been used to test the spectrometer itself and to validate the model for the transport of the electron in the drift tube including the residual magnetic field. The magnetic field produces a cut in the spectrum for energy below 0.25 eV.

The first spectrum of electrons emitted from Cs_2Te is presented. The peaks in the energy spectrum are resolved and assigned to transition between known structures in the density of states of Cs_2Te.

The next step towards an estimation of the thermal emittance is an upgrade of the system to reduce the residual magnetic field in order to lower the low energy cut.

Angle resolved spectra from Cs_2Te samples with proper normalization to reconstruct the momentum distribution are planned in the next future.

6 REFERENCES

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