ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-THPOPT026

ASSEMBLY AND CHARACTERIZATION OF LOW-ENERGY ELECTRON TRANSVERSE MOMENTUM MEASUREMENT DEVICE (TRAMM) AT INFN LASA

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Abstract

In the framework of high-brightness electron beam generation, thermal emittance is nowadays a key parameter. While alkali tellurides are extensively used in advanced electron sources, alkali antimonides photocathodes demonstrated high QE in the visible, thus making feasible CW operations for RF-based photoinjectors. The INFN LASA laboratory in Milan is fully equipped with dedicated production systems for photocathode preparation and optical setup for QE evaluation. In this paper, we describe a newly designed device dedicated to electron transverse momentum measurement (TRAMM). It will be connected to the main production chambers and will serve as an "emittance monitoring" system during photocathode growth. From the design phase, through the parameter estimate, assembly of the components, to the installation and first measurements, we describe the status of this project and its future developments.

INTRODUCTION

Laser-driven, visible light-sensitive photocathode based electron sources are crucial elements for the current 4th generation X-ray sources, namely Free Electron Lasers (FELs) and the upcoming and promising technology behind the Energy Recovery Linacs (ERLs).

The brightness of the electron beam generated at the photocathode strongly dictates the performance of all such systems. This parameter depends upon the cathode Quantum Efficiency (QE), i.e. the number of emitted electrons per incident photons, and the emittance of the source, ultimately limited by the thermal emittance. This last quantity determines the final capabilities of the machine.

At the LASA laboratories of INFN in Milano, we routinely produce high-yield photocathodes for high brightness RF guns. However, what we are missing is a diagnostic tool for the thermal emittance of our photocathodes at the production site. So, based on the idea developed at LBNL [1], we designed [2] and assembled a device for transverse momentum measurements that will be installed "in series" with our production system.

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PHYSICS PRINCIPLE

The physics principle of TRAMM is based on the conversion of the electron transverse velocity in a measurable displacement on a screen.

In fact, electrons are photoemitted by a suitable light beam from the surface of the photocathode located at position C in Fig. 1. A grid then accelerates the electrons to the kinetic energy of few keV, within a 100 ns order time given $t = g\sqrt{\frac{m_e}{2eV}}$ where g is the cathode-grid distance, m_e the electron mass, e the electron charge and V is the applied voltage.

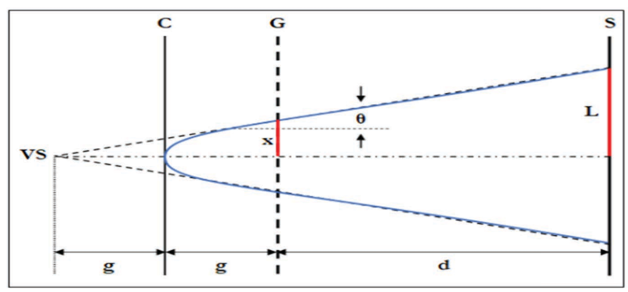

Figure 1: Schematics of the TRAMM experiment. Photocathode is placed at position C, grid in G and the screen at S.

From the grid onwards, electrons propagate freely with a transverse kinetic energy K_x and a deflection angle θ. On the screen S, the particles arrive with a transverse distance from the center L, corresponding to a transverse momentum:

$$\frac{p_x}{mc} = \frac{L}{2g+d}\sqrt{\frac{2eV}{mc^2}} \tag{1}$$

where d is the distance between the grid and the screen.

The accelerated electrons are collected on a screen composed of a phosphor and a CCD acquisition system. The acquired images are then processed to reconstruct the spatial distribution of the particle impinging on it. From the x-y function, we derive the mean square value $< p_x^2 >$ of the momentum distribution determined by the cathode density of states and electronic band structure.

Finally, we can evaluate the thermal emittance of the photocathode as a function of the laser wavelength:

$$\epsilon_n = \sigma_{x,y}\sqrt{\frac{< p_{x,y}^2 >}{mc}} \tag{2}$$

being $\sigma_{x,y}$ the r.m.s. spot size at the photocathode.

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DESIGN AND COMPONENTS

To evaluate the transverse momentum of the electrons emitted from our freshly produced photocathodes, we designed a brand-new device TRAMM (TRAnsverse Momentum Measurement) as shown in Fig. 2.

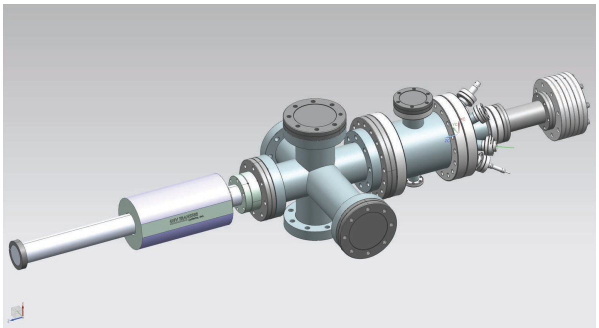

Figure 2: 3D model of TRAMM designed to be connectable to our preparation system. On the left the short UHV manipulator, in the middle the transport chamber and on the right the core of TRAMM, i.e. the detection system.

During the design of TRAMM, we have some specific requirements for operation of the system with our photocathodes and our preparation systems.

The main driving specifications are:

- Full compatibility with our production chamber: the connection of TRAMM to our UHV preparation system will allow the study of electron momentum distribution during and just after the cathode production. We expect to use the measured transverse momentum as an additional parameter to be taken into account during the photocathode deposition process.
- Guarantee UHV performance: to keep the pressure within the 1×10^{-11} mbar range necessary to safeguarding "green" photocathodes, we'll equip the device with a dedicated NEXTorr™ pump from SAES which combine a NEG pump with a SIP pump and provide the necessary pumping capacity also in case of power failure.
- Dedicated optical system: a Laser-Driven Light Source (LDLS™) from Energetiq provide a wide range light source that is transported to a monochromator by parabolic mirrors to produce a stigmatic and a micrometer-scale spot on the surface of the cathode. A small light spot size is mandatory to reduce the uncertainty in the photocathode thermal emittance reconstruction process.
- HV power supplies to feed the system with variable tension (2 kV to 6 kV) for the appropriate acceleration of the photoemitted electrons between the photocathode and the grid and to provide the proper HV to the MCPs.

Figure 3 shows a inner view of TRAMM detector assembly. The grids we selected for accelerating the electrons towards the screen are made of Copper (left) or Gold (right). These grids have a "1000" mesh, meaning the holes are 18 µm and the lines have a width of 7 µm, giving a total periodicity of 25 µm.

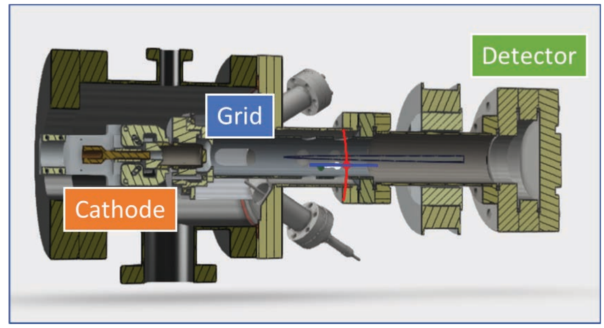

Figure 3: TRAMM detector inner view. Main components are the INFN plug where the photocathode is deposited, the grid accelerating system and the detector to convert the electron signal to an optical image.

The screen that records the spatial distribution of the electrons is a composite system of a phosphor screen (ITO) and dual-stage Multi Channel Plate assembly, which displays the light from the phosphor generated by the amplified electron signal. The image is recorded by a CCD camera and processed with a dedicated software, specifically designed in order to reconstruct the transverese momentum distribution.

All the major components of TRAMM are now at LASA, and have been cleaned and pre-assembled as shown in Fig. 4. The mechanical check has been succesfull and we will shortly proceed with the final installation.

As the device will be compatible with the production chamber, it will accept cathodes deposited on INFN Mo plugs and used in many facilities around the world (FLASH, PITZ, etc.). This will also allow mesuring photocathodes produced or used in laboratory different from INFN LASA.

PARAMETERS AND UNCERTAINTY EVALUATION

The performance of the device depends upon several parameters but the main contributor is the optical system.

Indeed, the light intensity plays a key role in generating the number of emitted electrons. To the overall efficiency of the system contributes the transmission of the UHV Sapphire viewport, the reflectance of the parabolic mirrors, and the throughput of the monochromator. If we look more deeply into the efficiency of the monochromator, we find that, considering the spectral radiance of our LDLS lamp at a reference wavelength of 543 nm (typical for "green" photocathode), the expected photon flux at the cathode surface is about 180 µW. This light power is converted into a photo emitted beam of 3.9 µA if we consider a 5 % QE for our photocathode. These emitted electrons are then sufficient to get a measurable signal after the MCP.

A second contribution to the performance of the system is also the transparency of the accelerating grid that, if not properly chosen, might drastically reduced the number of electrons that reach the MCP.

Clearly, a detailed analysis of the sources of uncertainties is of paramount importance in the final evaluation of the measured transverse momentum.

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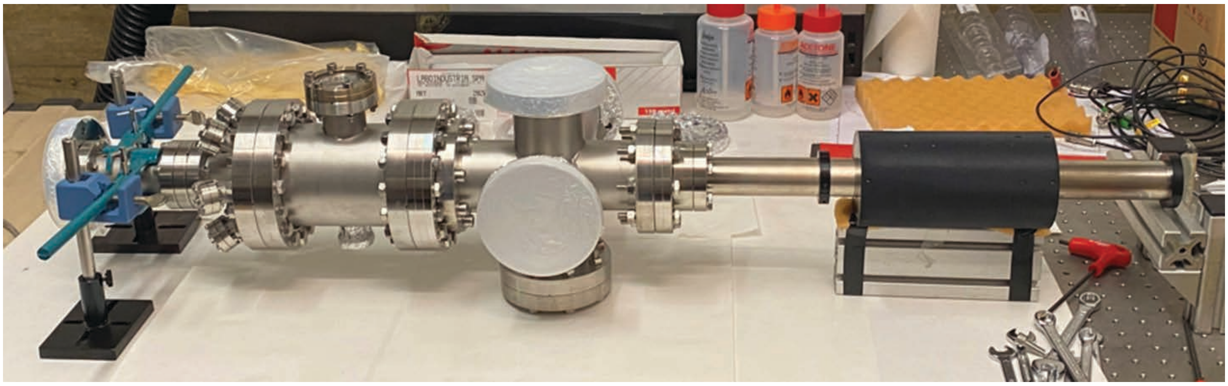

Figure 4: TRAMM vacuum system pre-assembled to check its functionality. We will start shortly the final installation and, afterwards, the apparatus commissioning.

We have identified different source of uncertainty that contributes to the reconstruction of the electron distribution. Table 1 reports, for example, the effect of the accelerating voltage on several parameters and the overall effect on the relative error in the reconstructed momentum.

The main contributors to the final uncertainty might be identified in:

- Davisson-Calbick effect [3]: the grid acts like a defocusing lens, changing the ideal trajectory of the electrons. This effect depends from the grid hole dimension and the cathode-grid distance. A typical value for the relative uncertainty given by this effect is in the 1 % range.
- MCP spatial resolution: in the dual-stage system, the resolution is 90 µm. This has effect on the final position uncertainty of the detected electrons.
- Stigmatism: the presence of non-parabolic mirrors can affect the light spot dimensions in the focal point, typically on the photocathodes. Ideally, one assumes a zero spot size at the photocathode and does not take into account any effect given by the finite size of the light beam. If this contribution becomes significant, then it is necessary to include it in the final evaluations.

Table 1: Uncertainty on reconstructed momentum versus different accelerating voltages. We report here also the effect of the HV on significant parameters of the TRAMM experiment.

Electron Kinetic Energy [keV]	**Diverg. angle [mrad]**	**Beam diam. at grid [mm]**	**Beam diam. at MCP [mm]**	$\frac{\Delta p_x}{p_x}$ **[%]**
0.5	7.07	0.071	4.38	4.1
1.0	5.00	0.05	3.1	5.8
2.0	3.54	0.035	2.19	8.2
4.0	2.5	0.025	1.55	11.6
6.0	2.04	0.02	1.27	14.2

FUTURE PLANS AND CONCLUSIONS

The present status of the TRAMM project is such that all UHV hardware components have been delivered, cleaned and succesfully preassembled. The next step will be its final assembly and its preparation for operation in UHV conditions which implies a bake out to achieve the final desired operative pressure.

At the same time, we need to concentrate our effort on assembling the optical system and work towards its optimization to make it capable of delivering a micrometer size, monochromatic and stigmatic spot to the cathode surface.

Once the UHV system and the optical system will be ready, we plan to test the apparatus with a reference material (for example Mo, for which the electronic band structure and the density of states are well known) and to use it to calibrate the system and to make a first assessment of the experimental uncertainties.

Only at the completion of this phase that will demonstrate the full capability of the apparatus, TRAMM will be connected to our production system and it will be an integral part of the diagnostic system we use during the cathode production allowing a quasi real-time monitoring of the transverse velocity evolution during photocathode deposition.

In conclusion, the increasing need to push FELs performances to the limit translates into the requirement of lowering as much as possible the cathodes thermal emittance. In this scenario, TRAMM plays a role of paramount importance in the R&D process of developing photocathodes ready for future light sources and ERLs.

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