

MEASURING THE SPECTRAL RESPONSE OF Cs-K-Sb PHOTOCATHODES FOR bERLinPro*

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Abstract

A spectral response setup was commissioned at the Cs-K-Sb photocathode preparation and analysis system, developed for the bERLinPro project. The setup is designed to measure the spectral quantum efficiency from 370 to 700 nm, to monitor the photocurrent during the photocathode growth process and the photocathode lifetime at 515 nm.

INTRODUCTION

At HZB an ERL type accelerator, called bERLinPro, is being built [1]. Cs-K-Sb photocathodes have been identified as electron source for low emittance and high current operation (100 mA). At the moment, the SRF-photoinjector for bERLinPro with an extensive diagnostics beam line is in the commissioning phase [2, 3], which will also serve as a testbed to assess the performance of in-house produced Cs-K-Sb photocathodes. The deposition of Sb, K and Cs in order to prepare Cs-K-Sb photocathodes is demanding and requests an ultra-high vacuum in the low 10^{-10} mbar range [4, 5]. Even marginal changes to the process may influence the spectral quantum efficiency, the emittance and the lifetime of the photocathode, and hence change the characteristics of the electron bunch in the SRF-photoinjector. In order to better understand and to optimize the preparation process, a comprehensive investigation of the mentioned properties of the photocathode is necessary. The work function of a material can also be determined from the spectral response.

This paper deals with the commissioning of an experimental setup, which allows to measure the spectral quantum efficiency (spectral QE) of a photocathode in the wavelength range from 370 to 700 nm and the temporal evolution of the QE at a fixed wavelength, e.g. during growth. The full description is given by H. Kirschner in Ref. [6].

EXPERIMENTAL SETUP

An experimental setup was designed to measure the spectral quantum efficiency of a photocathode in the visible wavelength range. The main parts are the white light source (PowerArc broadband Xe arc lamp (75 W) by Horiba), a monochromator (Czerny-Turner type by Horiba) and an optical path, which focuses the monochromatic light on the photocathode. The power of the light is measured with a power meter (PM100D by Thorlabs) and a calibrated photodiode (S130VC, 200 - 1100 nm, 500 pW - 0.5 mW by Thorlabs). The photocurrent is measured with a biased pickup anode,

combined with a pA-meter (Keithley 6487). Figure 2 shows this setup attached to the bERLinPro Cs-K-Sb photocathode preparation chamber.

COMMISSIONING

In order to ensure the reproducibility of the data, recorded with the aforementioned experimental setup, it is necessary to characterize its properties.

Spot Size

An iris is used to change the spot size on the photocathode stagelessly. The spot size at the cathode was measured with the smallest opening of the iris by a CCD camera (Prosilica GT 1920 by Allied Vision). The smallest possible iris aperture is 0.8 mm, which gives a spot size of 0.65 mm. From this, it follows, that the experimental magnification of the optical path is $M_{exp} = 0.8$. In Fig. 1, the spot size and its shape is shown. A flat top profile is formed for this small spot size.

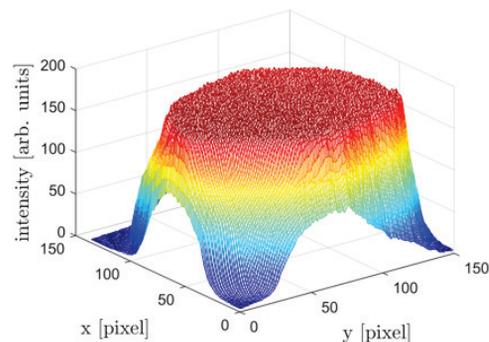


Figure 1: The minimum spot size measured at $\lambda = 515$ nm with the CCD camera. One pixel faces an area of $4.54 \mu\text{m} \times 4.54 \mu\text{m}$. A minimum spot size of $\varnothing = 0.65$ mm was determined.

Bandwidth

The light source offers a spectral flux in terms of [W/nm]. It is necessary to integrate over several nanometers to receive a certain amount of power. The interval of integration can be controlled by changing the slit width of the entrance and the exit slit of the monochromator. On one hand, a greater slit width corresponds to a wider integration interval and hence to more received power, which is desirable, see Fig. 3. On the other hand, the slit width controls the bandwidth (FWHM) of the light, which should be kept low. These two effects are contrary, so a compromise was chosen at a slit

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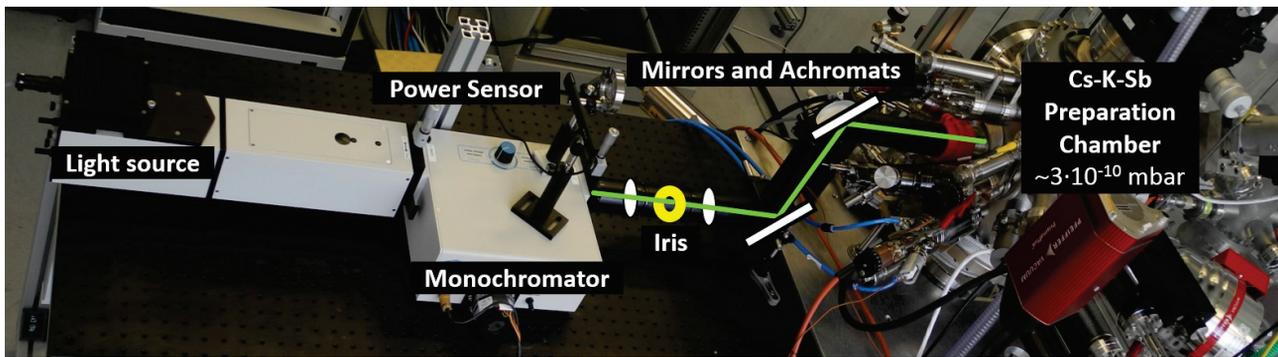


Figure 2: Spectral response setup attached to the bERLinPro Cs-K-Sb photocathode preparation chamber.

width of 1 mm which results in a wavelength bandwidth of 4 nm FWHM and $P \approx 8 \mu\text{W}$ power output at $\lambda = 515 \text{ nm}$.

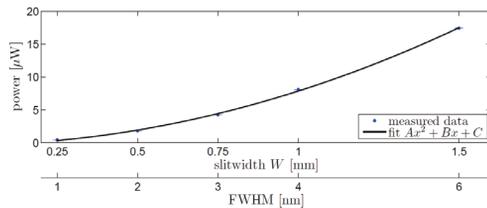


Figure 3: Changing simultaneously the width of entrance and exit slit (linearly), multiplies to a quadratic function.

Filtering the Second Order

Scanning from 370 up to 800 nm, the second order of the monochromator contributes to the photoelectric effect at the photocathode with light, which does not correspond to the actual wavelength. To suppress the second order and hence the additionally induced photocurrent, a longpass filter ($\lambda_{cut} = 345 \text{ nm}$) was introduced into the way of the light. The result is shown in Fig. 4.

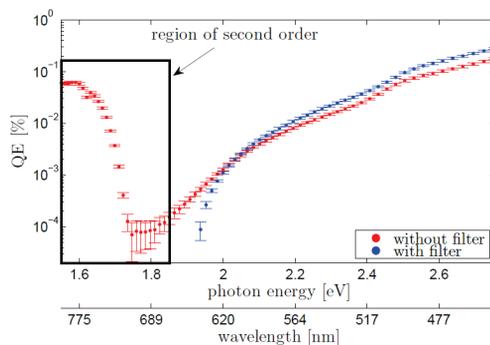


Figure 4: A filter suppresses the measured photocurrent at higher wavelengths, induced by the second order of the light.

Stability

The Xe arc lamp used in this setup does not provide a constant power after switch on, as it needs time to warm up to reach the desired power output. Further, the output is subject to the fluctuation of the Xe arc, producing the light. These parameters were analyzed by measuring the power

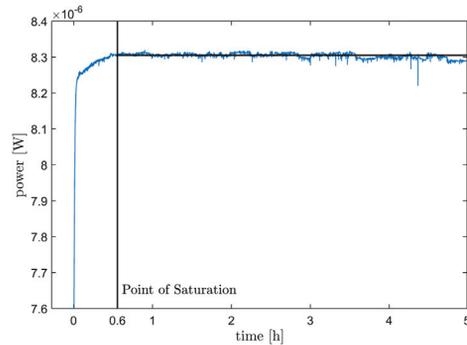


Figure 5: After 30 min the light source is stable over time.

output for 5 h at 515 nm and a slitwidth of 1 mm, see Fig. 5. The power output reaches a plateau after 30 min. Afterwards the fluctuation was calculated as the RMS value, resulting in a relative deviation of $\Delta P/P = 0.08 \%$.

Measurement Parameters

In order to achieve comparability of the measurements, standard settings were agreed on or are given by the experimental setup, respectively. Table 1 summarizes all parameters:

Table 1: Standard Measurement Parameters for the Spectral Response

| Parameter | Values |
|------------------------------------|------------------|
| Wavelength range | 370-700 nm |
| Bandwidth ranging | 4 nm |
| Power output at FWHM = 4 nm | 28 μW |
| Spot size on the photocathode | 0.65 mm |
| Stability over time (after 30 min) | 0.08 % |
| Magnification of optical path | 0.8 |
| Anode bias voltage | +300 V |
| Lowest detectable photocurrent | 0.1 nA |

SPECTRAL RESPONSE RESULTS

A Cs-K-Sb photocathode (P014) was grown by depositing a 30 nm Sb Layer and co-depositing K and Cs as second

step. While evaporating K and Cs, the photocurrent was monitored with this setup at a wavelength of 515 nm until the maximum photocurrent was reached. In Figure 6, the spectral response curve measured directly after finishing the growth process is shown. A quantum efficiency of 10.1 % at 515 nm was achieved, which fulfills the requirement for the electron source of bERLinPro from the QE's point of view.

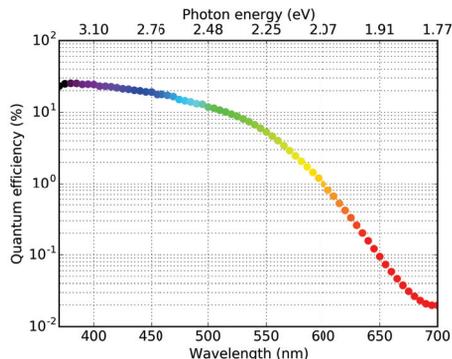


Figure 6: Spectral response of a Cs-K-Sb photocathode (P014) with a QE of 10.1 % at 515 nm measured with the presented experimental setup.

Based on spectral response measurements, an averaged work function (ϕ) of 1.96 ± 0.02 eV for several Cs-K-Sb photocathodes was extracted [6], which is in good agreement with the literature, related to the work function of CsK₂Sb [7, 8].

CONCLUSION

Cs-K-Sb photocathodes are promising candidates for the generation of low emittance and high current electron beams and can be excited using light in the visible wavelength region. Thus, in this paper an experimental setup was presented that allows to measure the spectral quantum efficiency of Cs-K-Sb photocathodes in a wavelength region from 370 to 700 nm. The setup offers a stable spectral power output, high enough to induce and detect the photoelectric effect on the photocathode. The monochromatic light is fo-

cused on the surface of the cathode and its spot size can be changed, enabling an integral quantum efficiency measurement as well as a mapping of the quantum efficiency over the cathodes surface. In the future, the system can be upgraded for measurements including the UV-range. With an optical chopper and a lock-in amplifier, the signal-to-noise ratio of the photocurrent measurement can be improved.

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