LONGITUDINAL BEAM HALO IN THE PHOTOEMISSION FROM GaAs-PHOTOCATHODES IN A 100 keV DC GUN

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Abstract

At Johannes Gutenberg Universität Mainz measurements of the time response of photocathodes can be performed routinely at the "Testquellenlabor" (source testlab) using a deflector cavity. Short electron bunches are generated using a femtosecond tunable laser system operating at 800 nm for best polarisation/QE if GaAs is used. In our experiment the laser radiation is also frequency-doubled to 400 nm in order to compare the time response at different wavelengths. First measurements show an important modification of the longitudinal beam profile at 400 nm without the trailing electrons which are typically observed at 800 nm.

INTRODUCTION

In addition to a high beam current of 10−100 mA, a long cathode lifetime, low emittance and a low dark current, future accelerator projects (e.g. Mainz Energy-Recovering Superconducting Accelerator (MESA), Berlin Energy Recovery Linac Project (BERLinPro)) require extremely low levels of unwanted beam. To achieve these demands, an analysis of the emitted electron bunches is necessary to determine if the pulse response corresponds to the acceptance of the accelerator.

Emission of electrons which occurs after a certain time may be considered as 'unwanted beam'. In the present paper we extent our old results for GaAs [1] towards excitation with photons in the blue wavelength region. This is typical for an injector into an ERL based light source, where production of polarised electrons (which is only possible with infra-red excitation) is of no importance.

Our measurements indicate that using photons of higher energy leads to a considerable reduction of the unwanted longitudinal beam.

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PHOTOCATHODES

For high average current machines only two out of the many possible types of photocathodes (see Figure 1) are of interest. Photocathodes of type Cs:GaAs belong to the group of semiconductors with a negative electron affinity (NEA) as opposed to semiconductors with positive electron affinity (PEA) such as K_2CsSb.

[1]FKZ: 05K12UM1 PCHB photocathodes

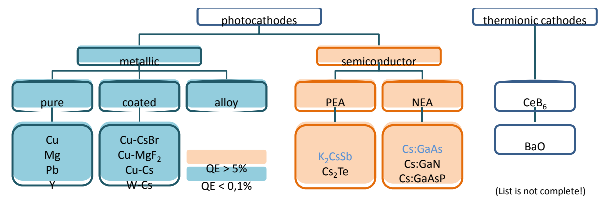

Figure 1: Overview of different cathode types [2]. The semiconducting photocathodes (highlighted) are the most interesting type for this analysis.

Until now, different types of GaAs photocathodes are used at both Mainzer Microtron (MAMI) and source testlab (PKAT) at Johannes Gutenberg University Mainz (JGU). At PKAT, there is the possibility of time response measurements. So, shape and length of electron bunches — generated by laser wavelength λ_{laser} of 800 nm — are well known [1].

Since early 2013 we have the possibility to study the pulse response also for photoexcitation with higher photon energies. Therefore, a direct comparison of the response of NEA-GaAs for excitation with sub-picosecond laser bunches with photon energies of $\approx$ 1.5 eV (800 nm) and $\approx$ 3 eV (400 nm) became possible.

EXPERIMENTAL SETUP

The time response of the emission process is encoded within the longitudinal beam profile. A TM_{110} deflector cavity operating at 2.45 GHz of the RF master of MAMI with a maximum input power of 340 W transforms the longitudinal beam profile into a transverse one. The beam spot is observable as an intensity distribution on a fluorescent screen (YAG-screen).

The design of the electron source at PKAT does not allow a bunch charge which is high enough for analysing a single electron bunch. Thus, the analysed image of a beam spot on a YAG-screen is a sample of more than 10^5 electron bunches. If the frequency of electron bunches is synchronised to the radio frequency (RF) of the defector cavity, every bunch is deflected at the same RF phase. Then the resulting intensity distribution represents the time dependency of electrons in one bunch.

Laser System

At PKAT the laser system consists of three components: A DC laser (P_{laser} = 10 W, λ_{laser} = 532 nm) is needed for pumping a modelocked Ti:Sapphire laser. The

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Ti:Sapphire laser can be operated DC or pulsed with a pulse length as short as 150 fs. The repetition rate of 76 MHz equates to the 32nd subharmonic of the RF cavity. The synchronisation is provided by locking the laser to the cavity by a PLL circuit. With its tunable wavelength, modelocking of the Ti:Sapphire laser is possible in a range of $\lambda_{\text{laser}} = 755{-}800\,\text{nm}$. This range can be extended to $\lambda_{\text{laser}} = 700{-}850\,\text{nm}$ by using optimised mirrors in the laser resonator. An external, single pass beta barium borate (BBO)-frequency doubler crystal is used in order to double the photon energy. By bypassing the doubler stage, it is possible to compare the time responses at the fundamental and the harmonic frequency. Changing from one type of excitation to the other typically requires 15 minutes.

PKAT Laboratory

The 100 keV DC photoemission electron source in PKAT is constructed in the same way as the polarised electron source of MAMI [3]. Besides the direction of the laser and the electron beam, the most important elements of the beamline for time response measurements are labeled in Figure 2: the deflector cavity, a fluorescence screen (YAG-screen), and the CCD-camera at the end of the beamline.

In 2013 the klystron [3] which was used to drive the cavity was replaced by a home build 2.45 GHz solid state amplifier.

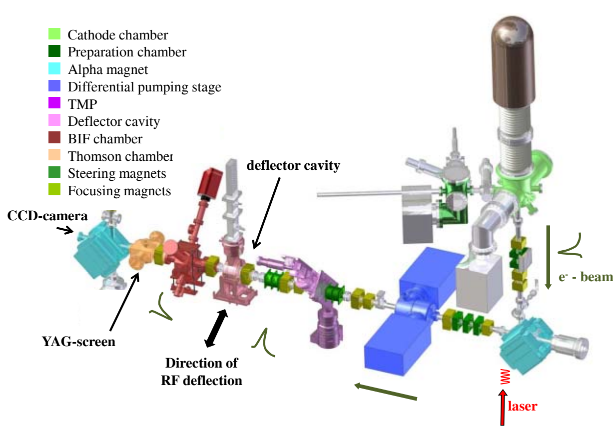

Figure 2: Test source laboratory PKAT at JGU. Direction of laser and longitudinal shape of electron bunches are shown schematically. [4]

TIME RESPONSE MEASUREMENT

The electron source at PKAT is not constructed for high bunch charges. So the observed image on the YAG-screen is no single shot but a sampling of many bunches depending on the exposure time of the CCD-camera. The contribution of timing jitter during the exposure time is estimated to be of the order of 1 ps or less.

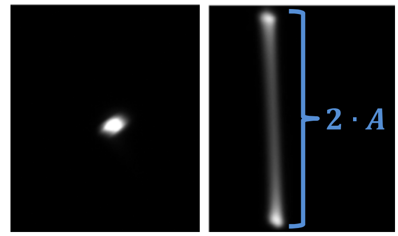

Figure 3: Transverse beam spot (RF off) on the left, and many electron bunches after RF-deflection on the right. RF and laser pulses are **not** synchronised. [5]

Calibration of the YAG-screen

A calibration of the YAG-screen is necessary to yield the correlation between time information and metric dimension of deflection as it is shown in Figure 3.

On the left a picture of transverse beam spot is shown. On the right RF is switched on but laser pulses are not synchronised to RF. The observed beam width corresponds to twice amplitude A of the RF.

The correlation between A and the power P_{RF} of RF is given by

$$A \propto \sqrt{P_{\text{RF}}} \tag{1}$$

The position on the screen is given by

$$x(t) = A \cdot \sin(\varphi_{\text{RF}}) = A \cdot \sin(\omega t) \tag{2}$$

where φ_{RF} is the RF phase. With the time derivation

$$\dot{x}(t) = A \cdot \omega \cdot \cos(\omega t) \tag{3}$$

the correlation between time and metric dimension can be done for $t = 0$.

Different calibrations with different P_{RF} (here at $\lambda_{\text{laser}} = 800\,\text{nm}$) confirm this correlation. Increasing P_{RF} means a better time resolution:

$$P_{\text{RF}} = 45\,\text{W} \Rightarrow 1\,\text{mm} \mathrel{\hat{=}} 6.6\,\text{ps}$$

$$P_{\text{RF}} = 339\,\text{W} \Rightarrow 1\,\text{mm} \mathrel{\hat{=}} 2.4\,\text{ps}$$

Preliminary Results

Figure 4 shows a qualitative comparison of two beam spots, left original (transverse) beam spot, right longitudinal bunch profile when RF and laser pulses are synchronised. Sections of such CCD frames then serve for quantitative analysis.

Preliminary results at low beam current ($I_{\text{e-beam}} < 10\,\text{nA} \mathrel{\hat{=}} 0.1\,\text{fC}$ bunch charge) are shown in Figure 5. Exposure time of the CCD-camera is 4 ms — this corresponds almost to 3×10^5 bunches. Four measurements (normalised intensity over time [ps]) of transverse and longitudinal electron bunches at $\lambda_{\text{laser}} = 800\,\text{nm}$ (red) and 400 nm (black) are shown in comparison to each other.

While the transverse diameters d_{FWHM} from both laser wavelengths are in the same range ($d_{\text{FWHM}} \approx 260\,\mu\text{m}$) the

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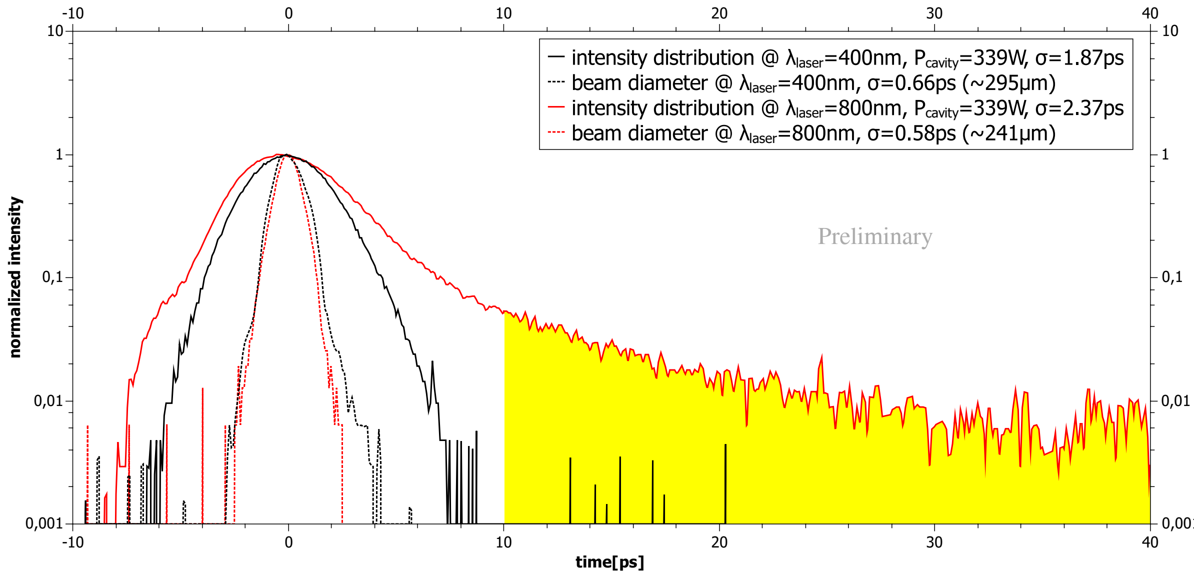

Figure 5: Longitudinal and transverse pulse profiles at λ_{laser} = 800 nm (red) and λ_{laser} = 400 nm (black) [5]. The yellow area shows the beam loss at the acceptance of an accelerator of σ_{pulse} = 10 ps.

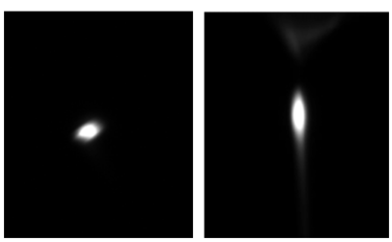

Figure 4: Original transverse beam (left), and longitudinal beam profile (right). RF and laser are synchronised. [5]

electron bunches have a different time structure. The response with deflection on is dominated by the longitudinal response for the bulk GaAs cathode used here, since the transverse extension of the beam is smaller by factor of 5. The tail of the bunches, which may be identified with the longitudinal halo, depends on λ_{laser} because of a higher absorption coefficient and smaller penetration depth at $\lambda_{\mathrm{laser}} = 400$ nm.

Assuming an acceptance of an accelerator of σ_{pulse} = 10 ps, almost 10% of the beam intensity is lost at λ_{laser} = 800 nm (yellow area in Figure 5), e.g. for a beam current of $I_{\mathrm{e\text{-}beam}}$ = 10 mA, 1 mA of current ("unwanted beam") will be lost.

Obviously, the contribution from unwanted beam for blue excitation is at least one order of magnitude smaller. A better estimation of the improvement will require a measurement of the beam profile with higher dynamic range.

OUTLOOK

To increase the dynamic range of time response measurements, implementation of an alternative method is planned. In addition to the YAG screen we will install a channeltron behind a 100 μm slit. We expect an large increase of sensitivity since then the dynamic range of the device is controllable by the amplification of the channeltron. Bandwidth will be of the same order as with the CCD since a fast steering magnet will be used for scanning the bunch profile over the slit.

In a next step, time response measurements will be repeated with PCA photocathodes. These cathodes are known to exhibit higher beam current and a better lifetime [6].

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