PULSE RESPONSE MEASUREMENTS OF NEA PHOTOCATHODES AT DIFFERENT LASER WAVELENGTHS

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Abstract

For high average electron beam currents the length of the electron bunches must match the acceptance of the accelerator. At Johannes Gutenberg-University Mainz we are able to measure the longitudinal pulse response of NEA photocathodes (GaAs) under photo excitation of different wavelengths. A time resolution of < 2 ps at a beam energy of 100 keV is achieved, furthermore, a high dynamic range allows to investigate long ranging tails of the response (longitudinal halo). This serves to identify the best possible operation mode for high current photo sources.

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 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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NEA PHOTOCATHODES

Until now, different types of GaAs photocathodes are used at both Mainzer Microtron (MAMI) and source testlab (PKAT) at Johannes Gutenberg-Universität 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 ≈ 1.5 eV (800 nm) and ≈ 3 eV (400 nm) became possible.

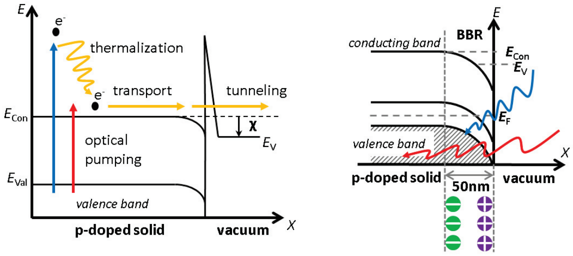

Figure 1: Left: Band scheme of a NEA photocathode. Right: Scheme of penetration depth. The arrows in blue (400 nm) and red (800 nm) indicate the different photon energies.

NEA (χ in Fig. 1) means a lower level of the vacuum energy than the level of the conducting band in the solid. With a typical band gap of 1.42 eV electrons from 400 nm become more excited than electrons from 800 nm and thermalize partially during their diffusion to the surface of the solid and get extracted to the vacuum as well as the electrons from 800 nm (see Fig. 1 on the left).

On the right the band bending region (BBR) is illustrated. The p-doping of GaAs causes an electrical field near the surface which allows the electrons to get accelerated respectively to get a momentum into the direction of the surface.

Outside the BBR the transport is mostly effected by diffusion [1] and depends on the diffusion consant D of the material and absorption coefficient $\alpha(E_\gamma)$, which is $< 0.8\ \mu\text{m}^{-1}$ for 800 nm [2] and around $67.4\ \mu\text{m}^{-1}$ for 400 nm radiation. Hence the typical distance which electrons have to travel are 1250 nm and 14.8 nm for red and blue respectively. Note that most blue-excited electrons are generated in the field region, which motivates that the charge is removed more quickly and to a larger extend compared to infrared radiation — see Fig. 5 below.

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 with a maximum input power of 340 W transforms the longitudinal beam profile into a transverse one. There are two possibilities for the time resolved measurements. On the one hand the beam spot is observable as an intensity distribution on a fluorescent screen (YAG-screen). On the other hand a 100 μm slit can be used to scan the beam profile. The transmitted current can be detected by a channeltron (CEM) which allows to measure currents in the region of < 100 fA.

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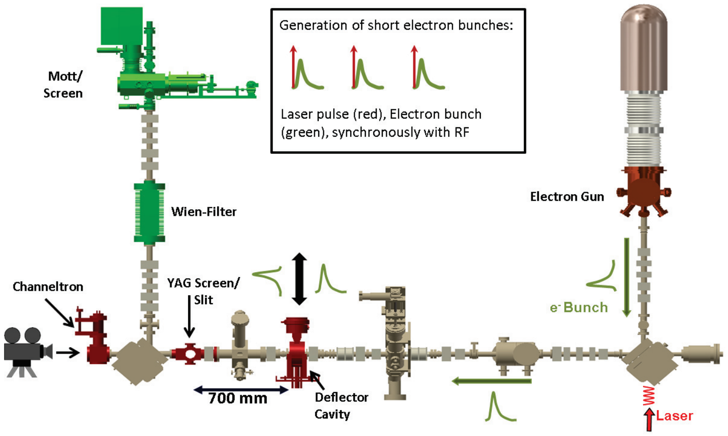

Figure 2: Scheme of the experimental setup at PKAT.

The design of the electron source at PKAT [3] does not allow a bunch charge which is high enough for analyzing a single electron bunch. Thus, the analyzed 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 synchronized to the radio frequency (RF) of the deflector cavity, every bunch is deflected at the same RF phase. Then the resulting intensity distribution represents the time dependency of electrons in one bunch.

Shifting the phase of the laser causes a transverse movement of the bunch after the deflection cavity. This can be used to move the bunch over a 100 μm slit.

Laser System

At PKAT the laser system consists of three components: A DC laser ($P_{\text{laser}} = 10\,\text{W}$, $\lambda_{\text{laser}} = 532\,\text{nm}$) is needed for pumping a modelocked Ti:Sapphire laser. The 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 synchronization 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 optimized 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 polarized 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) with the CCD-camera at the end of the beamline, and the slit with the CEM 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.

TIME RESPONSE MEASUREMENTS

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 or the measurement speed of the experimental setup behind the CEM. For time resolved measuements both is needed, the transverse and the longitudinal beam profiles. The contribution of timing jitter in both cases — during the exposure time of the CCD-camera and during the averaging and jittering of the current measurements — is estimated to be of the order of 1 ps or less.

Screen Calibration

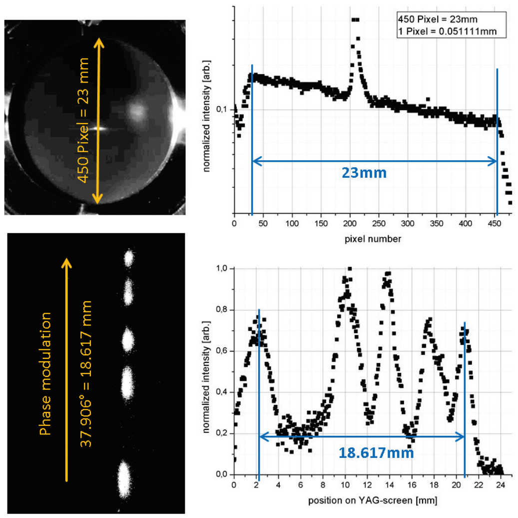

Figure 3: Calibration of the YAG screen for the dependencies pixel ↔ mm ↔ phase [°] ↔ time

The transverse beam profile is measured by using the YAG-screen and the CCD-camera. The information is given in pixel, and the relation between pixel and time is needed. Two steps are necessary: pixel↔mm and mm↔ps. The first calibration in Fig. 3 is done by using a scale, the second one by shifting the phase to move the synchronized electron bunch over the YAG-screen.

Electronic Phase Shifter

The phase shifter device has been designed in house [4]. Varying the operating voltage means shifting the phase. In comparison to a mechanical phase shifter it has a higher speed and a better reproducibility.

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 synchronized. For a good resolution a small transverse beamspot in the direction of deflection of the cavity at the position of screen respective the slit is necessary.

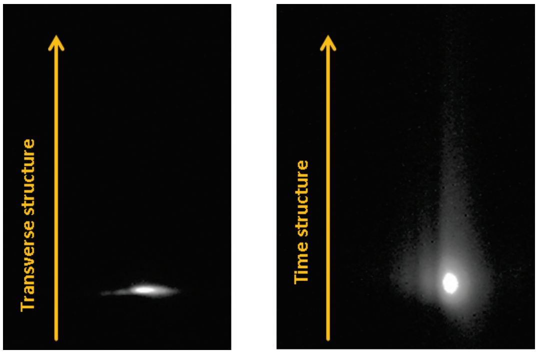

Figure 4: Original transverse beam (left), and longitudinal beam profile (right). RF and laser are synchronized.

First results with the slit method at low beam current ($I_{\text{e-beam}} < 10\,\text{nA} \triangleq 0.1\,\text{fC}$ bunch charge) are shown in Fig. 5. One measurement cycle takes about 15 min for tho shifting the phase respective the time over 60 ps. One point of Data takes 3 ms — this corresponds almost to 3×10^5 bunches. Two measurements (normalized intensity over time [ps]) of longitudinal electron bunches at $\lambda_{\text{laser}} = 800\,\text{nm}$ (red) and 400 nm (blue) are shown in comparison to each other.

While the transverse electron beam diameters from both laser wavelengths without the RF deflection are in the same range ($\sigma_{\text{trans}} < 260\,\mu\text{m}$) the 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 $\lambda_{\text{laser}} = 400\,\text{nm}$.

For emission times larger 10 ps the relative intensity 'blue' response is almost two orders of magnitude smaller than the 'infrared'. This would lead to corresponding reduction of losses in the accelerator if one assumes such a phase interval which is typical for Rf-guns.

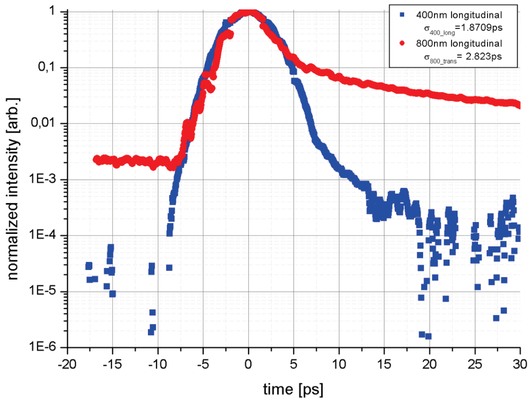

Figure 5: Longitudinal and transverse pulse profiles at $\lambda_{\text{laser}} = 800\,\text{nm}$ (red) and $\lambda_{\text{laser}} = 400\,\text{nm}$ (blue).

OUTLOOK

For a better statistic repetitions of the measurements especially at $\lambda_{\text{laser}} = 400\,\text{nm}$ are planned for a better understanding of the pulse response. To increase the resolution of the apparatus the laser beamline is going to be modified to reach the best possible laser spotsize on the photocathode.

In 2016 a Wien Filter (see Fig. 2) was installed which replaces the former Torus-spectrometer/Spin tranformer which had to be removed because of space restrictions. On the one hand the Wien-Filter can be used as a spectrometer to optimize the beam through the deflecting cavity. On the other hand time resolved polarization measurements are possible. The polarization in one bunch decreases with the time as it is shown in [3]. This fact can be used to doublecheck the time response measurement for $\lambda_{\text{laser}} = 800\,\text{nm}$.

Beside NEA photocathodes (GaAs) we are able to use homemade PEA photocathodes (K_2CsSb) to analyze the time response of this photocathode type [5].

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