Micrometer positron beam characterization at the Scanning Positron Microscope Interface

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Abstract. For the investigation of inhomogeneous defect distributions the Scanning Positron Microscope (SPM) of the Universität der Bundeswehr München provides a pulsed positron beam with a diameter of about 1 µm and a time resolution of 250 ps (FWHM). To increase the count-rate the SPM is currently transferred to the intense positron source NEPOMUC.

To connect the SPM to the NEPOMUC source a special interface was build, which transforms the NEPOMUC beam to the requirements of the SPM. In this contribution we will give an overview of the SPM interface, and its performance. The beam is characterized at the finale stage of the interface, the positron elevator, where the potential energy of the beam is increased, without altering other beam parameters.

From our measurements we are able to predict the performance of the SPM at NEPOMUC. In future position resolved measurements will be possible with an improved spatial resolution of about 0.3 µm and an event rate of about 3.7 kHz.

1. Introduction

To characterize inhomogeneous defect distributions on the micrometer scale, e.g. precipitation hardened alloys, defect distributions close to fatigue cracks or grain boundaries with positron annihilation lifetime spectroscopy (PALS) a pulsed beam of variable energy and a spot size in the micrometer range is required.

The Scanning Positron Microscope (SPM) [1, 2] complies with these requirements. To achieve positron pulses of 200 ps duration and a spot size below 2 µm a narrow intense positron beam of about 5 mm² cross section and 30 meV transverse energy spread is required. Therefore, even with a primary source of 0.5 GBq ²²Na, only event rates of 100 to 500 Hz are achievable. This leads to exceedingly long measurement times. To overcome this limitation, the SPM is currently being connected to the intense positron source NEPOMUC [3, 4].

The primary beam of NEPOMUC delivers up to 5·10⁸ e+/s with a transverse phase space of about 3 000 mm²·eV. A first re-moderation stage reduces this phase space to about 5 mm²·1.3 eV and a intensity of 6·10⁷ e+/s for the re-moderated beam at the experiment entrance [5].

For further reduction of the phase space and pulsing the continuous NEPOMUC beam a dedicated interface was constructed for the SPM [6]. The newly develop final component of the interface, the positron elevator, increases the potential energy of the beam to the required potential at the entrance of the SPM. A brief description of the interface is given in section 2.

The knowledge of the actual beam parameters is important for further developments of the SPM interface and the SPM. Therefore we performed and report measurements of the beam.
characteristics and the influence of the elevator on the time structure. Finally, we predict the expected performance of the SPM at NEPOMUC.

2. The SPM interface at NEPOMUC

Figure 1 shows an overview of the SPM interface and the SPM. For the desired spatial resolution a narrow, monoenergetic beam with small energy spread is crucial. Therefore, the re-moderated positron beam of NEPOMUC is directed onto the SPM interface, which includes an additional remoderator (2nd remoderator). The last re-moderation stage (3rd remoderator) is a part of the SPM. In both re-moderation stages, magnetic lenses and W(100) single crystals in reflection geometry are used.

For positron lifetime measurements the continuous beam of NEPOMUC has to be pulsed. A narrow pulse width is essential for a good time resolution. To use as many positrons as possible a sawtooth prebuncher compresses the beam. In addition, two sine wave bunchers reduce the pulse width. A chopper cuts out the positrons between the pulses, thus reducing the background.

In each re-moderation stage several keV of kinetic energy are lost. The elevator compensates these losses between the re-moderation steps. Therefore, the 3rd remoderator can be set close to ground potential, as in the laboratory set up of the SPM. The elevator keeps the required high-voltage low and allows implantation energies up to 20 keV (see figure 1).

With a properly adjusted SPM interface, the 3rd remoderator provides a pulsed monoenergetic positron source of a few micrometer in diameter. Up to now, the SPM interface works as expected.

3. Test chamber and beam characterization

For proper adjustment the beam characteristics have to be determined in front of the elevator. Therefore, a special test chamber was build for the SPM interface and installed at the position of the elevator (see figure 1).

3.1. Test chamber

The test chamber is shown in figure 2. The positron beam enters from the left and is electrostatically guided via the shutter gap into the chamber. The beam is deflected by scanning coils and magnetically focussed at the sample position. The detector is placed behind a tungsten shield. Due to the large inner volume of the chamber, the homogeneous electrical field inside and the shielding of the detector, no backscattered positrons are detected. For a better analysis of the beam characteristics the magnetic lens of the 3rd remoderator stage is used at the test chamber [7].
3.2. Experimental results
The sample consists of a conductive carbon tape and metallic glass, as shown in figure 3(a).
These materials differ in positron lifetime due to the metallic quality of the glass and positronium production in the polymer.

![Figure 3](image)
Figure 3. (a) Illustration of the sample and (b) mean positron lifetime map of the scanned area. In (c) the measured line scan is shown as indicated with the white line in (b).

All measurements were recorded with an implantation energy of 1.5 keV. In figure 3(b) the spatial distribution of the mean lifetime is shown. The scanning area is about 1.8 x 1.8 mm² and free of image distortion. The beam diameter of (180 ± 10) µm is estimated from the full width at half maximum (FWHM) of the slope of the line scan in figure 3(c).

Two positron lifetime spectra for the different sample materials are also obtained with high statistics (P_{Tape} and P_{Met} in figure 3(b)). The spectra are mainly free of backscatter peaks with a peak to background ratio of 1000. From these spectra a pulse duration of (257 ± 3) ps (FWHM) is derived.

4. The positron elevator
The elevator is the final stage of the SPM interface. It elevates the potential energy as indicated in figure 1 from -5 keV to +5 keV. In this way the positrons can be accelerated to the required energies for the implantation into the remoderator or the sample. Here we follow closely the detailed description in [8].

4.1. Setup of the positron elevator
The positron elevator consists of three electrodes, the entrance-, central- and exit-electrode. The entrance-electrode is on a negative potential of $U_{ent} = -5$ kV, the exit electrode is at $U_{exit} = +5$ kV. The central-electrode is on a static voltage of 0 V superimposed by a 10 kV (peak to peak) sine wave signal of $f = 50$ MHz; $U_{cent}(t) = 0 V + 5 kV \sin(2 \pi f t)$.

The incoming pulsed positron beam is focused into the middle of the central electrode. Adjusting the beam velocity and the phase of the elevator to the positron pulses, they pass the gaps when they are field free. Thus the only effect of the elevator on the positron beam is the raised potential energy. The setup includes also a monitoring system with an Einzel-lens,

![Figure 4](image)
Figure 4. (a) Schematic of the positron elevator and the beam monitoring system. (b) Working principle and desired potential setup of the elevator.
scanning coils and a circular aperture. The beam can be scanned over the aperture in order to
determine the beam diameter and the transverse momentum of the beam. These measurements
are possible for both, the elevated and the non-elevated beam.

4.2. Experimental results
By adjusting the elevator correctly, almost all positrons with an energy gain of 1keV are
transmitted through the gaps which are 4 mm in diameter.

We investigated the influence of the beam elevation on the time structure as shown in
figure 5(a). The two spectra are normalized and shifted in time. There is no broadening of
the peak, which means that the influence of the elevator on the time structure is negligible.

Figure 5(b) shows a scanning image of the aperture. The dark region (high count rate) is
attributed to be the aperture surface where the count rate becomes higher due to the positron
annihilation. From the rectangular areas in figure 5(b) the beam diameter can be calculated
as shown in figure 5(c). We obtain beam diameters of 0.6 mm and 1.2 mm (FWHM) in x- and
y-direction respectively.

Figure 5. Experimental results of the positron elevator commissioning. (a) influence on the
time structure, (b) count rate map of the scanned aperture, (c) transition plotted as profiles
with respect to the indicated boxes in (b).

5. Conclusion and outlook
The newly implemented SPM interface with the positron elevator has been used to adapt the
NEPOMUC beam properly to the required input characteristics of the SPM: the continuous
beam is pulsed, enhanced in brightness and elevated to 5 keV potential energy with respect to
ground.

Thus we expect for the SPM at NEPOMUC a time resolution of 250 ps and an improved
spatial resolution of about 300 nm (FWHM) at a drastically improved count rate of 3700 events
per second in comparison to the laboratory setup [8].

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References
[1] Kögel G 1997 Appl. Surf. Sci. 116 108 – 113
[2] David A, Kögel G, Sperr P and Triftshäuser W 2001 Phys. Rev. Lett. 87 067402
[3] Kögel G and Dollinger G 2006 Appl. Surf. Sci. 252 3111 – 3120
[4] Hugenschmidt C and Piochacz C 2015 Journal of large-scale research facilities 1 A22
[5] Stanja J, Hergenhahn U, Niemann H, Paschkowski N, Pedersen T S, Saitoh H, Stenson E, Stoneking M,
Hugenschmidt C and Piochacz C 2016 Nucl. Instrum. Methods Phys. Res., Sect. A 827 52 – 62
[6] Piochacz C 2009 Generation of a high-brightness pulsed positron beam for the Munich scanning positron
microscope Ph.D. thesis TUM
[7] Britton D, Uhlmann K and Kögel G 1995 Appl. Surf. Sci. 85 158 – 164
[8] Dickmann M, Mitteneder J, Kögel G, Egger W, Sperr P, Ackermann U, Piochacz C and Dollinger G 2016
Nucl. Instr. Methods in Phys. Res. A 821 40 – 43