Proc. of the 15th Int. Workshop on Slow Positron Beam Techniques and Applications, Prague, September 2–6, 2019

Upgrade of the NEPOMUC Remoderator

M. Dickmann[a,*], W. Egger[a], G. Kögel[a], S. Vohburger[b] and C. Hugenschmidt[b]

[a]Institut für Angewandte Physik und Messtechnik LRT2 Universität der Bundeswehr München, Werner-Heisenberg-Weg 39, 85577 Neubiberg, Germany

[b]Heinz Maier-Leibnitz Zentrum (MLZ) and Physik Department E21 Technische Universität München, Lichtenbergstraße 1, 5748 Garching, Germany

The neutron-induced positron source Munich (NEPOMUC) provides a monochromatic low-energy positron beam with an intensity of $> 1 \times 10^9 e^+$ s^{-1} and a full width at half maximum (FWHM) diameter of about 10 mm. To create a small beam focus or sharp positron pulses of 100 ps FWHM the beam brightness needs to be enhanced by remoderation. This is achieved by focusing the primary beam magnetically onto a tungsten single crystal W(100) in reflection geometry. Afterwards the beam exhibits an intensity of $> 5 \times 10^7 e^+$ s^{-1} and a diameter of < 2 mm FWHM. To further optimize the beam quality of NEPOMUC we redesigned the remoderation unit. The new setup allows a precise positioning of the remoderator crystal within the focus of the magnetic lens. Additionally, a replacement of the crystal within several minutes and without breaking the beamline vacuum is possible that offers the opportunity for systematic tests of different remoderator materials.

DOI: 10.12693/APhysPolA.137.149

PACS/topics: 78.70.Bj, 41.75.Fr, 36.10.Dr

1. Introduction

The reactor-based positron source NEPOMUC provides an intense, mono-energetic positron beam for various experiments: The Coincidence Doppler-Broadening Spectrometer (CDBS) [1], the Pulsed Low-Energy Positron System (PLEPS) [2], the Scanning Positron Microscope (SPM) [3], the Surface Spectrometer (SusSpect) [4], and an open beam port for temporary devices, which is presently used for an electron-positron pair plasma experiment [5]. The NEPOMUC primary beam intensity reaches a yield of more than $1.1 \times 10^9 e^+$ s^{-1} [6]. It is transported in a magnetic field of about 4 mT [7] and owns a mean diameter of about 10 mm FWHM.

The primary beam can directly be used for all apparatuses connected with NEPOMUC. However, most experiments require a higher beam quality, where the beam diameter is smaller and the transverse phase space density is higher [8]. For this reason the primary beam can be transported in a remoderation unit where it leaves the magnetic transport field and is transported only electrostatically. Here it is focused by a magnetic lens and implanted into a W(100) single crystal with 1 keV kinetic energy. The remoderation process works in reflection geometry and, depending on the crystal potential, the kinetic energy of the remoderated beam is in the range of usually 20 eV. Because of the distinctly different beam velocities, primary and remoderated beam can be separated from each other by a magnetic dipole-switch. After remoderation the beam is re-injected into the magnetic transport field of the beam line. The remoderated beam is now smaller in diameter and owns less transverse momentum, however, its intensity is also inferior compared with the primary beam. Table I shows a selection of the most important beam properties before and after remoderation in comparison with a conventional ^{22}Na-based beam.

TABLE I

Main characteristics of a tungsten moderated 6 mCi ^{22}Na source based beam and NEPOMUC. The beam brightness B is calculated with the beam intensity I, and the FWHM beam diameter d as $B = I/\left(d^2 E_\perp\right)$, where $E_\perp = p_\perp^2/(2m_e)$ is the component of the kinetic energy, which belongs to the momentum component $p_\perp$ transverse to the beam propagation direction.

	^{22}Na-based	NEPOMUC-	
		prim	rem
I [e^+ s^{-1}]	2×10^5	1.14×10^9	5.0×10^7
d [mm]	3.0	9.3	1.85
$E_\perp$ [eV]	0.1	50	1.0
B [e^+/(mm^2 eV s)]	4.4×10^5	5.3×10^5	1.8×10^7

The main drawback of this setup is the fixed position of the remoderator crystal. It cannot be moved or changed without higher effort and a precise positioning within the short focal length of the magnetic lens is impossible. Therefore, the crystal is on a non-optimal position and its surface is out of the beam focus. A smaller beam spot size, however, would lead to a reduced diameter of the remoderated beam so that the following electrostatic lens system would add less transverse moment and, as a result, the beam brightness increases. To overcome this limitation we re-designed parts of the remoderation unit. The new setup allows a precise positioning

*corresponding author; e-mail: marcel.dickmann@unibw.de

of the crystal within the short focal range of the magnetic lens. Furthermore, it permits the feasibility to completely remove the remoderator crystal and replace it within a short amount of time and without breaking the beamline vacuum. This offers the possibility for systematical studies of new remoderator materials.

2. Reconstruction and upgrade of the remoderator unit

A cross-sectional drawing of the redesigned remoderation unit is shown in Fig. 1. The main difference to the old setup is the movable crystal holder, which can be shifted within a travel range of 500 mm with a precision and accuracy in the range of 0.1 mm. In operation the crystal position is close to the last electrostatic lens within the focal range of the magnetic lens. The lens properties can be adjusted by the electric current running through the windings of the main coil. The magnetic field is concentrated by an iron pole shoe. In this way the primary beam is focused on the crystal surface within a spot diameter of about 2 mm FWHM. The strong magnetic field, however, counteracts a high quality of the remoderated beam. If there would be no magnetic field, the transverse momentum space of the remoderated beam would be mainly determined by the thermal spread of the kinetic energy of positrons leaving the crystal surface. Since the additional momentum occurring from a magnetic field is conserved, the transverse momentum space increases with the magnetic field strength at the crystal. Therefore, the new setup contains two additional coils close to the crystal. One coil subtracts the magnetic field to almost zero, and with the other coil we can correct the focus position very sensitively. Figure 2 shows a simulation of the magnetic flux density in the crystal environment.

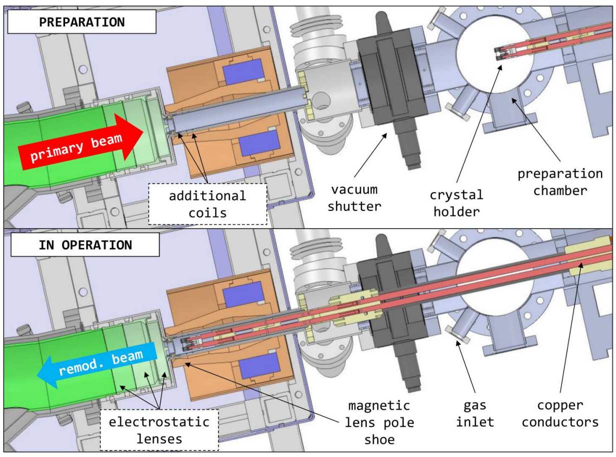

Fig. 1. Cross-sectional drawing of the re-designed remoderation unit in operation mode (bottom) and during the crystal preparation (top).

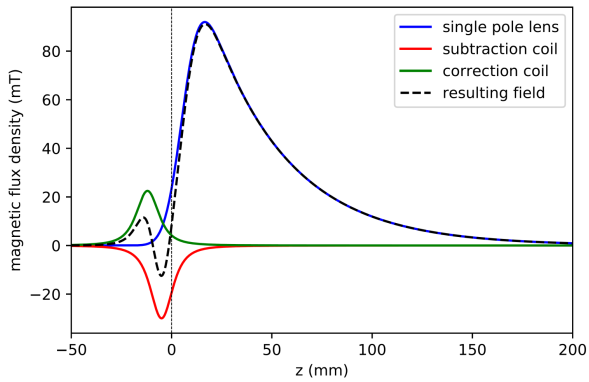

Fig. 2. Simulated magnetic flux density close to the position of the remoderator crystal (z=0). The resulting field (dotted line) occurs by using all magnetic coils in combination. The subtraction coil eliminates the magnetic field almost at z=0. The correction coil can be used to adjust the focus position precisely.

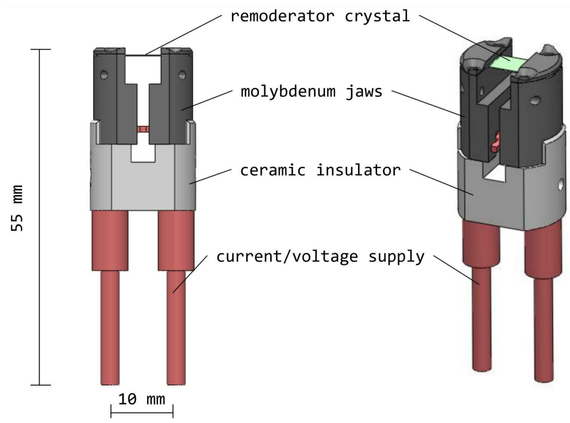

Fig. 3. Technical drawing of the new remoderator crystal holder. The design is optimized for crystal sizes of 5×13 mm^2 and thicknesses between 0.1 and 0.6 mm.

To optimize the beam intensity the system allows to heat and anneal the crystal by electric current at any position with a maximum current of 120 A. The complete crystal mounting can be moved into a preparation chamber behind a vacuum shutter. Here it is possible to remove the complete crystal holder (shown in Fig. 3) within a short amount of time and without breaking the beam line vacuum. The holder is designed for crystal sizes of 5×13 mm^2 and a thickness between 0.1 and 0.6 mm. The holder jaws are electrically insulated from each other and made out of molybdenum, which has similar material properties as tungsten. In addition, the preparation chamber is equipped with a gas inlet, which we can use to inject different gases like oxygen or atomic hydrogen directly on the crystal in order to terminate the surface after heating. The process can be monitored by a CCD camera.

3. First results and outlook

Within one reactor cycle of 60 days we were able to test the new setup and all components work as desired. After optimizing all parameters we obtained an increased beam intensity by a factor of ≈ 1.5 with respect to the old setup. The whole system ran stable for the whole time of 8 weeks and the values are reproducible. However, within this first test period it was not possible to measure the exact beam properties sufficiently. However, all instruments which used the remoderated beam of the new setup worked properly without any restrictions. Because of the higher beam intensity it was possible to reduce the measurement time of some experiments. Nevertheless, in the near future we will concentrate on a precise determination of the beam characteristics like diameter, intensity, and energy distribution. The next step afterwards is a replacement of the tungsten crystal with other remoderator materials, e.g., silicon carbide (SiC) or diamond. Previous experiments [9, 10] show that SiC possesses a high positron emission rate. Also diamond shows promising re-emission properties for positrons [11, 12]. Since these materials are insulators with high mobility, they are both candidates for high efficiency field assisted remoderators.

4. Conclusion

We described within this article the new NEPOMUC remoderator setup. The renewed system generates a beam of higher brightness with respect to the old setup. The increased beam quality is beneficial for all positron experiments connected with the NEPOMUC source. Our new setup allows to change the remoderator crystal without higher effort. Additionally, we can use the device for systematical tests of new remoderator materials.

References

[1] T. Gigl, C. Piochacz, M. Reiner, C. Hugenschmidt, *J. Phys.: Conf. Ser.* **505**, 012032 (2014).

[2] W. Egger, P. Sperr, G. Kögel, G. Dollinger, *Phys. Status Solidi C* **4**, 3969 (2007).

[3] M. Dickmann, C. Piochacz, *JLSRF* **1**, 26 (2015).

[4] S. Zimnik, M. Dickmann, C. Hugenschmidt, *Surf. Sci.* **664**, 61 (2017).

[5] H. Saitoh et al., *AIP Conf. Proc.* **1928**, 020013 (2018).

[6] C. Hugenschmidt et al., *J. Phys.: Conf. Ser.* **505**, 012029 (2014).

[7] C. Hugenschmidt, K. Schreckenbach, M. Stadlbauer, B. Straßer, *Nucl. Instrum. Methods Phys. Res. A* **554**, 384 (2005).

[8] C. Hugenschmidt, C. Piochacz, M. Reiner, K. Schreckenbach, *New J. Phys.* **1**, 055027 (2012).

[9] L.V. Jorgensen, A. van Veen, H. Schut, *Nucl. Instrum. Methods Phys. Res. B* **119**, 487 (1996).

[10] M.H. Weber, C.G. Fischer, K. Sato, K.G. Lynn, *Mater. Sci. Forum* **445**, 416 (2004).

[11] G.R. Brandes, A.P. Mills, D.M. Zuckerman, *Mater. Sci. Forum* **105** 1363 (1992).

[12] G.R. Brandes, K. Canter, A. Krupyshev, R. Xie, A.P. Mills, *Mater. Sci. Forum* **255**, 653 (1997).