Implementation of a ^{22}Na Based Positron Beam

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INTRODUCTION

Positrons are applied as nano-probes for the non-destructive detection of lattice defects with highest sensitivity. By using monoenergetic positrons, the implantation depth can be varied that hence allows for the investigation of defect profiles, thin films or interfaces. A slow positron beam with a β^+-emitter as positron source was installed and set into operation at MLL in 2013. This facility enables long-term experiments with monoenergetic positrons.

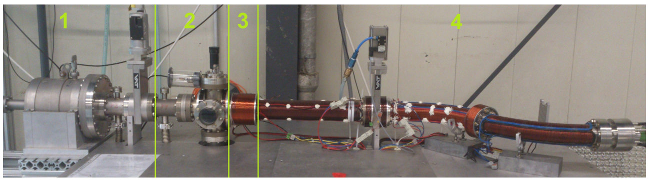

Figure 1: Setup of the slow positron beam at MLL. The components are: ^{22}Na-Source (1), moderator (2), injection into magnetic guidance field (3), beam line (4), and annihilation target with detectors at the end (not shown).

^{22}NA AS POSITRON SOURCE

Positrons are emitted from the β^+-emitter ^{22}Na: $^{22}\text{Na}\rightarrow^{22}_{10}$ Ne + e$^+$ + ν_e. This nuclide was chosen due to its long half-life of 2.6 years, and its high positron yield of 0.9. The continuous β^+-spectrum of ^{22}Na has an end-point energy of 544 keV. The source itself is behind a thin (10 μm) Ti window and separated from the main vacuum chamber of the beam.

MODERATION

The moderation technique is used to generate a monoenergetic e$^+$ beam. For this purpose, a material with a negative positron work function Φ^+ is needed. In this setup a 10 μm thin annealed single-crystalline tungsten foil (Φ^+ = -3 eV) is used as moderator in transmission geometry. The fast positrons thermalise due to inelastic scattering within a few picoseconds before a certain fraction of thermalized positrons can diffuse to the surface and is reemitted as free particles with a narrow energy distribution according to the positron work function. The moderation efficiency is in the order of 10^{-4} to 10^{-3}[1].

POSITRON BEAM TRANSPORT

The moderated positrons are extracted from the moderator foil within a longitudinal homogeneous magnetic field, which is generated by Helmholtz coils around the source-moderator section. The electric acceleration field is produced by electrostatic lenses. A solenoid around the beam tube generates the static magnetic field (typically 5 mT in z-direction) for adiabatic beam guidance. During the flight through bends the so-called drift force in the direction $\vec{R} \times \vec{B}$ affects on the positron beam. In order to compensate the drift motion and external stray fields two pairs of additional coils in x- and y-direction are mounted on the tubes as well.

RESULTS

The shape and the diameter of the positron beam was observed with a Micro-Channel-Plate (MCP) and a CCD camera. For the intensity measurement, the MCP was used as annihilation target, and the CCD camera was replaced by an BGO detector in order to detect the annihilation radiation. The ^{22}Na source with an activity of 10^8 Bq yielded about 4000 moderated positrons per second, and hence an overall efficiency of about $4 \cdot 10^{-5}$ was achieved. The diameter of the beam amounts to about 2.5 mm.

In 2013, a new pulsing device comprising bunching and chopper units was set into operation. This device is a prerequisite to install a novel so-called *positron-elevator*, which will allow to increase the total energy of the positron beam by 1-10 keV.

OUTLOOK

In 2014, the Na source will be replaced by a new one with a higher activity in the order of 1-2$\cdot 10^9$ Bq. In addition, a revision of the moderator is expected to raise the moderation efficiency. Therefore, the measurement time will be reduced at least by a factor of 20.

At present, a sample chamber with a cryostat is implemented in order to enable temperature dependent Doppler broadening spectroscopy in coincidence (CDBS) of the annihilation line. For this purpose, high-purity Ge detectors will be positioned around the annihilation target.

It is also planned to install a further device, which allows experiments with a pulsed structure of the positron beam.

REFERENCES

[1] Peter J. Schultz, K. G. Lynn: ”Interaction of positron beams with surfaces, thin films, and interfaces”, Rev. Mod. Phys., 60(3):701 779, July 1988