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Status of the pulsed low energy positron beam system (PLEPS) at the Munich Research Reactor FRM-II

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ABSTRACT

The Munich pulsed low energy positron beam system (PLEPS) is now installed at the high intensity positron source (NEPOMUC) at the Munich Research Reactor FRM-II. In order to enhance the performance of the system several improvements have been implemented: two additional collinear detector ports have been installed. Therefore in addition to the normal lifetime measurements it is now possible to simultaneously perform Doppler-broadening, coincident Doppler-broadening and age momentum correlation experiments. An additional chopper was included to periodically suppress pulses and therefore to extend the standard time window of 20 ns for precise measurements of longer lifetimes. First test-experiments have been performed in May and July 2007. With all pulsing components in operation we achieved a count-rate of 1.4×10^4 counts per second. The total time resolution (pulsing and detector) was about 240 ps (FWHM) with a peak to background ratio up to 6×10^3:1.

1. Introduction

Low energy positron beam systems of variable energy have shown their ability for depth profiling of defects from nanometer to micrometer resolution [1,2]. In order to perform positron lifetime measurements it is necessary to obtain precisely the time when the positron hits the sample. With the application of conventional rf-pulsing methods, well known from particle accelerators [3], a time resolution which is necessary for positron lifetime spectroscopy was achieved. The system PLEPS for positron lifetime spectroscopy was developed at our institute in the past two decades. The details of the latest version being in operation over the last years are described in Refs. [4,5]. Many successful investigations on metals and alloys [1,2], polymers [6] and semiconductors [7] have been performed with this instrument, often in cooperation with external users. The exploitation of the full potential of PLEPS however, was restricted due to the insufficient beam intensity obtainable with conventional laboratory sources. Therefore the right decision was to transfer PLEPS to the best currently available positron source, the high-flux positron beam facility NEPOMUC at the Munich Research Reactor FRM-II [8], which has shown an intensity of about 10^8 positrons per second. After remoderation [9] a monoenergetic positron beam with a small diameter (about 2 mm) is available. At the moment we have about 3–4% of the intensity in the remoderated beam [9]. Prior to the installation of PLEPS at the FRM-II some modifications have been performed, in order to improve the performance of the system.

2. Operation principles and technical details

The basic principles of operation and details of the individual pulsing components, the pre-buncher, the chopper and the main buncher are given in literature [4,5]. The essential design characteristics of PLEPS have been maintained. The remoderated positron beam with diameter of about 2 mm and an energy of 20 eV is fed over a long beam line (about 20 m) and a beam switch to the aperture of the pre-buncher (Fig. 1). The beam is transported by a solenoidal magnetic guiding field of 7 mTesla. A lot of transverse steering fields along the beam line allow to correct the position of the beam.

The positron beam successively passes the pre-buncher, the chopper and the main buncher. These devices are operated at a frequency of 50 MHz, corresponding to a time window of 20 ns.

PLEPS had shown a beam pulse width at the target of about 150 ps (FWHM) when it was installed at its original position in the laboratory [4,5]. To get the same pulse width at all implantation energies, only the final narrow pulses are accelerated to the desired implantation energy between 0.5 and 22 keV. The drift tube is necessary to account for the differences in time of flight between

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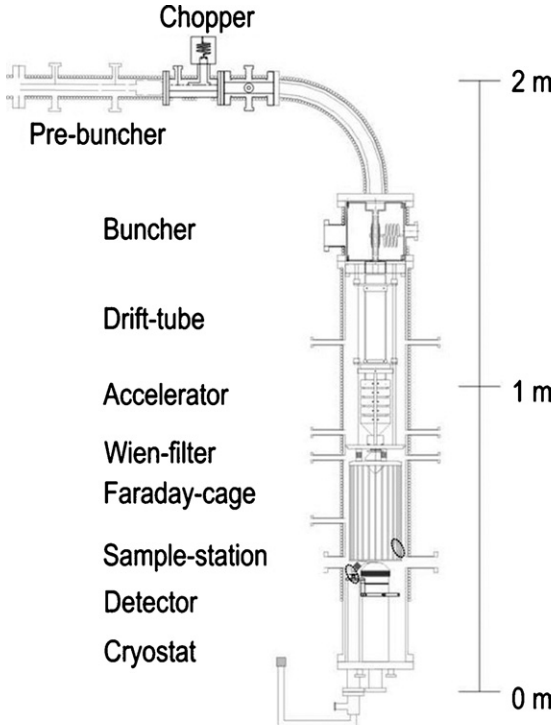

Fig. 1. Schematic view of PLEPS as it is installed at the FRM-II. The additional detector ports are tilted by 45° with respect to the plane of the target.

the exit of the buncher and the sample. After the accelerator the positrons pass the field-free Faraday-cage until they reach the target. The annihilation quanta are recorded in a BaF_2 scintillator coupled to a photomultiplier. The detector is placed from below as close as possible to the target. The PLEPS is located directly in the reactor hall of the FRM-II. This location, together with all necessary components like power supplies, electronics, controls and data acquisition system is shown in Fig. 2.

3. Modifications and improvements

A major modification has been made at the sample station. Two collinear detector ports have been implemented. In addition to

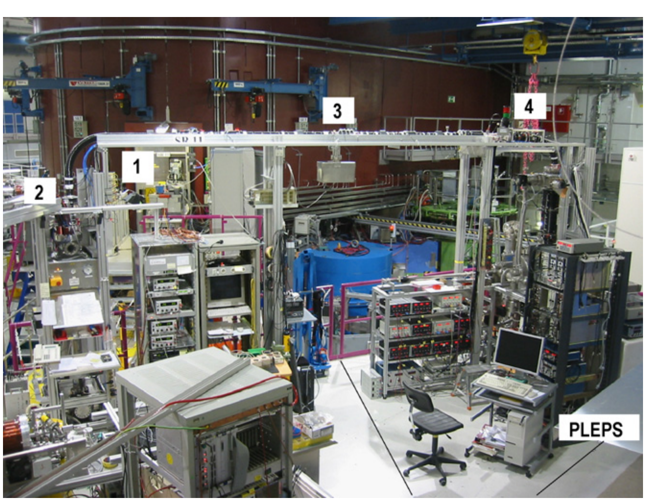

Fig. 2. Location of PLEPS in the reactor hall of the FRM-II. (1) Primary positron source NEPOMUC [8] and remoderator [9], (2) beam switch, (3) beam line to PLEPS, (4) pre-buncher and chopper.

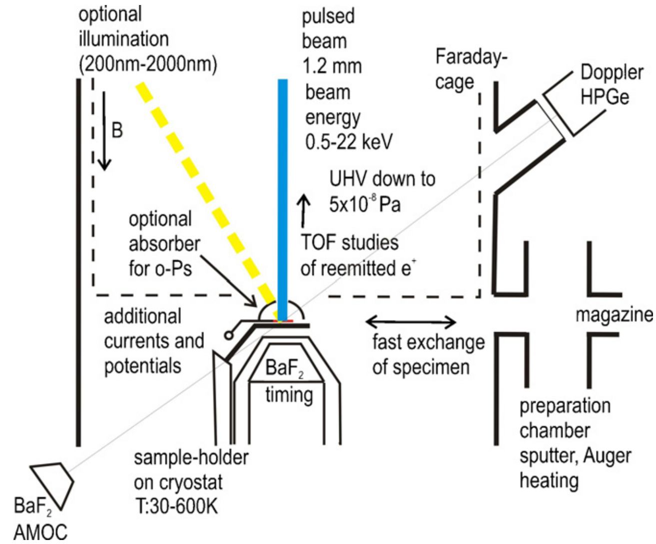

Fig. 3. The modified sample station (schematic) of the pulsed low energy positron system [11]. The controlled experimental parameters are indicated.

normal lifetime measurements, also Doppler-broadening, coincident Doppler-broadening and AMOC experiments are possible (see Fig. 3). At top of the Faraday-cage an absorbing W-structure was mounted, in order to suppress background contributions from annihilating positrons which are back-scattered from the sample. The original chopper has also been modified. An additional deflection plate has been mounted in front of the entrance slit of the chopper. Applying a periodical blanking signal, which is phase locked to the masteroscillator, but divided in frequency by orders of two, the time window can be expanded. Therefore precise measurements of long lifetimes, as they occur in polymers or low-k dielectrics, become possible. These modifications are given in more detail in Ref. [10].

4. First test-experiments at the FRM-II

First test-experiments with the newly installed PLEPS at the FRM-II have been performed recently in May and July 2007. Starting with a beam of an energy of 20 eV from the remoderator and after adjusting and tuning all magnetic field components along the beam line and in the beam switch we had the dc-beam at the target. 5×10^4 counts per second were recorded in the detector. Taking into account the solid angle and the detector efficiency this number corresponds to about 10^6 positrons per second at the sample. Starting with about 5×10^7 positrons per second from the primary source this time, we must conclude that the missing positrons are due to a low remoderator efficiency and losses in the beam line and in the beam switch. These features will be carefully investigated in further beam times. As a next step the performance of each pulsing element was investigated and carefully tuned. After putting all elements: pre-buncher, chopper (with reduced slits) and main buncher together, we had the pulsed beam at the target with 1.4×10^4 counts per second recorded in the detector. Compared to 500 counts per second which we have obtained with our laboratory source (^{22}Na, 30×10^7 Bq) this is a large progress. Within 4 min a single lifetime spectrum with more than 3×10^6 counts can be accumulated. A complete depth profiling (25 spectra) can be performed in less than 2 h. One of the first samples which were used for the test-experiments was a hardened epoxy resin (EEW 190). The results, an example of a raw spectrum given in Fig. 4, clearly show the long lifetime of about 2.2 ns. The achieved peak to background ratio is 3×10^3:1.