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Low-energy positrons of high intensity at the new positron beam facility NEPOMUC

C. Hugenschmidt*, K. Schreckenbach, M. Stadlbauer, B. Straßer

Technische Universität München, ZWE FRM-II/E21, Lichtenbergstraße 1, 85747 Garching, Germany

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Abstract

In summer 2004 the NEutron-induced POsitron source MUniCh—NEPOMUC—of the new Munich research reactor FRM-II was set into operation at the nominal reactor power of 20 MW. With this novel facility one of the worlds most intense low-energy positron beam is now available. Intensity and positron beam profile measurements were performed at 1 and 30 eV, respectively. Within the first reactor cycle a yield of up to 10^8 moderated positrons per second was achieved. In the present arrangement of NEPOMUC's instrumentation the monoenergetic positron beam is magnetically guided to a coincident Doppler broadening (CDB) facility and to a positron-induced Auger electron spectroscopy (PAES) analysis chamber.

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1. Introduction

Positron beams of high intensity and low energy are of major interest in solid state and surface physics, in material science as well as in atomic physics. For most experiments, an intense beam is desirable in order to reduce the time of measurement or improve statistics. Moreover, strong positron beams are even crucial in a variety of experiments for which sophisticated techniques may be applied: coincident detection of both annihilation quanta, that leads to an efficient background reduction and enhances energy resolution at coincident Doppler broadening (CDB) measurements [1–4]; multiple remoderation for brightness enhancement and hence improved lateral resolution [5,6], e.g. for positron lifetime measurements; Auger-electron detection after slow positron impact, a technique, which will not tap its

*Corresponding author. Tel.: +49 89 28914609; fax: +49 89 28913779.
E-mail address: Christoph.Hugenschmidt@frm2.tum.de (C. Hugenschmidt).

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full potential until intense positron beams are available [7]; production of exotic leptonic bound states such as the negatively charged positronium Ps^- [8].

Conventional laboratory beam facilities consist of a β^+ active isotope and a positron moderator. The yield of moderated positrons ranges between 10^4 and 10^5 positrons per second and does usually not exceed 10^6 positrons per second. Therefore, great efforts have been made to generate positrons by pair production using bright γ-sources, i.e. bremsstrahlung in a target at electron linear accelerators [9–11], γ-radiation from nuclear fission [12,13] or high-energy prompt γ-rays after thermal neutron capture [14,15].

Several (n,γ)-reactions were elaborately studied at the research reactor at the ILL in Grenoble in order to benefit from the released high-energy γ-radiation for the e^+e^- pair production in tungsten [14]. At NEPOMUC positrons are generated by pair production from absorption of high-energy prompt γ-radiation in platinum after thermal neutron capture in cadmium [16].

In March 2004, the Munich research reactor FRM-II produced the first neutrons at low power of a few kilowatts [17]. First evidence of positrons delivered from NEPOMUC was observed at 15 kW reactor power [18]. During the first reactor cycle at the nominal power of 20 MW the positron beam was adjusted and an intensity up to 10^8 moderated positrons per second was achieved.

Within the scope of this publication, an overview of the positron beam facility with the connected spectrometers is given and the experimentally determined beam parameters of NEPOMUC are presented. In addition, future plans of the positron instrumentation are outlined as well.

2. NEPOMUC and positron beam experiments at FRM-II

2.1. The intense positron source

The neutron-induced positron source is installed as an in-pile component inside the inclined beamtube SR 11 of the new research reactor FRM-II (see Fig. 1). The positrons of NEPOMUC are generated by pair production from absorption of high-energy prompt γ-rays after thermal neutron capture in cadmium [16]. For this purpose, a cadmium cap is mounted inside the tip of the beam tube, which is located in the heavy water moderator tank of the reactor.

In order to convert the high-energy γ-radiation into positron–electron pairs a structure of platinum foils is mounted inside the cadmium cap which acts as bright γ-source. This platinum structure is composed of three zigzag-shaped ring sections with a diameter of 65 mm and a honeycomb-like structure which is mounted on a front plate. Positron moderation in annealed platinum leads to emission of monoenergetic positrons due to the negative positron work function [19,20]. Positive high voltage is applied at the platinum foils and at additional electrical lenses in order to extract the moderated positrons. The kinetic energy of the positrons can be varied between a few eV and 1 keV. The positrons are magnetically guided in a solenoid field of typically 6 mT. The positron beam passes three bends in the biological shield in order to eliminate background of fast neutrons as well as γ-radiation from the reactor core and the cadmium cap.

Details of the positron source design as well as results of heat input, neutron and γ-flux obtained by Monte-Carlo calculations are presented elsewhere [21,22]. In addition, experimental experience was gained with a prototype of the in-pile positron source which was installed on a movable support at an external neutron guide of the high-flux reactor at the ILL/Grenoble [23].

2.2. Positron beam facility and instrumentation

Inside the reactor the evacuated tubes as well as the magnetic field coils are made of aluminium in order to minimize neutron activation of the components. The positrons are magnetically guided to the outside of the biological shield where measurements of the beam parameters such as intensity and beam profile are performed. Subsequent to a first vacuum pumping unit the beam line leads to the experimental platform which is located in the north-east corner of the