INTENSE POSITRON SOURCE AT THE MUNICH RESEARCH REACTOR FRM-II

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ABSTRACT

Principle and design of the in-pile positron source at the new Munich research reactor FRM-II are presented.

Absorption of high energy prompt γ-rays from thermal neutron capture in ^{113}Cd generates positrons by pair production. For this purpose, a cadmium cap is placed inside the tip of the inclined beam tube SR-11 in the neutron field of the reactor, where an undisturbed thermal neutron flux up to $2\cdot10^{14}$ n·cm^{-2}s^{-1} is expected. At this position the flux ratio of thermal to fast neutron will be better than 10^4. Monte Carlo calculation showed that a mean capture rate in cadmium between 4.5 and $6.0\cdot10^{13}$ n·cm^{-2}s^{-1} can be expected. Absorption of γ-rays would lead to a heat impact less than 4 Wcm^{-2}.

Inside the cadmium cap a structure of platinum foils is placed for converting the γ-radiation into positron-electron pairs. As converting material platinum is used, since the cross section for pair production is even higher than in tungsten. The heated foils also act as positron moderators to generate monoenergetic positrons. After acceleration to 5 keV the positron beam is formed by electric lenses and guided by magnetic fields. In the primary positron beam an intensity of about 10^{10} slow positrons per second can be expected. Outside the biological shielding a remoderation stage leads to an improvement of the positron beam brilliance before the positrons enter the vacuum chamber of the experimental facilities.

INTRODUCTION

Intense positron beams are of major interest in atomic and particle physic as well as in material science. The investigation of structure and defects in the near surface region of samples by slow positron beams plays a fundamental role in solid state physics. For many applications of positron annihilation technique a high counting rate is desirable, i.e. scanning microbeam, depth dependent lifetime and Doppler broadening measurements, PAES – positron induced Auger electron spectroscopy and ACAR – angular correlation of the annihilation radiation in thin films or small crystals. Particularly coincidence technique will be feasible, where both annihilation quanta are detected. This leads to a remarkably background reduction and enhances time resolution at lifetime experiments respectively energy resolution at 2D-Doppler broadening measurements.

In recent years great efforts have been undertaken to develop positron beams of high intensity. Hence, there are a number of various techniques which can be classified into two categories: positron sources based on β^+ decay of radioactive isotopes and positron generation by pair production from absorption of γ radiation.

Beams of the first category are realised in usual labs based on commonly used β^+ sources like ^{22}Na or ^{58}Co. Combined with tungsten moderators intensities up to some 10^5 e^+s^{-1} are achieved. At a reactor dedicated materials can be exposed to thermal neutron flux for the activation of short lived positron emitting isotopes. For instance via the reaction ^{63}Cu(n,γ)^{64}Cu after moderation the yield of the continuous positron beam is about 10^7 e^+s^{-1} (see [1] and [2]).

The facilities summarised in the second group generate positrons by pair production of high energy γ rays. Positrons can be created in a target or a beam dump of linear accelerators, where bremsstrahlung converts to e^+e^- - pairs in the field of target nuclei. Difficulties arise from defects produced by energetic leptons and fast neutrons of (γ,n)-reactions in the moderator material. Also thermal load in the conversion target has to be dissipated where the electrons with typical energy of 100 MeV deposit almost the whole kinetic energy [3]. Principally the primary positron beam has a pulsed structure due to the electron pulses of the linac. The typical intensity of a slow positron beam produced at a linac is of the order of $5 \cdot 10^8$ positron per second [4].

High energy γ radiation is also available at reactors as primary γ rays from nuclear fission or secondary γ's due to (n,γ)-reactions. At the new research reactor FRM-II positrons will be created by pair production from absorption of high energy prompt γ rays after thermal neutron capture in cadmium.

PRINCIPLE OF THE SOURCE

The principle of the positron source that will be applied at FRM-II is based on thermal neutron capture in cadmium (figure 1). This process is completely dominated by the nuclear reaction ^{113}Cd(n, γ)^{114}Cd due the enormous cross section for thermal neutron capture of 26000 barn of ^{113}Cd. In natural cadmium the abundance of ^{113}Cd is 12.22 %, that leads to an total thermal neutron capture cross section of 2450 barn. The neutron binding energy of 9.05 MeV is released as γ radiation, where on an average 2.3 γ's with more than 1.5 MeV per captured neutron are emitted.

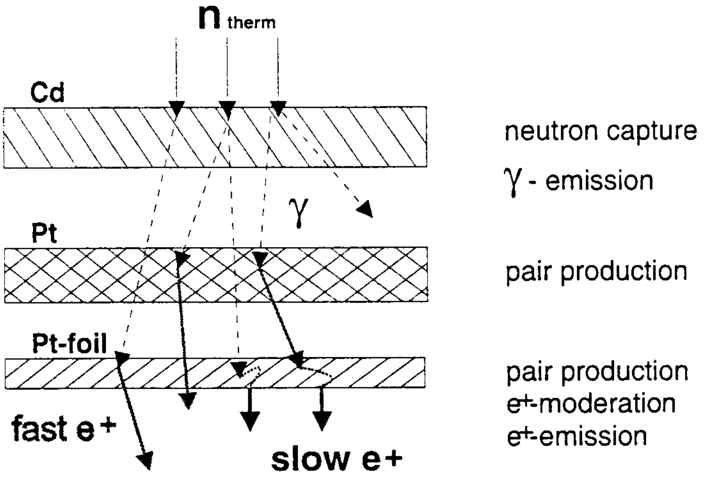

Fig. 1: Principle of the neutron induced positron source at FRM-II: Thermal neutron capture in cadmium provides γ - radiation. In platinum absorption of γ - rays generates e^+ by pair-production. Fast positrons are moderated in platinum foils (selfmoderation).

Absorption of the high energy γ radiation generates positrons by pair production with a maximum intensity at a positron energy of 800 keV [5]. The γ - e^+e^- - conversion should take place in matter with high nuclear charge Z, since the cross section for pair production is approximately proportional to Z^2. Therefore, platinum is used as converting material where the cross section for pair production is about 11% higher than in tungsten. Platinum is also applied as moderator due to its long term stability in the radiation field and the expected vacuum condition inside the beam tube tip of about 10^{-7}mbar. Taking into account that the optimal thickness is about 0.2 - 0.8 g·cm^{-2} to produce a great amount of positrons the volume of the converting material should be maximised [5]. To enhance the output of moderated positrons the surface to volume ratio of the moderator has to be maximised by using thin foils.

A preliminary set-up of a reactor based positron source with tungsten foils was realised and tested at the FRM (see [6] and [7]).

TECHNICAL LAYOUT

The positron source is placed in the tip of the declined beam tube SR11 at FRM-II. The design of the source is schematically shown in figure 2. Inside the tip of the beam tube a cap of cadmium (diameter = 110mm, length = 95mm) acting as broad γ source is encapsulated in aluminium. Besides the function as γ source cadmium is a perfect shielding for thermal neutrons, consequently, it also protects inner source components from neutron activation.

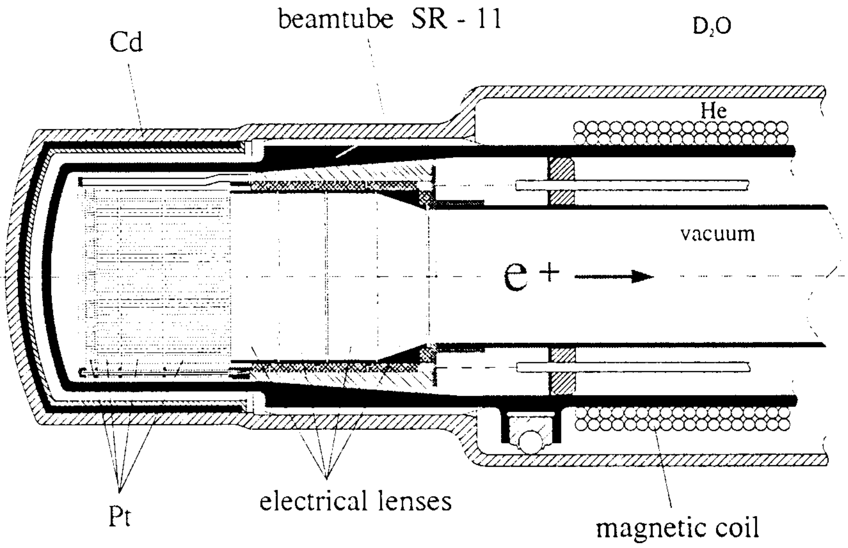

Fig. 2: Cross-sectional view of the in-pile positron source at FRM-II.

The inmost part of the source consists of a honeycomb structure at the tip and cylindrical layers of platinum acting as converter and positron moderator. Electrical acceleration lenses and magnetic coils are used for beam formation.

Model calculation (MCNP: Monte Carlo N-Particle-transport-calculation) were done to find the optimum working position for the cadmium cap as an in-pile component of the reactor. Actually, the source is placed in a high thermal neutron flux that enhances the brightness of the positron beam. For this, the calculation showed that at the fixed position of the positron source the undisturbed thermal neutron flux is up to $2 \cdot 10^{14}$ n·cm^{-2}s^{-1}. Considering flux depression caused mainly by cadmium itself and other mountings in the moderator tank this leads to a mean thermal neutron capture rate of $5 \cdot 10^{13}$ n·cm^{-2}s^{-1} in cadmium at the tip of the beam tube. Capture of thermal neutrons leads to a macroscopic burn down of ^{113}Cd. Therefore, in the layout of the positron source the wall thickness of the cadmium cap amounts 3mm according to a burn down of natural cadmium after five years, i.e. 25 reactor cycles equal to 1250 days.

In the vicinity of the cadmium cap the n flux depression due to neutron capture should not significantly disturb the neutron flux of neutron beam guides near the positron source. The closer the source to the reactor core is the higher the flux of fast neutrons, leading to neutron induced radiation damage of the source material. Consequently, higher fast neutron flux leads to the formation of positron traps in the moderation foils and, hence, to a decrease of slow positron emission. Results of MCNP calculation showed that at the position of the positron source the flux ration of fast to thermal neutrons is rather high, e.g. more than 10^4.

Inside the cadmium cap the mean γ flux with minimum energy of 1.022 MeV needed for pair production is calculated to $4.1 \cdot 10^{13}$ photons$\cdot$cm^{-2}s^{-1}. About 6% of the γ radiation (ca. $5.2 \cdot 10^{12}$ photons$\cdot$cm^{-2}s^{-1}) originates from the reactor core and d(n, γ)t-reaction in the surrounding heavy water. The resulting heat input from absorption of γ radiation in the components of the beam tube ("γ heating") is expected to be less than 4 Wcm^{-2}. The sandwich structure Al-Cd-Al guarantees an almost perfect heat conduction to the surrounding heavy water of the moderator tank. Therefore, the heat input that stems mainly from γ heating in cadmium can be directly dissipated to the heavy water and, consequently, an active cooling device can be avoided. Thermal load arising from neutron scattering can be neglected since it is less then 1% of the value calculated for γ absorption.

Taking into account the neutron capture rate, absorbing masses, geometry and moderation efficiency an intensity of the order of 10^{10} slow positrons per second in the primary beam is expected. The moderated positrons will be extracted and accelerated by electric lenses with an acceleration potential of the order of 5 kV. Afterwards the beam is guided by magnetic solenoids and compensation fields onto a remoderation device outside the biological shielding of the reactor. There a tungsten single crystal will be used as remoderator in back reflection geometry to improve beam characteristics. A typical moderation efficiency of 10-15% for 5 keV positrons would finally lead to a positron beam intensity of about 10^9 e^+s^{-1}.

After passing a bend the beam line is guided to a platform (not shown) where it is connected via a beam switch to the experiments. In a first arrangement it is planned to install a positron lifetime spectrometer, a scanning microbeam and a PAES device.

OUTLOOK

The beam tubes with magnetic coils and cadmium as n-γ-converter were mounted as in-pile components in the moderator tank of FRM-II in summer 2000. After tests with platinum as moderator in June 2001 at ILL the positron source will be integrated in the beam tube. Finally the first experimental devices (scanning positron microbeam, pulsed lifetime spectrometer and PAES) will be installed and connected with the beamline.

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