Development and application of the intense slow positron beam at IHEP *

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Abstract This paper describes the development and application of an intense slow positron beam at IHEP with regard to its two main components. The Variable-Energy Positron Lifetime Spectroscopy (VEPLS) based on the pulsing system consisting of a chopper, a prebuncher and a buncher has been constructed in order to meet the needs of materials science development. At present, the time resolution of the VEPLS can easily reach about 386 ps with a peak-to-background ratio of about 600:1. A plugged-in ^{22}Na positron source section for adjusting the newly built experimental station and for increasing the beam operation efficiency has been constructed. A slow positron beam with an intensity of 2.5×10^5 e^+/s and the beam profile whose diameter is 10 mm has been obtained; the moderation efficiency of the tungsten mesh moderator reaches 5.1×10^{-4} as calculated with an original positron source activity of 52 mCi.

Key words plugged-in ^{22}Na positron source, VEPLS, time resolution

PACS 78.70.Bj

1 Introduction

Slow positron beam is especially advantageous as a non-destructive probe to investigate the property of surface, thin films, and the depth dependence of the structural properties of solids. The positron source based on electron linear accelerator (linac) can successfully increase the positron beam intensity by more than several orders of magnitude[1]. So using the linac of Beijing Electron-Positron Collider (BEPC), the Intense Slow Positron Beam has been constructed at IHEP[2]. The ISPB intensity is about 10^6 e^+/s with the energy spread of about 1.8 eV (FWHM) after the pulsed positrons are stored and stretched in the penning-trap section to a dc-like beam as described in Ref. [2]. And preliminary application studies with Doppler broadening measurements on silicon dioxide film, GaN film and MoSi multilayer film studies were performed.

The simulations[3] predict that higher slow positron beam intensity of about $10^7\sim10^8$ e^+/s could be obtained with the linac running in the mode of 1.0 GeV electron energy, 2.5 μs pulse width, 50 pps repetition rate and 50 mA electron peak current after the accomplishment of BEPCⅡ (an upgrade project of BEPC). In order to meet the needs of materials science development and new running parameters of the BEPCⅡ linac, some improvements have been done on ISPB. As the frequency and pulse width of the primary electron pulses are changed, a new penning-trap section has been constructed. A sample chamber has been rebuilt which is connected to a pre-evacuated chamber and a magnetic transmission system. To avoid discharge, a new sample holder has been built. The VEPLS based on the pulsing system has been constructed. And a plugged-in ^{22}Na positron source section for adjustment of the newly built experimental station and for increase of the positron beam running time has been established. A MCP (Microchannel Plate) mounted on the convergence of the plugged-in ^{22}Na based slow positron beam and linac based slow positron beam is used to monitor the position and beam profile through an observation window.

The slow positron beam section based on linac consists of a target-moderator assembly located at

Received 23 March 2007, Revised 9 May 2007
* Supported by National Natural Science Foundation of China (10475096, 10575112) and Special Fund for Equipment of Chinese Academy of Sciences (U-37)
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the end of the BEPC linac, a total 12 m long transportation vacuum tube with four bends, a penning-trap section[2] and a sample chamber. The plugged-in ^{22}Na slow positron source section has been built at the experimental ground. The VEPLS has been built between the sample chamber and the penning-trap section. The schematic drawing of ISPB is shown in Fig. 1. In this paper we present details of the plugged-in ^{22}Na slow positron source section and the VEPLS.

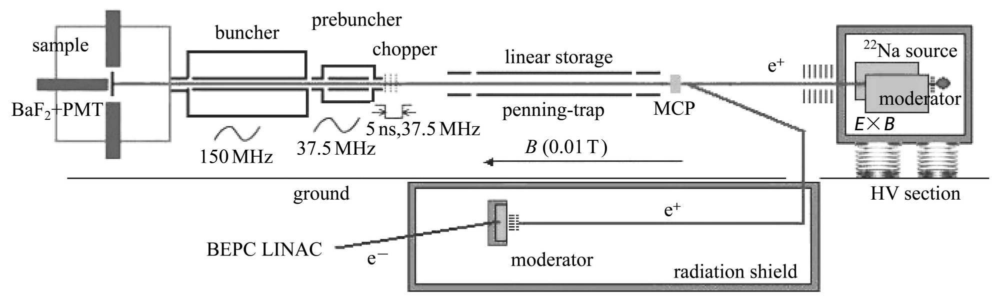

Fig. 1. Schematic drawing of ISPB at IHEP.

2 The plugged-in ^{22}Na slow positron source

The encapsulated ^{22}Na source has an intensity of 52 mCi made by iThemba Laboratory for Accelerator Based Sciences in South Africa. The moderator contains twelve layers of tungsten mesh (0.02×100×100 mm, 50 mesh), which are annealed at 1623 K as shown in Fig. 2. The encapsulated ^{22}Na source insulated from the moderator by the ceramic plate is fixed on the top of the copper bar.

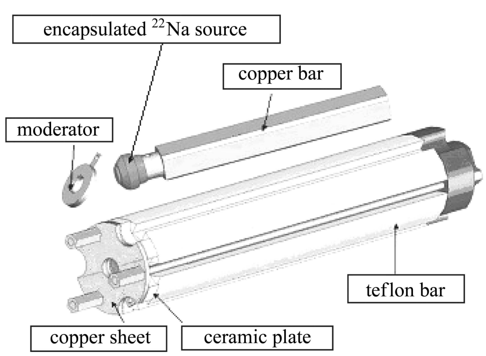

Fig. 2. Schematic drawing of ^{22}Na source and moderator.

The positrons after being moderated are selected by a cylindrical $\boldsymbol{E}\times\boldsymbol{B}$ energy filter and stepped down 30 mm through a 12 mm collimating aperture, while fast positrons and γ rays from the ^{22}Na source are completely shielded by an 80 mm thick W80Cu20 alloy. The positron source, the moderator and the $\boldsymbol{E}\times\boldsymbol{B}$ energy filter are floated to a variable positive voltage from 0 to 30 kV while the transportation vacuum tubes and the sample chamber are grounded so that the experimental conditions are more flexible for sample management. The acceleration of the slow positrons is achieved by applying a regulated voltage through six stages of stainless plates separated by five high voltage resistors. The schematic drawing of plugged-in ^{22}Na source is shown in Fig. 3.

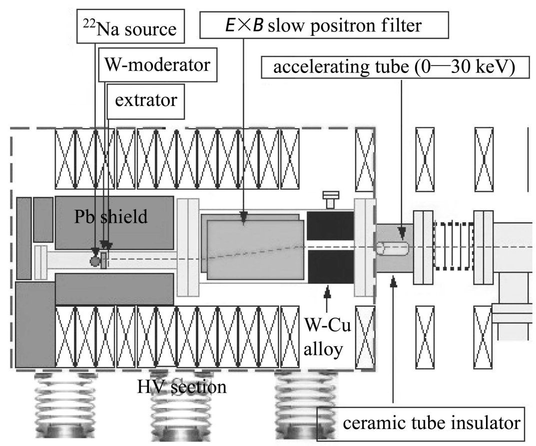

Fig. 3. Schematic drawing of the plugged-in ^{22}Na source.

The variable mono-energetic positrons (0—30 keV) are guided to the sample chamber by a magnetic field with strength of 0.01T. The beam position is adjusted by three pairs of correcting cosine coils that supply spatially uniform magnetic field[4]. The intensity of slow positron beam based on the plugged-in ^{22}Na source is 2×10^5 e^+/s and the calculated moderator efficiency is 5.07×10^{-4}. The beam profile observed by MCP whose diameter is 10 mm, and the energy spread is 4 eV (FWHM) while the positron energy is 177 eV. The ^{22}Na-based beam has been used for adjusting the VEPLS.

3 The VEPLS

In order to study the depth-dependent characteristics of open-volume defects near the surface of materials, the VEPLS has been constructed which consists of a pulsing system[5], an electronic system and a detector. The continuous beam is transformed into a pulsed beam by the pulsing system. The stop signal for the positron lifetime measurement and the power signal for the pulsing system running are supplied by the electronic system. The start signal for the positron lifetime measurement is derived from the detector.

The pulsing system consists of a reflection type chopper, a prebuncher and a buncher as shown in Fig. 4[5].

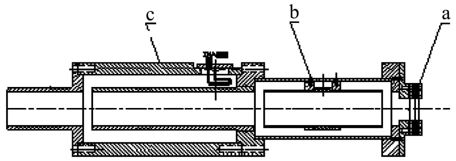

Fig. 4. Schematics of the pulsing system: a. chopper, b. prebuncher, c. buncher.

The chopper consists of three metal grids. Static voltage of 80 V and −260 V are applied to the first grid and the third grid respectively, and short pulses are applied to the second grid. The pulse frequency is 37.4725 MHz and the pulse width can be adjusted from 3 to 8 ns. The prebuncher has two modulation gaps. The distance between two gaps is 143.6 mm, ensuring that both gaps can contribute to the time compression of the beam[6]. The buncher is a quarter-wave coaxial resonator and the RF signal is fed in by a coupling loop. The resonance frequency of the buncher is 149.89 MHz and the reflection factor is about 0.05 measured by Network Analyzer. The Q-factor of the buncher is about 2000.

The electronic system as shown in Fig. 5 can generate three synchronic signals, their phases and amplitudes can be adjusted independently.

The signal for the positron annihilation is detected by a BaF_2 scintillation detector, which is used as the start signal of the positron lifetime measurement. The scintillator is attached to a Hamamatsu R3377 photomultiplier tube (PMT) with silicone oil. The timing signal is taken from the anode. The detector is placed behind the sample. As the detector is inside the magnetic field generated by Helmholz coils, it is placed into a magnetically shielded detector well. The magnetic shielding is realized by three stages[7]. The first stage is to use a solenoid, which can create inverse magnetic field. The second stage is accomplished with a silicium steel cylinder and the third one is with a permalloy cylinder. The second stage and the third stage are assembled together into a light shield of PMT.

Figure 6 shows a lifetime spectrum for pure aluminum obtained after preliminary tests with the above-mentioned set-up. Analysis shows that the time resolution of this system reaches about 386 ps (FWHM), the incident positron energy was 10 keV during the measurement. The counting rate is about 200 cps and peak-to-background ratio of this spectrum is about 600:1. Further work towards a much improved time resolution and peak-to-background ratio is still ongoing.

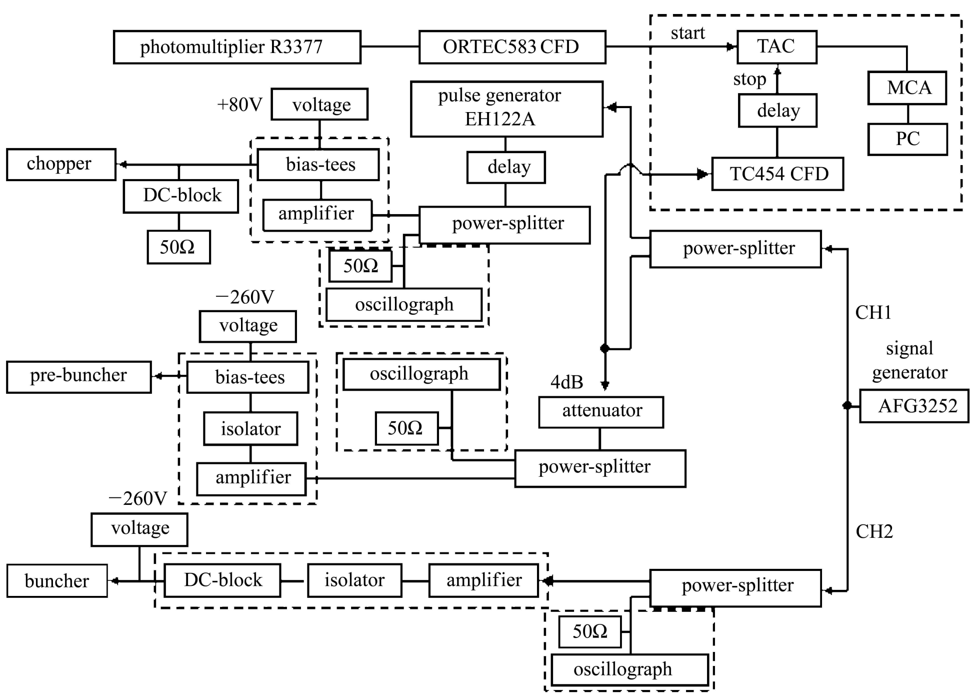

Fig. 5. Diagram of the electronic system.

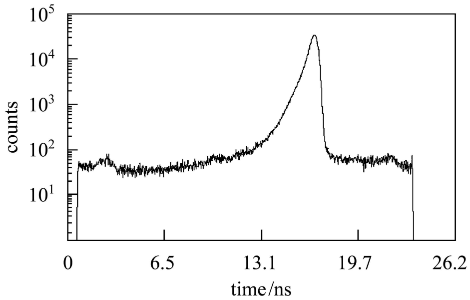

Fig. 6. Measured lifetime spectrum for an Al sample with 10 keV incident positrons.

4 Summaries

A report on the development of an intense slow positron beam system at IHEP has been given. With the accomplishment of BEPCⅡ, this system will run at higher efficiency with a much higher beam intensity. After finishing the construction of VEPLS, it is possible to perform positron annihilation lifetime and Doppler broadening measurements simultaneously. Preliminary tests of VEPLS showed that a time resolution of 386 ps and a peak-to-background ratio of about 600:1 can easily be obtained. This at least enables the study of certain samples where positronium formation and annihilation happens.

The authors would like to thank Dr. R. Suzuki (AIST) and S. L Pei (IHEP) for their helpful discussions.

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