Materials Science Forum *Online: 2001-04-02*
ISSN: 1662-9752, Vols. 363-365, pp 658-660
doi:10.4028/www.scientific.net/MSF.363-365.658

Research and Development of High Energy Pulsed Positron Beam

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Keywords: Positron Accelerator, Positron Annihilation Lifetime Spectroscopy

Abstract

We have been developing a high-energy (1 MeV) pulsed positron beam apparatus employing an RF acceleration method. From the performance tests using an electron beam, a high-energy fine pulse beam (0.5-1MeV) with a 350 ps period was confirmed to be generated. From the detailed measurements, the large time resolution was shown to be due to the satellite pulses resulting from sub-optimal bunching. Several possibilities to improve bunching characteristics are discussed.

Introduction

It is interesting to investigate the behavior of defects in materials under extreme conditions like high temperature and high pressure in connection with the semiconductor crystal growth and the design of nuclear reactor materials. Positron annihilation lifetime spectroscopy (PALS) is a nondestructive method for detecting open volume type defects. A number of investigations using PALS have been performed on defects in metals and semiconductors [1, 2]. PALS measurements for bulk materials at high temperatures have been performed successfully using the $\beta^+\gamma$-coincidence method with a high-energy positron beam produced by a Pelletoron accelerator [3]. Another possibility to perform positron lifetime measurements is to create a pulsed positron beam [4, 5]. To generate a high energy (>500 keV) pulsed beam, an RF acceleration method, which is used for the acceleration of electrons and ions, is quite useful. By pulsing, the chance coincidence due to randomly coming positrons can be considerably reduced in positron lifetime measurements. In addition, by using the RF signal which provide simultaneous beam pulsing and acceleration as a PALS trigger signal, the system resolution will be ultimately improved because of the reduction of the timing jitter. Thus, we have developed a high-energy pulsed positron beam apparatus with such an RF acceleration method and completed its

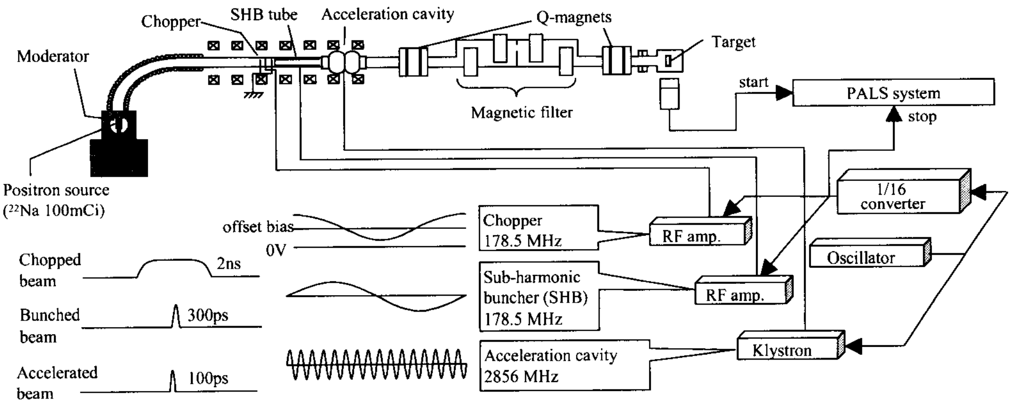

Fig. 1. Schematics of high-energy pulsed positron beam apparatus.

performance tests with electrons. We will discuss final critical problems, which should be solved before eventual installation of positron source.

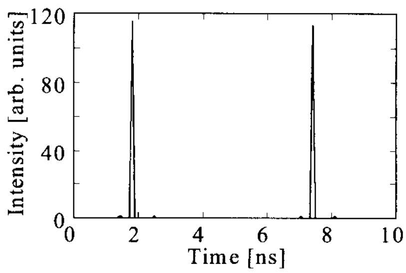

Fig.2 Simulated beam time structure after the acceleration cavity with the operating parameters shown in Fig.1.

Concept of the positron accelerator system

Our system consists mainly of a positron source, reflection type beam chopper, sub-harmonic buncher (SHB), RF acceleration cavity, magnetic filter and focusing magnets as shown in Fig. 1. To perform positron lifetime measurements, actual pulse period should be 5-10 ns. Thus, the continuous beam transported at 1 keV is first pulsed to 300 ps width at the chopper and SHB driven with 178.5 MHz sine waves (5.6ns period). The pulsed beam is further bunched to 100 ps width and accelerated to 1 MeV at the standing-wave type cavity with a klystron tuned to 2856 MHz. Electrons discharged from the cavity wall are removed by the magnetic filter. The beam can be focused onto a target by two sets of quadropole focusing magnets installed above and below the magnetic filter. Figure 2 shows the result of numerical simulation for the expected beam time structure. It was confirmed that in principle a fine beam with 100ps width can be formed by this system.

Characteristics of accelerated beam

To confirm beam acceleration up to 1 MeV, we measured the beam energy as a function of klystron power. As a result, the beam energy was found to be controlled up to 1 MeV with an energy spread of approximately 5 % within the nominal power of the klystron (300 kW). The period of final beam pulse was about 350 ps, which is in good agreement with that derived from the klystron frequency (2856MHz). From the direct observation of the beam, it was verified that its diameter could be adjusted to 0.8 mm.

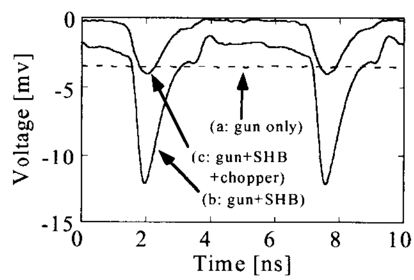

Fig.3. Time structures of low-energy beam below the SHB.

The time structure of the pulsed beam was measured using a Tektronix TDS694C DSO with a DC to 3 GHz bandwidth. A faraday cup was used as an electron detector. The first step was to measure the pulse shape of the low energy beams produced without using the RF acceleration cavity. The results are shown in Fig.3. As seen from line (a), a stable DC beam is emitted from the electron gun. When the SHB is driven with a sine wave at 178.5 MHz, a pulsed beam with a period of 5.6 ns is obtained as shown by line (b) in Fig. 1. The pulse width is

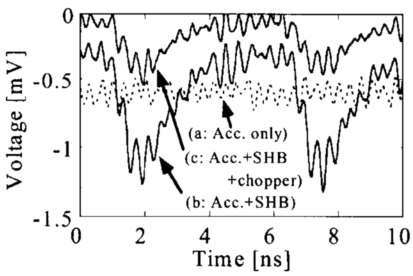

Fig.4. Time structures of the 500 keV beam below the acceleration cavity.

approximately 1ns (FWHM) and the S/N ratio is 7:1. An improvement in beam characteristics is expected if the beam chopper was driven. The time structure of the pulsed beam observed after using the chopper is represented by line (c) in Fig.1. The S/N ratio has now increased to 30:1, whereas the pulse width is not sufficiently reduced by the chopper.

The pulse width (1ns) at SHB shown above is too large to generate a pulse train which is well-separated at a 5.6 ns period. Since unsufficiently bunched beam at the SHB is accelerated at the cavity, sattelite pulses together with the 5.6 ns period pulses are formed. In fact, as shown in Fig. 4, even when the chopper and SHB are driven, satellite pulses appear with the main pulses separated at a 5.6 ns period.

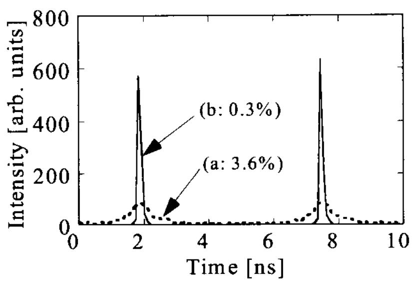

Fig.5. Simulation results of bunching behavior of low-energy beams. Dotted and solid lines correspond to the results for the energy spread of 3.6% and 0.3% for the initial low energy beam.

The satellite pulses superposed on a broad pulse might result in pseudo-lifetime components. Further improvement of the beam pulse structure is therefore necessary to perform PALS analysis. As pointed out above the satellite pulses are due to the insufficient bunching at the chopper and SHB, which is probably caused by a large energy spread of the initial low energy beam. Indeed, the simulation result of bunching behavior (Fig. 5) shows that the pulse width below the SHB strongly depends on the energy spread of the initial beam. Assuming 3.6% energy spread for the initial beam, the pulse width below SHB is obtained to be 1 ns, which is in good agreement with the observation (line (c) in Fig. 3). When the energy spread is reduced to 0.3%, the pulse width of 300 ps is acquired as represented by line (b) in Fig. 5. Such a narrow energy spread of the initial beam is expected to be completed by optimizing the transportation energy and/or refining the chopper system.

Summary

We have tested performances of our high-energy pulsed positron beam apparatus. In this apparatus, we have obtained the maximum beam energy of 1 MeV with an energy spread of 5 % and a focused beam size of 0.8 mm. The time structures of beams have been characterized using a wide bandwidth DSO. As a result, short pulses superposed on broad pulses were observed. In order to achieve single fine pulses, further improvement of the beam bunching is required.

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Positron Annihilation - ICPA-12
10.4028/www.scientific.net/MSF.363-365

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