

PRELIMINARY CONCEPT OF FAST POSITRON SOURCE BASED ON PHOTO-INJECTOR*

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Abstract

Based on the past experience in slow positron beam, researchers at NSRL/USTC proposed a fast positron source for detection of material deep tiny flaws. Different from conventional positron sources used in positron annihilation techniques, the planned positron source will be a positron production linac, similar to positron injectors used in colliders. To compress the positron pulse, the bombarding electron beam comes from a short bunch photo-injector. A computer simulation was performed using EGS4 and PARMELA code. The bombarding electron bunch is 300pC, with an energy of 30MeV. Simulations results showed that it is reasonable to expect a beam of more than 10^5 positrons per pulse for future positron annihilation studies. Further work is to be done to achieve precise control of beam energy.

INTRODUCTIONS

Positron annihilation spectroscopy (PAS) can be used to study the microstructure, the electron momentum distribution and the defect properties of matter [1]. As a non-destructive method, it is broadly used in study of solid state physics, surface physics and material science, etc. Conventional positron source in positron annihilation techniques always use a radioactive source and the positron pulse length is several hundred ps to several μ s. In recent years, linac-based short pulse positron source shows exciting potential in positron annihilation techniques [2].

Accelerator-based positron sources have several advantages: the whole facility and working environment is radiation-less when shut down; as the accelerator itself is pulsed, cost of the chopping and bunching equipment in conventional radioactive positron source is then saved; the positron energy can be alterable and then deep detection can be realized.

Typical positron annihilation spectroscopy facilities are always used to study material surface, the positron bunch from either accelerators or radioactive sources should be slowed down to several keV before injected to samples. It is attractive to image what fast positron bunch with energy of several MeV can do. In fact, fast positron beam can be helpful to detect the flaws that are mm-cm deep inside large samples, which means it will be useful in the analyses and evaluation of neutron irradiation damage for reactor pressure vessel, detection of high-speed railway defects and aircraft engine blade defects and so on. It is only natural for researchers to propose a fast positron test

facility for PAS usage.

The positron source consists of an electron source, a converter target and a positron transport line. The electron source is a linac, accelerates the electron bunches which come from a photocathode RF electron gun to 30MeV. The converter target is made of tungsten. The transport line uses an adiabatic magnetic field and several focusing coils and solenoids to capture and confine positrons.

PAS AND FAST PAS

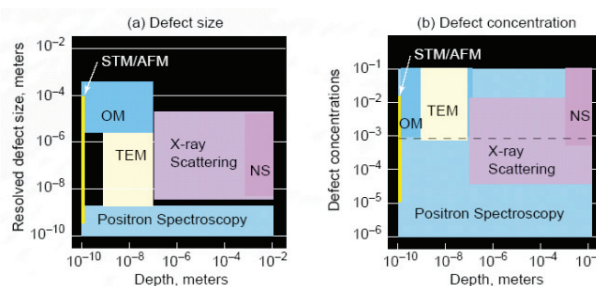


Figure 1: Methods of matter defect detection.

Figure 1 shows several methods of matter defect detection. One can see that PAS is the only method that can people can use to detect a sample with certain defect size and concentration, i.e. a cm-thick sample with atom size defect. Here abbreviation OM means optical microscope, STM means scanning tunnelling microscope, AFM means atomic force microscope, TEM means transmission electron microscope and NS means neutron scattering.

Generally speaking, the detect depth can be estimated by the equation [3]:

$$Z = AE^n [\text{nm}]$$

While

$$A \approx 40/\rho$$

Here $n \approx 1.62$, ρ is density of sample with dimension of g/cm^3 and E is energy of the positron with dimension of keV.

For a positron bunch of 5MeV and a sample of $19\text{g}/\text{cm}^3$, the detect depth is 2.068mm, while a 5keV bunch can only achieve a detect depth of 28.55nm.

The number of positrons that a conventional PAS equipment uses is about 10^4 - 10^5 per second. For conventional PAS positron source, it is easy to get keV positron bunch. To get MeV level energy, accelerator technology becomes essential. In addition, positron source based on accelerators provides other advantages.

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POSITRON SOURCE BASED ON PHOTO-INJECTOR

There are more advantages that an accelerator-based positron sources can provide:

First, accelerator-based sources use converter target to generate positron, while conventional positron source uses radioactive source i.e. Na^{22} . The whole facility and working environment is radiation-less when shut down, which will be very attractive for long-term usage, not to mention the cost of radioactive source and dealing with the waste.

Second, since the bombarding electron is pulsed, the positron that the accelerator generates is pulsed, too. In the conventional positron sources the original positron beam is DC, which means to measure the time scientists have to use chopping and bunching equipment to get pulsed beam. Cost of this part is then saved.

Finally, the quality of positron beam is controllable. The accelerator-based positron sources were used in colliders, while technologies of the beam control and diagnostics are essential for both colliders and synchrotron light sources. NSRL had built a photo-injector for frontier research such as FEL and ultimate storage rings [4], provided possibility of a high intensity, very short bunch positron source. The energy, bunch length and beam spot size can be alterable and then deep detection can be realized.

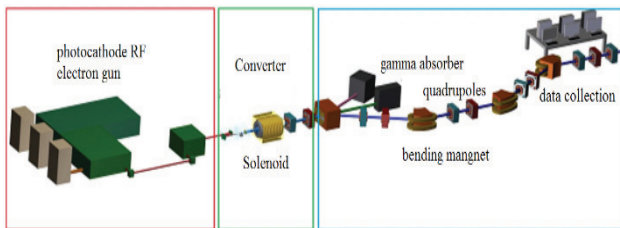


Figure 2: Sketch of positron source.

Figure 2 shows general sketch of positron source. The part of accelerate pipe where electron bunch from RF gun gains energy to 30MeV is omitted. The converter target is made of tungsten. The production and distribution of positron and its dependence on target thickness, bombarding energy and other parameters were discussed in next section.

The pair-produced positrons out of target have divergent angles, a broad energy spectrum, and a much larger emittance than that of the initial electron beam, thus a matching device is first needed to transfer the transverse emittance of the positron beam to the acceptance of the downstream system. Several focusing coils are installed outside the vacuum chambers to confine the transverse divergence. The bending magnets are used to choose positron energy and separate the electrons, positrons and gamma rays, while quadrupoles are set up to compress the bunch spot and also confine the transverse divergence.

SIMULATION AND DISCUSSION OF THE CONVERTER

Researchers used computer simulation to estimate the production of positrons, tried to find out the best thickness and bombarding energy. Meanwhile, the distribution of positrons is also needed so as to find out the best acceptance of the downstream system.

Here the EGS nrc version and PARMELA codes are applied. The number of incidents is set to 10^5 , which is believed to be large enough and can be used to estimate the production process of real beam.

Bombarding Energy and Thickness of the Target

Figure 3 shows the dependence between the number of electrons and the bombarding energy. Surely one can see the larger the bombarding energy is, the more positron the converter target produces. The charge of the bombarding bunch is 300pC, that is about 1.58×10^9 instances. To get more than 10^5 positrons per bunch, assume the capture and transport efficiency is 1% due to large divergence, 10^5 instances should produce more than 10^3 positrons. There's hardly any positrons when the electron energy is too low (lower than 5MeV). As higher energy results in higher cost, an energy of 30MeV is enough for the production of positrons.

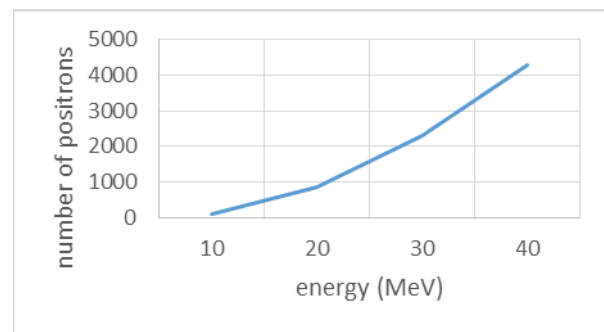


Figure 3: Number of positrons and electron energy.

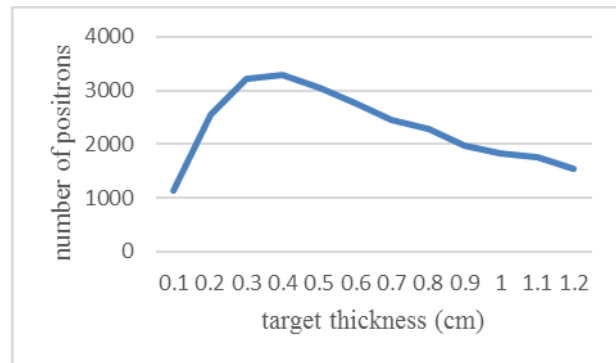


Figure 4: Number of positrons and target thickness.

Figure 4 shows dependence between the number of positrons and the target thickness. The converter produces the most positron when the target is 0.3-0.4cm thick. Taking the mechanical strength and fabrication difficulty into consideration, the thickness of the converter was then set to 0.8cm.

DISTRIBUTION AND TRANSPORT EFFICIENCY OF POSITRONS

EGS nrc is used to calculate energy spectrum and distribution of positrons produced by a bunch of 10^5 electron bombarding a tungsten convert target of 0.8cm.

The energy spectrum is showed in figure 5. At the range between 0MeV and 20MeV, there are plenty of positrons at low-energy, and the amount of positrons decrease along with the increase of energy. To increase the capture efficiency, the capture energy should be set at low-energy range. Figure 6 shows the distribution of positrons along radius. Similar to what the energy spectrum shows, most of the positrons gather in a small range of radius. Figure 7 shows the angle distribution of positrons that full of the angle space ($0^\circ\sim 90^\circ$).

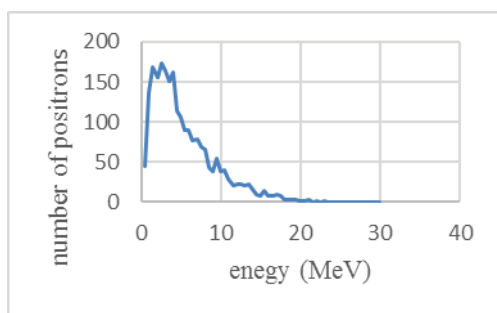


Figure 5: Energy distribution.

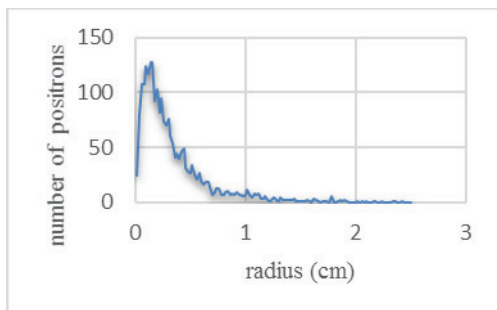


Figure 6: Distribution by radius.

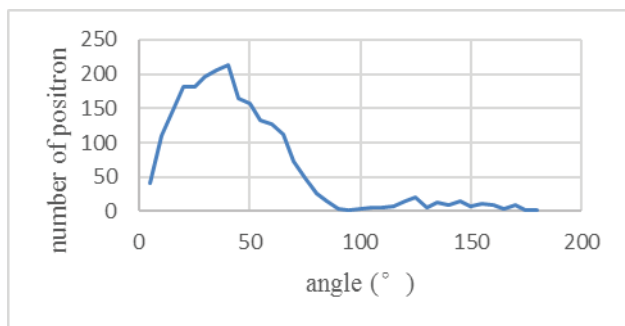


Figure 7: Distribution by emission angle.

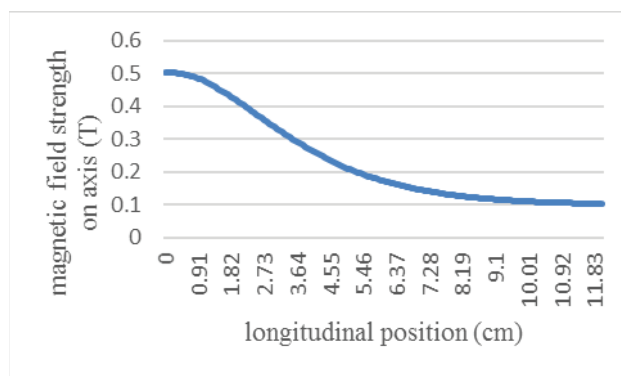


Figure 8: The magnetic field of the adiabatically tapered solenoid.

Figure 8 shows the magnetic field that yield by a 10cm adiabatically tapered solenoid which is put before the accelerator. The magnetic field decrease from 0.5T to 0.1T. The simulation is performed in PARMELA code. About 11.75% of the positrons are transported to the end of according to the simulation result.

CONCLUSION AND FUTURE WORK

Researchers finished a simple, preliminary concept of a novel fast positron source which might be useful in future material science and techs. In this design, an electron bunch of 30MeV, generated by a photo-injector and accelerated by a linac, is used to bombard a tungsten convert target of 0.8cm. It can be believed that the final production number of positron per electron bunch can be higher than 10^5 , which is good enough for defect detection.

The accelerator and the positron transport line still needs further study and a lot of optimization work in the coming year.

ACKNOWLEDGMENT

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