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PRESENT STATUS OF THE POSITRON FACTORY PROJECT AND DEVELOPMENT OF POSITRON BEAM TECHNIQUES

Sohei OKADA, Hirohisa KANEKO, Atsuo KAWASUSO, Shin-ichi MASUNO, HIromi SUNAGA, Haruki TAKIZAWA and Keiichi YOTSUMOTO

Advanced Radiation Technology Center, Takasaki Establishment, Japan Atomic Energy Research Institute 1233 Watanuki, Takasaki, Gunma 370-12, Japan

Abstract

A preliminary experimental result confirmed a possibility to study defects in silicon with an internal positron source produced by a proton beam from a cyclotron. A pulsed MeV positron beam, which can be applied for detailed bulk defect analysis of wider range of materials, is under construction. In the design study for the Positron Factory, a feasibility of simultaneous extraction of multi-channel monoenergetic positron beams was demonstrated by an experiment using an electron linac.

1. Introduction

We have been developing positron spectroscopy techniques combined with accelerator technology. Detailed bulk defect analysis using an internal positron source in silicon produced with a cyclotron is now in progress. The preliminary result is reported. We have been constructing a pulsed MeV positron beam line for the same purpose, which will be applied not only for silicon but for various materials. Outline of the design is described.

We have been promoting design studies for the 'Positron Factory' [1], in which linac-based intense monoenergetic positron beams are planned to be applied for advanced materials characterization and new fields of basic research. A tentative goal of the slow (i.e. mono-energetic) positron beam intensity is 10^{10}/sec, which is larger by two orders of magnitude than those of existing strongest beams in the world. We have proposed a concept of simultaneous extraction of multi-channel mono-energetic positron beams, on the basis of a Monte Carlo simulation, in the design study. In this report, an experimental result to confirm the feasibility of this concept is demonstrated.

2. Internal Positron Source Production with a Cyclotron

It is possible to produce a positron emitter ^{22}Na inside silicon from a nuclear reaction ^{28}Si(p,^{7}Be)^{22}Na with a proton bombardment. This internal positron source enables thermal defect studies by using positron lifetime measurement at high temperature where usual positron sources would be melt down.

Positron lifetime spectra of a high-purity FZ-silicon irradiated by 70 MeV proton from the TIARA AVF cyclotron in JAERI Takasaki Establishment are shown in Fig.1. The fluence was 2.5×10^{17}cm^{-2}. The lifetime measurement was carried out at room temperature. The spectrum (a) is for the sample as irradiated. It is resolved into three components: τ_1=170ps(I_1=59.4%), τ_2=284ps (I_2=39.0%) and τ_3=1.73ns(I_3=1.6%), where τ and I are the lifetime and the intensity, respectively. The value of τ_3 is too large for that corresponding to defects in silicon. When the irradiated specimen was sandwiched between two unirradiated ones, this component disappeared as shown in the spectrum (b). Consequently, this extra component of small amount is assumed to come from positrons emitted from the vicinity of the surface of the irradiated specimen into air and/or surrounding materials like a detector. This is an important fact to which we must pay attention in use of the internal positron source technique.

The value of τ_2 indicates that vacancy clusters were induced by the irradiation, which survive even at room temperature. We will further investigate the detail of the cluster with elevating the temperature and also the behavior of thermal vacancies at much higher temperatures.

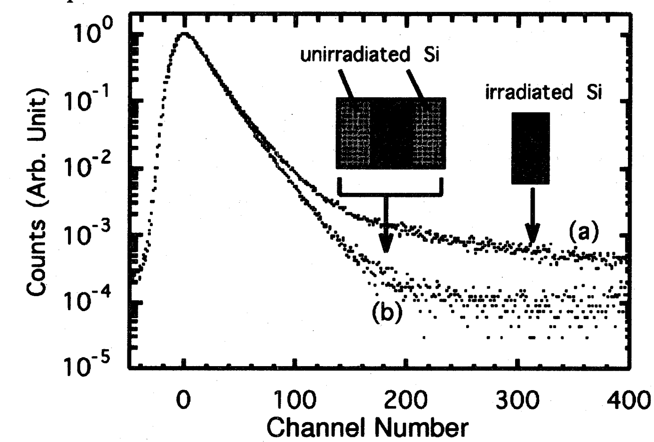

Fig.1 Positron lifetime spectra of a high-purity FZ-silicon irradiated by 70 MeV proton, which were measured by using the internal positron source technique.

3. Construction of a Pulsed MeV Positron Beam Line

The above internal positron source technique has an advantage that ion-induced defects can be studied in addition to thermal defects at higher temperatures. However, available materials are limited. A pulsed positron beam, on the other hand, makes it possible to analyze defects in a variety of materials at arbitrary temperatures. Suzuki et. al. [2] constructed a pulsed slow positron beam line connected to an electron linac and succeeded in various sorts of surface characterizations. The pulse width is about 100ps, and the beam energy range is from several tens of eV to several tens of keV.

To study defects in a 'bulk' as well as those at a surface is important. Fig.2 shows stopping probability of 1 MeV positron beam onto tungsten, which was calculated with a Monte Carlo simulation system EGS4-SPG developed by us[3]. The fraction of implanted positrons was 0.63 and the others were back-scattered. It is deduced that almost all implanted positrons annihilate in a bulk of the material. If the beam is accelerated not by an electrostatic field but by RF, only a little portion of the back-scattered positrons may reenter the material.

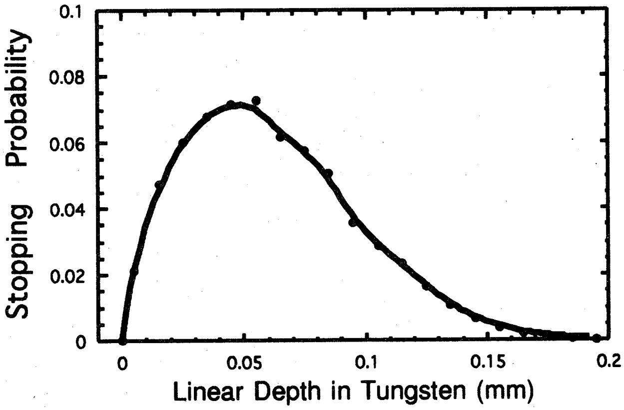

Fig.2 Stopping profile of 1 MeV positron inside tungsten calculated with EGS4-SPG.

On the basis of this concept, we have been constructing a pulsed MeV positron beam line with a pulse width of 100ps, for detailed bulk defect analysis. Schematic view of the beam line is shown in Fig.3. The parts of the positron source, the slow positron beam generation and the beam transport were already installed. The subharmonic buncher (178.5 MHz) and the acceleration cavity (2856 MHz) will be installed by the end of 1996 fiscal year.

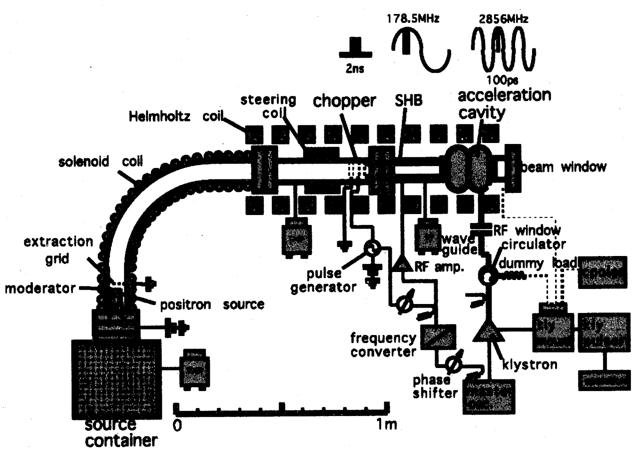

Fig.3 Schematics of a pulsed MeV positron beam line.

4. Design Study for the Positron Factory

We have performed design studies for the Positron Factory until 1994 as follows[4]:

1) An optimum electron beam energy for slow positron generation was estimated to be around 100 to 150 MeV.
2) It was calculated that a tentative goal of the slow positron beam intensity (10^{10}/sec) could be attained with a linac of 100 kW class with the above energy range.
3) A technical survey study confirmed a feasibility of manufacturing such a state-of-the-art linac.
4) Further detailed analyses were carried out concerning thermal deformation of the accelerator structures, beam instability, reliability of the components, down-sizing of the machine and a computer-aided control system.
5) A 'self-driven rotating converter' suitable for the high power beam was proposed and successfully tested.

In the design study, we have also proposed 'multi-channel moderator assemblies' to supply multiple slow positron beams simultaneously as shown in Fig.4. The slow positron yield, that is a ratio of the number of slow positrons emitted from each tungsten moderator assembly to that of incident electrons onto the tantalum converter, was estimated using the EGS4-SPG. The result is shown in Fig.5. The contribution by energetic positrons from the converter to generate slow positrons drastically decreased at the assemblies distant from the converter. It was deduced from tracking of the particles that this is caused by spatial spread of the positron beam. On the contrary, there still were sufficient slow positron yields originating in energetic photons, even at the rear assemblies. This is because the photons go almost straightforward and cause pair production reactions uniformly in every assembly. Thus produced positrons have comparatively lower energies, which results in higher probabilities to be thermalized in each moderator foil.

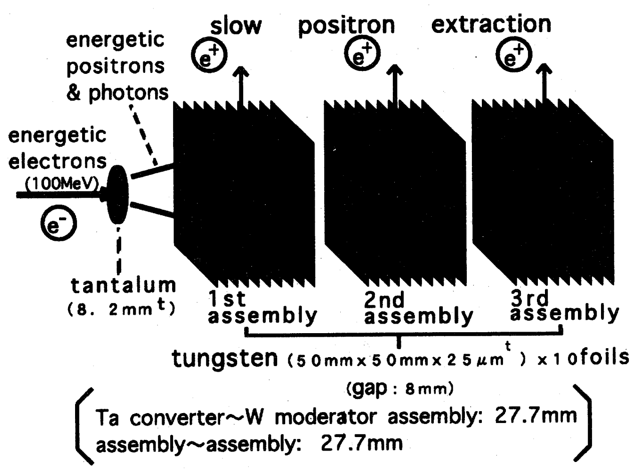

Fig.4 A concept of the simultaneous multi-channel extraction of slow positron beams by multiple moderator assemblies.

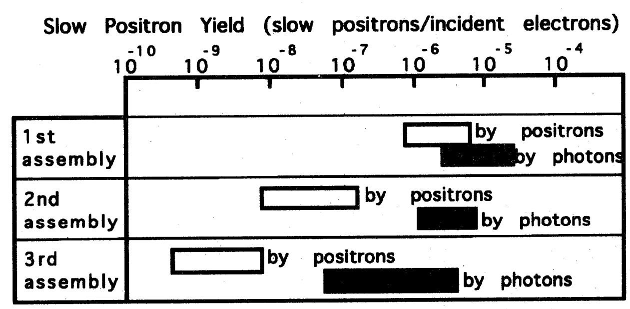

Fig.5 Slow positron yield calculated with EGS4-SPG for the multiple moderator assemblies shown in Fig.4. The incident electron beam energy is 100 MeV. Contributions by energetic positrons and photons from the converter are estimated separately.

To demonstrate a feasibility of the simultaneous extraction of multi-channel slow positron beams, we fabricated a set of 2 channel tungsten moderator assemblies as shown in Fig.6. The set was composed of 18 tungsten foil layers of 25μm in thickness. Slow positrons from each 9 layers were separately extracted by 2 tungsten mesh grids. Each moderator layer was divided into 3 parts, electrically separated and biased to drift emitted slow positrons by sloping the electric field toward the extraction grids. We observed the slow positron beam profile from the assemblies with a MCP (micro channel plate), using a 100 MeV electron beam from a S-band electron linac at Osaka University.

The result is shown in Fig.7. Three peaks were observed in the slow positron beam intensity. The largest one was attributed to slow positrons from the first channel which was nearer to the tantalum converter. The second and third peaks were both attributed to slow positrons from the second channel. It is assumed that back-scattered positrons and pair production reactions by photons give rise to the third peak, because thick tungsten plates were placed at the end of the second moderator assembly. This means that positrons and photons passing through the first and second assemblies still have a potential to generate slow positrons, and also that it will be efficient to place a heavy metal at the end in fabrication of moderator assemblies.

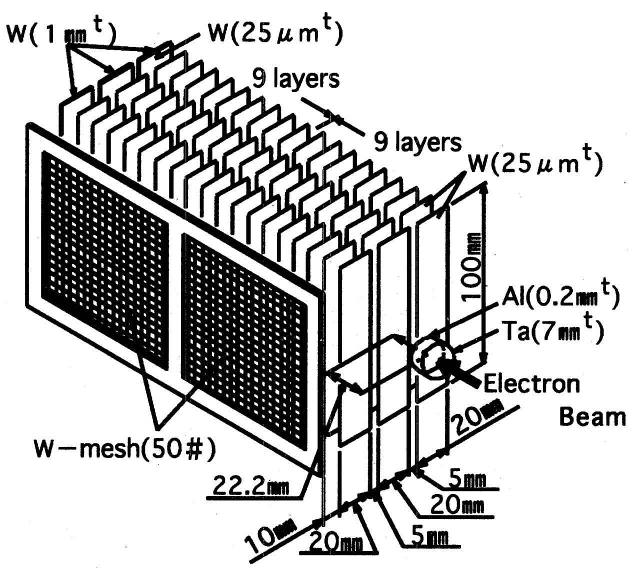

Fig.6 Experimental setup of 2-channel moderator assemblies for the demonstrative experiment of simultaneous extraction of multi-channel monoenergetic positron beams.

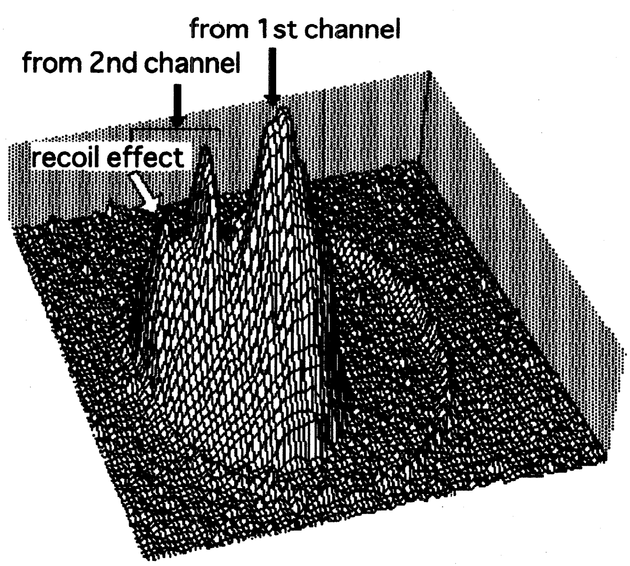

Fig.7 The intensity of slow positrons extracted from the moderator assemblies shown in Fig.6, observed with a MCP.

The intensity of slow positrons from the second channel was smaller only by a order of magnitude than that from the first channel, which agreed well with the simulation result. It was concluded that such an extra beam will be useful for preliminary or potential researches which are promoted simultaneously with main experiments using the strongest beam.

5. Conclusion

We confirmed a possibility to study defects in silicon with an internal positron source produced by proton bombardment. In the positron lifetime spectrum, a small extra component which may originate in escaping positrons from the irradiated specimen was found. Construction of a pulsed MeV positron beam, which is applicable for defect analysis of various materials, will be completed at the end of 1996 fiscal year. In the design study for the Positron Factory, we demonstrated a feasibility of simultaneous extraction of multi-channel monoenergetic positron beams using an electron linac, by an experiment.

The experiments of the internal positron source production and the multi-channel positron beam extraction were carried out in cooperative researches with Tohoku University and Osaka University, respectively. The authors wish to thank Prof. M.Hasegawa, Prof. S.Tagawa, Dr. Y.Honda and their colleagues for their cooperation.

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