Present Status of the Positron Factory Project and Development of Positron Beam Techniques (II)

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Abstract

Thermal defects in silicon was studied with an internal positron source produced by a proton beam from a cyclotron. A pulsed MeV positron beam, which enables more accurate defect analyses of wider range of materials, was almost constructed. In the design study for the Positron Factory, the conceptual design has been performed, and efficient moderator structures are proposed on the basis of both an experiment and a Monte Carlo simulation.

1. Introduction

We have been promoting four different types of activities related both to accelerators and positron utilization: positron spectroscopy using an internal positron source produced with a cyclotron, construction of positron beam lines including a pulsed MeV positron beam, design studies for the Positron Factory[1] (linac-based intense monoenergetic positron beam facility) and ion beam induced fine structures studied by positron spectroscopy. The last one will be presented elsewhere. In this report, the present status of the upper three activities is described.

2. Thermal Defect Study with an Internal Positron Source Produced by a Cyclotron

We produced a positron emitter ^{22}Na inside a FZ-silicon specimen by a nuclear reaction ^{28}Si(p,^{7}Be)^{22}Na with a proton bombardment from the JAERI AVF cyclotron. This internal positron source enables thermal defect studies by using positron spectroscopy at high temperature where usual positron sources would be melt down. It is an urgent issue in semi-conductor industries whether the thermal defects are formed or not.

The radiation-induced defects were eliminated by annealing up to 900 deg.C. After the annealing the Doppler-broadened annihilation radiation energy spectra were measured with elevated temperatures. The result is shown in Fig.1. The S-parameter drastically increases around 1100 deg.C, which suggests formation of thermal defects. The formation energy was evaluated to be about 4.7 eV from the result.

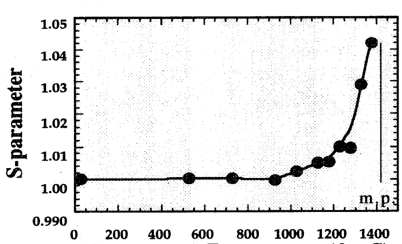

Fig.1 S-parameter of a FZ-silicon with an internal positron source measured with elevated temperatures.

The experiment suffered from squeezing-out of active sodium atoms from the specimen, which might cause uncertainty in the result. Farther detailed investigations will be necessary to get a clear answer.

3. Construction of Positron Beam Lines

The above internal positron source technique has advantages in good S/N ratio and availability in extreme conditions such as high temperature. But there is a limitation of materials to produce the internal source by ion beam irradiation.

Positron lifetime measurements with a pulsed positron beam have the same advantages and no such limitations. Pulsed positron beams having energies up to several tens keV for surface study exist in the world[2], whereas higher energy pulsed beams for bulk analysis do not.

We have been constructing a pulsed MeV positron beam line (PUMPS: PUlsed MeV Positron Source) with a pulse width of 100 ps. Schematic view of the beam line is shown in Fig.2. Slow positron generation and transportation with good performance in the part from the source to the chopper tube were confirmed in the beam experiments using a 3.7 MBq ^{22}Na positron source and an electron gun.

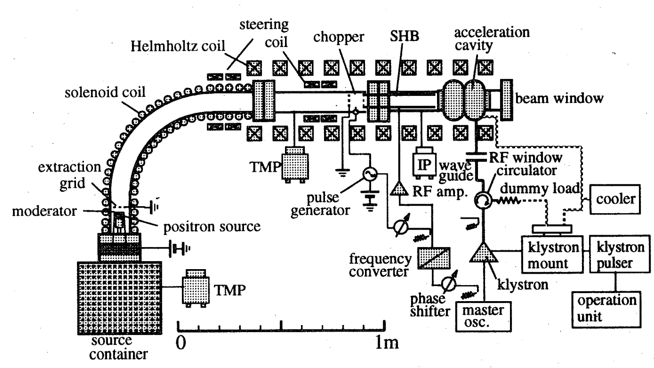

Fig.2 Schematics of PUMPS.

The chopper performance was tested with a low emittance electron beam which emulates a slow positron beam emitted from the moderator surface by the negative surface work function. The transmitted current of the accelerated beam was zero when the chopper potential was higher than the acceleration voltage, and sharply increased with lowering the chopper potential, as shown in Fig.3. The chopping efficiency for a 500 eV beam was estimated to be 75 %. Here the pulse level was assumed to be 5 V, which is a maximum of our available pulse generator (HP8131A; rising time < 200 ps). A well coincident chopped beam with the pulse level change in a time range of 2 ns was also observed as shown in Fig.4.

The subharmonic buncher (SHB; 178.5 MHz) and the acceleration cavity (2856 MHz) was already installed. In the operation test of the klystron (2856 MHz), the performance with 8 μs pulse width and 100 pps repetition was obtained, which is better than its specification (>300 kW, >4 μs, >50 pps). The acceleration efficiency of an injected 500 eV beam with a pulse width of 2 ns from the chopper into the SHB was estimated to be 70 % from the acceleration phase width calculated by a simulation as shown in Fig.5.

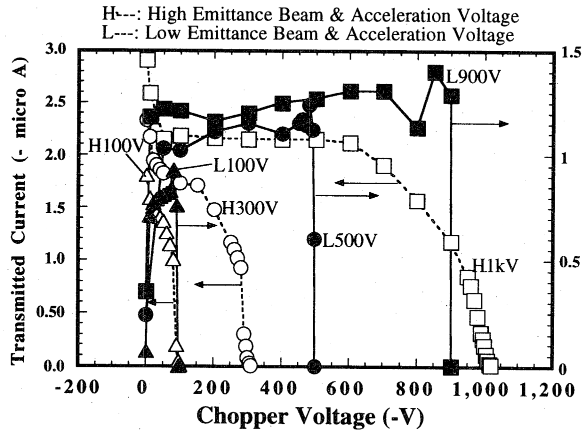

Fig.3 Chopper transmission performance of PUMPS.

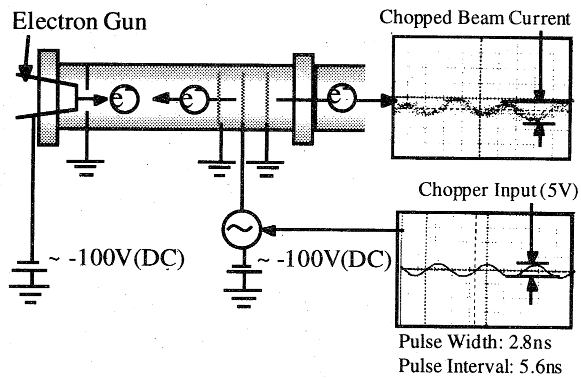

Fig.4 Chopper timing performance of PUMPS.

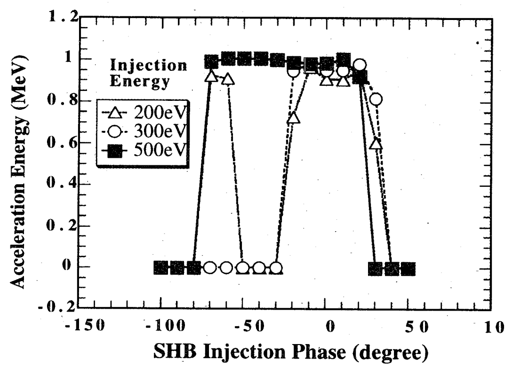

Fig.5 Acceleration energy in the SHB and the acceleration cavity vs. injection phase to the SHB.

The waveguide circuit will be installed, and the beam line will be completed by March 1998. After the completion, the electron gun will be replaced by a 3.7 GBq ^{22}Na positron source.

We have also developed an isotope-based and electrostatically guided slow positron beam. The beam line was completed, and the overall efficiency of slow positron generation and transportation to the specimen was measured to be 2.6x10^{-5} to 5.5x10^{-5} depending on the acceleration energy up to 30 keV. These are fairly good for an electrostatic slow positron beam line.

4. Design Study for the Positron Factory

Isotope-based slow positron beams cannot be applied for advanced analyses such as time-dependent observation of transient phenomena and fine structure investigation of sub-micron size local region of materials, because of the insufficient intensity. We have been promoting design studies for the Positron Factory, which will produce linac-based intense slow (i.e. monoenergetic) positron beams of more than 10^{10}/s in intensity. The conceptual design of the main parts of the facility has been completed as shown in Fig.6.

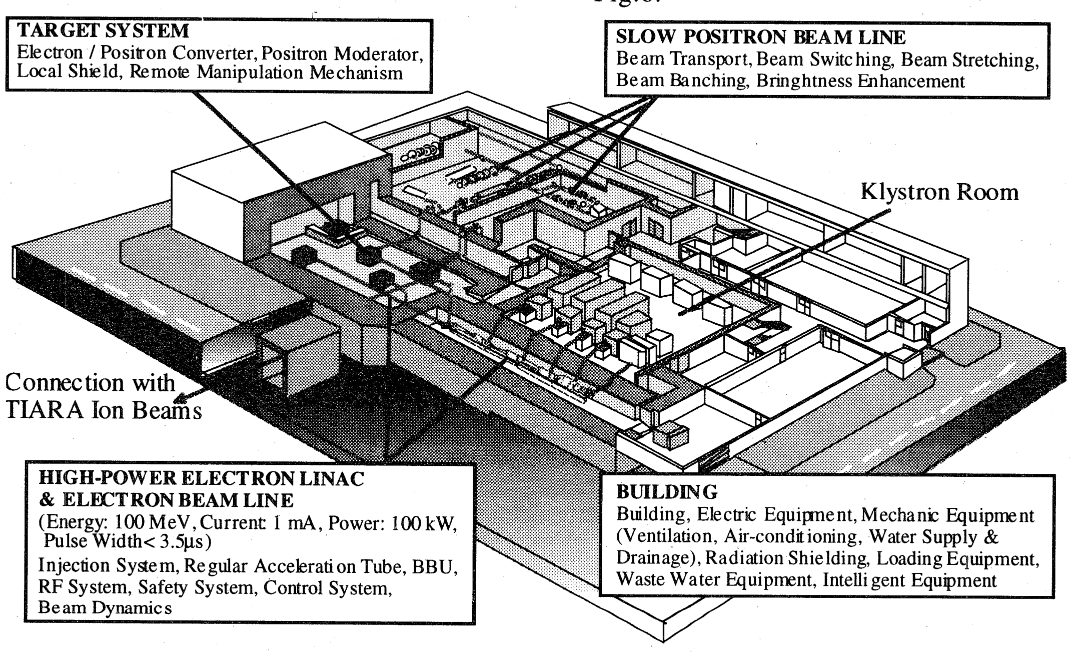

Fig.6 Conceptual design of the planned Positron Factory.

In the design study, we have proposed 'multi-channel moderator assemblies' to supply multiple slow positron beams simultaneously, on the basis of the simulation system EGS4-SPG developed by us[3]. The feasibility of the proposal was confirmed by a demonstrative experiment using an electron linac[4], as shown in Fig.7, which was reported previously. We estimated slow positron yields from each layer of tungsten moderator foils for the same structure as that used in the experiment, using EGS4-SPG. The result is shown in Fig.8, which agreed well with the experimental result.

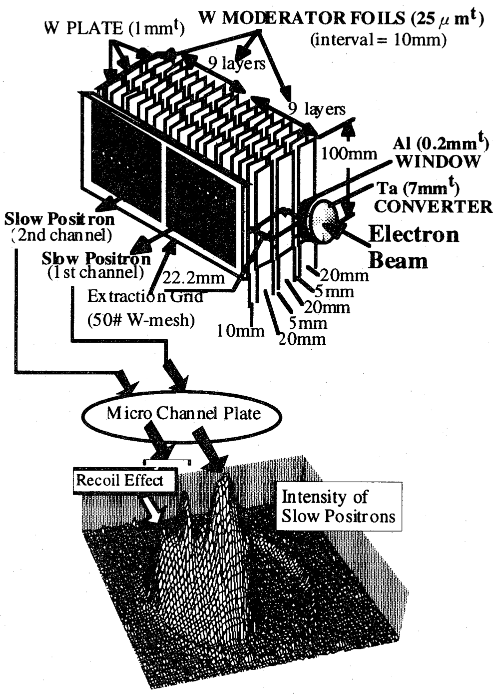

Fig.7 Experimental setup of 2-channel moderator assemblies for the demonstrative experiment of the simultaneous extraction of multi-channel monoenergetic positron beams and the intensity of extracted slow positrons observed with a MCP.

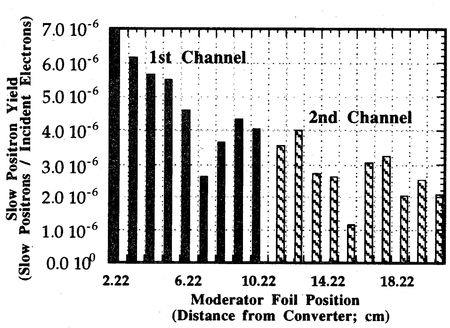

Fig.8 Calculated slow positron yields from tungsten foil layers of the 2-channel moderator assemblies used in the experiment as indicated in Fig.7.

The demonstrative experiment result suggests usefulness of a heavy metal plate for a reflector to enhance the slow positron yield, which is indicated as 'recoil effect' in Fig.7, and importance of the moderator assembly structure. To evaluate the structure effect, we calculated slow positron yields for various moderator assembly structures as shown in the upper side of Fig.9, using EGS4-SPG.

The lower side of Fig.9 shows the calculation result. It is obvious that the structure effect is remarkable. Especially a structure of honeycomb-like assembled tungsten foils surrounded by thick tungsten reflectors is expected to produce more than three times larger amount of slow positrons compared to the usual structure.

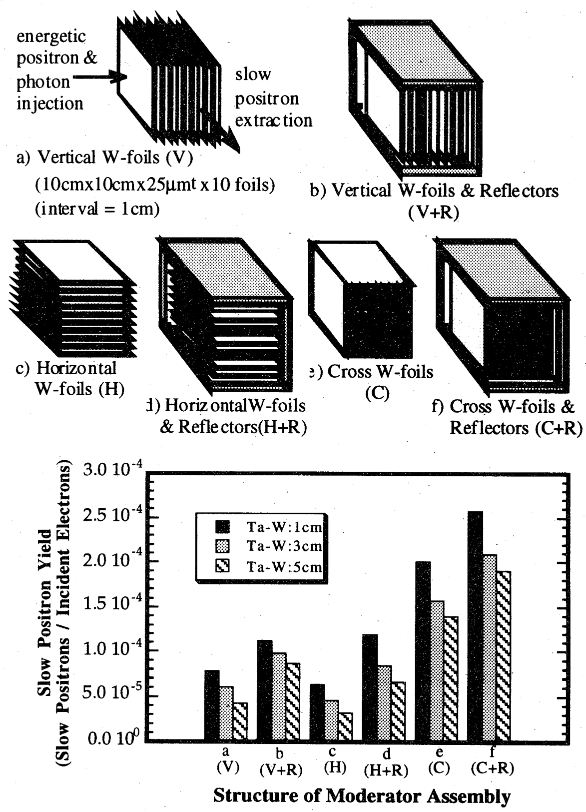

Fig.9 Moderator assembly structure effect.

5. Conclusion

We have been developing accelerator related positron spectroscopy techniques. Positron spectroscopy with elevated temperatures using an internal positron source in silicon produced with a cyclotron suggested a possibility of the thermal defect formation. A pulsed MeV positron beam line, which will be applied not only for silicon but for various materials, was almost constructed remaining the RF waveguide circuit for RF feed to the acceleration cavity. An electrostatically guided slow positron beam line was also constructed.

In the design study for the Positron Factory, the conceptual design of the main parts has been completed. An efficient moderator structure of honeycomb-like assembled tungsten foils surrounded by thick tungsten reflectors is proposed on the basis of an experiment and a Monte Carlo simulation, which will give more than three times larger slow positron yield compared to the usual one.

References

[1] S.Okada and H.Sunaga: Nucl. Instr. and Meth. **B56/57** (1991) 604-609
[2] R.Suzuki et. al.: Japanese Journal of Applied Physics **30** (1991) L532-L534
[3] S.Okada and H.Kaneko: Appl. Surface Science **85** (1995) 149-153
[4] S.Okada et. al.: Proc. 1996 Int. Linac Conference, Vol.1 (Geneva, 1996) 249-251