Constructuon of Pulsed MeV Positron Source

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Abstract

We have been constructing a pulsed MeV positron beam line (PUMPS: Pulsed MeV Positron Source). PUMPS can form a high-energy (1 MeV) short-pulsed (100 ps) positron beam. Study of bulk properties under extreme conditions with PALS (Positron Annihilation Lifetime Spectroscopy) measurement becomes possible by using this beam. Fabrication of PUMPS was already completed, and the acceleration up to 1 MeV was confirmed by using an electron beam. Beam diameter of 0.5 mm, 150 ps-pulse width and low normalized emittance were also measured.

1 Introduction

We have been constructing a pulsed MeV positron beam line (PUMPS: Pulsed MeV Positron Source)[1][2]. PUMPS can form a high energy short-pulsed positron beam that has two remarkable performances; one is beam energy (1 MeV) and the other is pulse width ($\sim$ 100 pico seconds; ideally several tens pico seconds). Study of bulk properties with PALS (Positron Annihilation Lifetime Spectroscopy) measurement becomes possible using the high energy and short-pulsed positron beam injected into deep region of materials and compressed within a time resolution of the measurement system. In conventional PALS method, a positron source attached to specimens would be broken in extreme conditions such as high temperature. The positron beam can avoid the difficulty because the specimen is placed apart from the source. Pulsed positron beams having energies up to several tens keV for surface study exist in the world [3], whereas higher energy pulsed beams for bulk analysis do not.

2 Concept of Pulsed MeV Positron Source

Schematic view of PUMPS is shown in Fig.1. Positrons generated by 3.7 GBq ^{22}Na positron source are moderated and thermalized in a tungsten moderator whose thickness is 6 μm. Positrons emitted from the moderator surface by the negative surface work function are extracted as a DC slow positron beam and transported by a magnetic guiding field. The continuous positron beam is converted to a pulsed beam whose pulse width is 2 ns at the chopper tube consisting of 3 grids, due to a sharp fluctuation of an electric potential of one of these grids by a pulse generator (HP8131A, rising time <200 ps). The following subharmonic buncher(SHB) modulates the chopped beam using a high frequency (178.5 MHz) electric field and converges to 100 ps pulse width. This bunched beam is accelerated up to 1 MeV in the following standing wave type acceleration cavity. Simultaneously the pulse width is reduced to several tens pico seconds ideally. The RF source of this cavity is a klystron (Mitsubishi PV-2012) that amplifies 2856 MHz RF wave with 400 kW output power at maximum.

We found a serious problem that the accelerated beam contains many high energy discharge electrons from the cavity wall, which were observed as dark current mixed with the normally transported beam. Such electrons might damage specimens and disturb the high sensitivity measurement which is an advantage of positron application. A magnetic filtering system consisting of 4-bending magnets and a slit is applied to remove the discharge electrons. Two sets of triplet quadropole magnets focus the normally accelerated beam onto a target. Annihilation gamma-rays emitted from the specimen, which are detected by plastic scintillators and photomultipliers, are used for PALS measurements.

The short-pulsed high-energy positron beam reaches the specimen at an interval of 5.6 ns (178.5 MHz) synchronized with the chopper, which enable PALS measurement of semiconductors and metals . This interval can be changed by adjusting the operation mode of the chopper. Consequently PUMPS can also be applied to specimens having longer positron lifetimes like polymers.

3 Results of Performance Tests

Fabrication of PUMPS was already completed, and the performances were confirmed in the beam experiments using an electron gun and a 3.7 MBq ^{22}Na positron source.

3.1 Transportation of Low Energy Beam

The chopper performance was tested with a low emittance electron beam which emulates a slow positron beam [4]. The chopping efficiency for a 500 eV beam was estimated to be 75 % from the result of the transmitted current measurement. Here the pulse level was assumed to be 5 V, which is a maximum of our pulse generator. A well coincident chopped beam with the pulse level change in a time range of 2 ns was also observed.

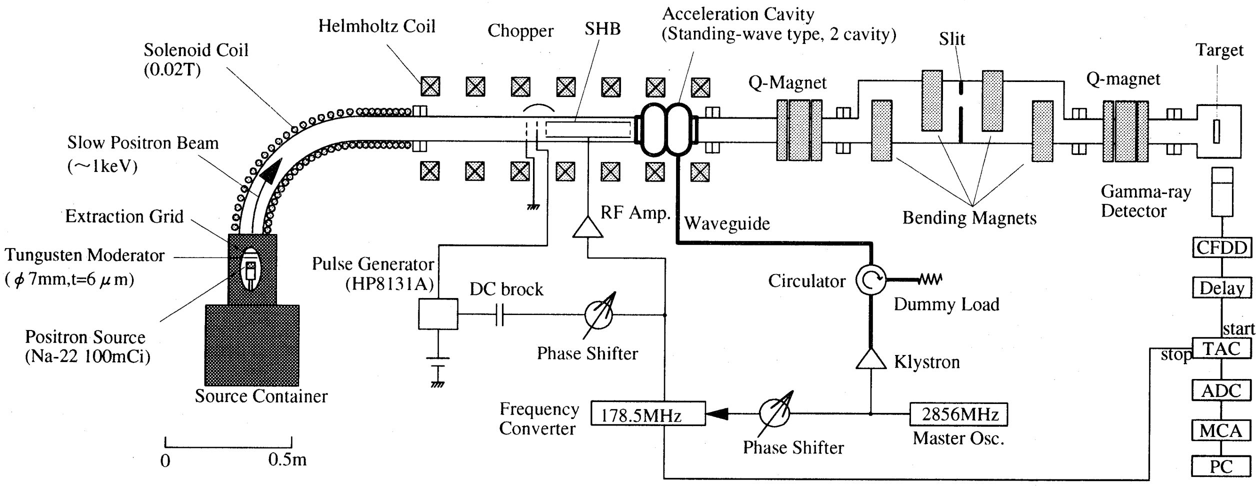


Fig.1 Schematic of PUMPS

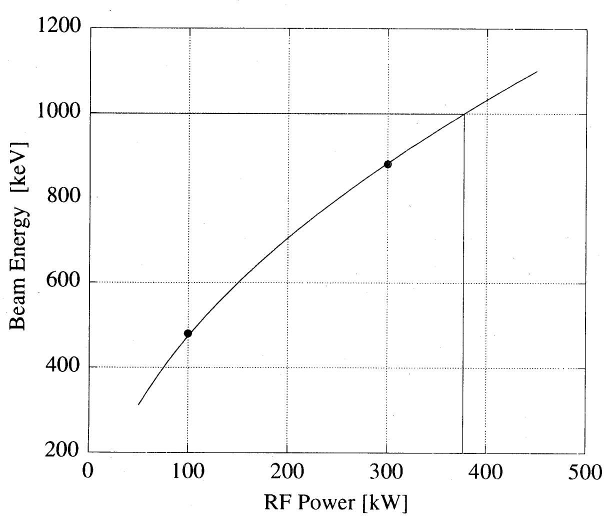


Fig.2 Accelerated Beam Energy

3.2 Accelerated Beam Energy

In the operation test of the klystron, the performance with maximum 400 kW output power, 8 μs pulse width and 100 pps repetition was obtained, which is better than its specification (>300 kW, >8 μs, >50 pps). Beam energy was measured from the injection range in Aluminum as shown in Fig.2. As the energy gain E of the standing wave type acceleration cavity has a relationship with the RF power P like $E \propto \sqrt{P}$, a beam energy of 1 MeV was estimated to be obtained within the nominal output power of the klystron. 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. The detail of this work is described in ref [4].

Table 1 Vertical Normalized Emittance [πmm•mrad]

		beam current [mA] 0.42	0.9
beam energy [MeV]	0.594	33.1	89.2
	0.801	98.6	263.0

Table 2 Horizontal Normalized Emittance[πmm•mrad]

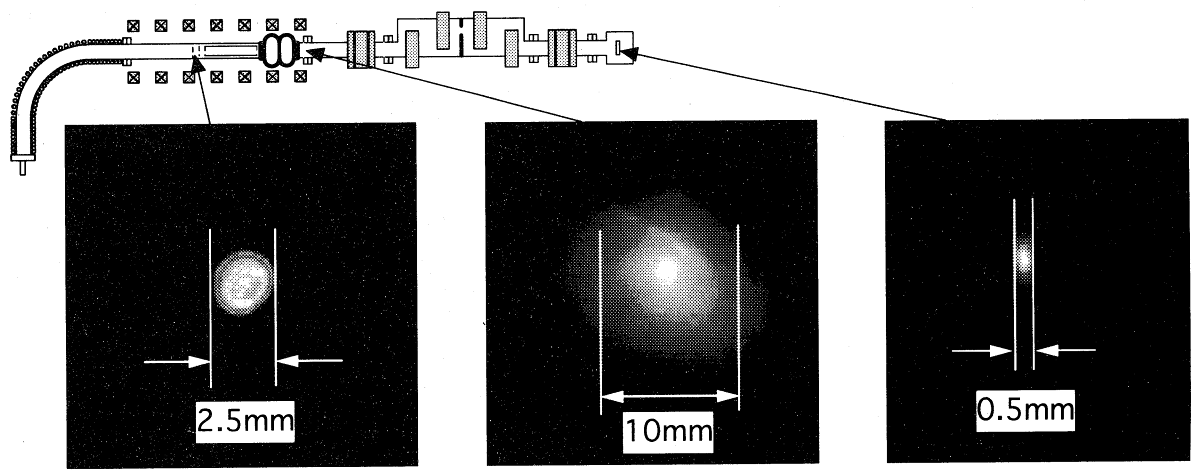
		beam current [mA] 0.42	0.9
beam energy [MeV]	0.594	2.24	4.64
	0.801	69.99	49.56

3.3 Beam Profiles

Beam profiles were observed as shown in Fig.3. Due to the discharge electrons, a 10 mm beam diameter was observed at the end of the acceleration cavity(b) though the beam size was 2.5 mm at the chopper(a). A well-converged beam, whose diameter is 1 mm or less, was obtained on a target(c) by applying Q-magnets and a magnetic filter. This size is suitable for the practical use of our beam.

3.4 Emittance

Beam emittances on a target were also estimated by adjusting focus powers of the Q-magnets. The vertical and horizontal normalized emittances are shown in Table 1 and 2. Those comparatively small values indicate that the beam quality is good enough for beam utilization. Differences between the vertical and horizontal emittances are due to configuration effect of the magnetic filter. Emittance growth with increase of beam current or RF power is considered to be caused by space charge effect or existence of discharge electrons.



(a) Chopper (b) Acc. Cavity (c) Target

Fig.3 Beam Profiles

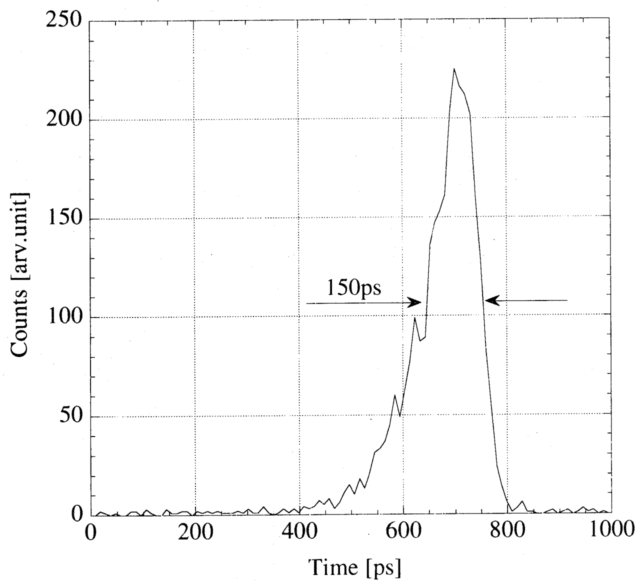


Fig.4 Pulse Width

3.5 Pulse Width

Pulse width of 150 ps at minimum was observed as shown in Fig.4. This value is near to the practical one because the time resolution of a general positron lifetime measurement circuit is around 100 ps. A noise suppression system of our pulsing system is not perfect at present, which prevented the chopper from normal working. Advanced shielding between noise sources and high frequency circuits of the pulsing system will reduce the pulse width. From calculations using a simulation developed by us, it is concluded that a smaller energy spread (0.3 % at present) of an injection beam into the SHB is required to farther reduce the pulse width. Improvement of the slow positron transportation part to reduce the energy spread is expected.

4 Conclusion

We have been constructing a pulsed MeV positron source named PUMPS, which has a possibility of expanding positron applications to new techniques in characterizing materials. Fabrication of PUMPS was completed and we confirmed the good performances, for example, 1 MeV beam energy, 0.5 mm beam diameter, 150 ps pulse width and low emittance. After exchanging an electron gun to a 3.7 GBq ^{22}Na positron source, a pulsed MeV positron beam will be applied for PALS measurements in extreme ambience such as at high temperatures and under dynamic stresses. We plan to investigate thermal vacancies in silicon and microvoid creation in nuclear power plant materials.

References

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