

Design of a pulsed positron system at Trombay

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Abstract. We present here the design of a pulsed beam setup to deliver narrow time width positron pulses. The major constituents of the setup include- ²²Na radioactive source and moderator assembly, ExB deflector for filtering out high energy positron and gamma rays, chopper-prebuncher-buncher assembly for time bunching of the slow positrons. In the ExB section, crossed electric and magnetic fields guide the slow positrons through an off-centered hole in a tungsten block. The initial beam will then be time bunched by using a reflection type chopper and a double gap prebuncher. The main buncher is designed as a quarter wave resonator with base frequency of 150 MHz. To prevent the sagging of the cantilevered inner tube of the resonator, we will support the inner conductor using an alumina post. There will be provision of tuning the frequency by using a tuner made of conducting material. The incident beam energy will be varied by biasing the sample.

1. Introduction

Energy tunable pulsed positron beam can be used to probe defect characteristics of surfaces, subsurfaces and buried interfaces in thin films. Such experiments provide a huge advantage over the conventional positron annihilation lifetime technique where the bulk of the sample is probed ($\sim 100 \mu\text{m}$) owing to the wide energy range of the emitted positrons from the radioactive source. We present here a simulation and design of a ²²Na radioactive source based pulsed positron beam. Conventionally, positron pulsing techniques are derived from the ion bunching field because of the low initial current and hence higher need to minimize loss (ion beams tend to be in nanoamps while positron beams are in femtoamps). Also, the positron β values ($\sim 10^{-2}$) for materials science applications are comparable to that of the heavy ion beams[1]. Almost all of the existing pulsed positron beams are based on some variation of chopper-prebuncher-buncher arrangement. The Munich group [2] used a time dependent transverse electric field to kick away the non-time-synchronized positrons by increasing the Larmor radius of the positrons. For the prebuncher and buncher, they used the conventional design of resonant cavities. The pulsed beam developed by Suzuki et al. [3] used a reflection type chopper composed of three parallel grids to convert the DC positron beam to a pulsed beam of 2.5 ns FWHM. PALS setup at both these groups have a timing resolution $\sim 250 - 300$ ps which is sufficient for lifetime measurements.

2. Design and Simulations

In the following sections, we will discuss the various components of the spectrometer: ExB filter, chopper & prebuncher, buncher. The complete beam assembly is shown in Fig. 1.



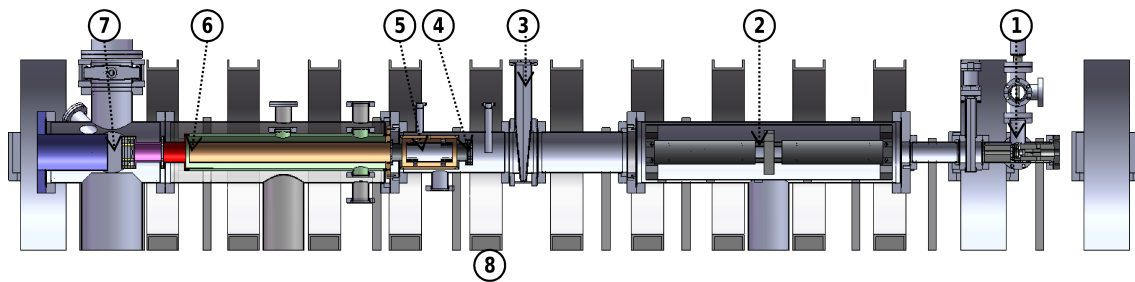


Figure 1. Design of the pulsed positron beam. 1. Source+Moderator Setup 2. ExB filter 3. Isolation Valve 4. Chopper 5. Prebuncher 6. Main buncher 7. Sample 8. Helmholtz coils.

2.1. Energy filtering of fast positrons

The positrons emitted from the ^{22}Na source have a wide energy distribution with end point being ~ 540 keV and a mean of ~ 190 keV. These high energy positrons are moderated using a $1\ \mu\text{m}$ Tungsten foil which produces slow positrons with mean energy equal to the absolute value of the positron work function (~ 3 eV) with a spread of ~ 0.5 eV and efficiency of $\sim 10^{-4}$. Most of the high energy positrons ($\sim 90\%$) actually pass through the moderator unaffected. Conventionally, a solenoidal bend in the beam is used to filter the high energy positron beam with the assumption that the change in the B field will not be adiabatic for the fast non-thermalized positrons [4]. But the drawback of such setups can be understood by noting that range of energy of the positrons allowed to pass through for a 90° bend with $B=90$ G is 0-3 keV. Use of crossed magnetic fields (BxB) for fast positron filtration has been suggested as well which has same drawback as the "90 $^\circ$ bend" [5]. On the other hand, ExB filtration provides excellent energy selection ($\sim 10\%$) [6]. Conventionally, it is achieved by using a set of parallel plates where the electric field (E) is perpendicular to the magnetic (B) field. The positrons, which were initially following the magnetic field, are deflected up (direction perpendicular to both E and B fields) and are made to pass through an off centered hole. The deflection, y , is given by $y = \frac{EL/B}{\sqrt{2T/m}}$, where E is the electric field, B is the magnetic field, L is the length of the plate, T is particle's kinetic energy and m is the mass of the positron. This arrangement introduces distortion such that the initial circular cross section of the beam is transformed to an elliptical one. Hence we have used cylindrical plates to eliminate these distortions [7]. A disadvantage in using cylindrical plates for ExB filters is that such arrangement only works for one set of beam energy and plate voltage. Hence we have decided to float the ExB filter assembly. The SIMION [8] simulations indicate that with the dimensions of ExB plates ($L=250$ mm, $B=40$ G) with 30 mm vertical deflection will deliver an almost Gaussian beam of mean energy 250 eV having FWHM of 10 eV (see Fig. 2) [9].

2.2. Time bunching of positrons

The time bunching of the positrons is achieved by a combination of chopper, prebuncher and buncher. The chopper will be made of three tungsten mesh ($2\ \mu\text{m}$, 100 mesh/in) which are separated by Macor insulators with a gap of 5 mm. The middle mesh is fed a square wave RF of 37.5 MHz with a DC bias of 260 V. The chopper has a duty cycle of 15 %. The prebuncher consists of two concentric cylinders and the RF pulse is fed to the inner tube. The acceleration gap at the entrance and exit of the outer cylinder is defined by the axial distance between the inner and the outer cylinder (10mm). The two bunching gaps are separated by 125 mm which is also the half wave length of the RF pulse (37.5 MHz) at the positron energy of 250 eV. The chopper and prebuncher combination was simulated in SIMION.

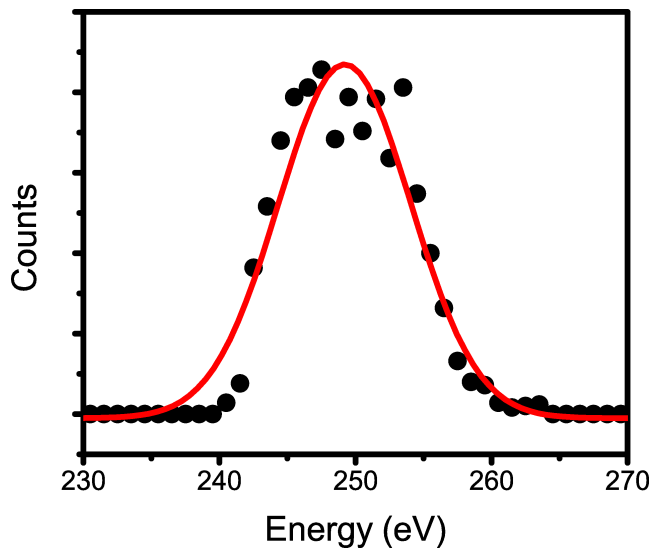


Figure 2. Transmission function of the ExB plates. The beam is centered at 250 eV with FWHM of 10 eV.

Table 1. Parameters of the quarter wave resonator(E_{max} is the value of maximum electric field).

Parameter	value	Parameter	value	Parameter	value
Length(inner)	469 mm	Gap Length	10 mm	Diameter(inner)	20 mm
Diameter(outer)	52 mm	E_{max}	$9 \times 10^7 V/m$	Q	2200

2.3. Main Buncher

The main buncher is designed as a quarter wave resonator with a base frequency of 150 MHz and a Q value of 2200. The main parameters of the buncher are summarized in Table 1. The buncher has been simulated using CST Microwave software. Since the inner tube of the buncher is cantilevered at one end, it can sag at other end causing the change in resonant frequency. For this we have proposed to support it using a post made of alumina (Fig. 3). The change in frequency as a function of the alumina post position is shown in Figure 3(b).

Provision has been kept to vary the frequency of the resonant cavity using a copper tuner of 14 mm diameter and 30 mm length. The variation of the frequency is related to the reduction in the volume (achieved by the varying the plunger depth) by the Slater's perturbation theorem [10]

$$\frac{\delta f}{f} = \frac{\int_{\delta V} (\mu_0 H^2 - \epsilon_0 E^2) dV}{\int_V (\mu_0 H^2 + \epsilon_0 E^2) dV}$$

where δV is the change in cavity volume, V is the cavity without the tuner, E and H are the magnitude of the unperturbed electric and magnetic field. The simulated variation of the frequency with tuner depth is shown in Fig 3(b).

3. Conclusion

In conclusion, we have optimized preliminary design of a pulsed positron beam using SIMION and CST microwave studio. This design will provide 250 eV positron pulses of duration less than 200 ps. The distance between the moderator and the sample will be ~ 2 m and the average beam intensity will be $\sim 10^3$. When combined with timing resolution of the gamma detectors

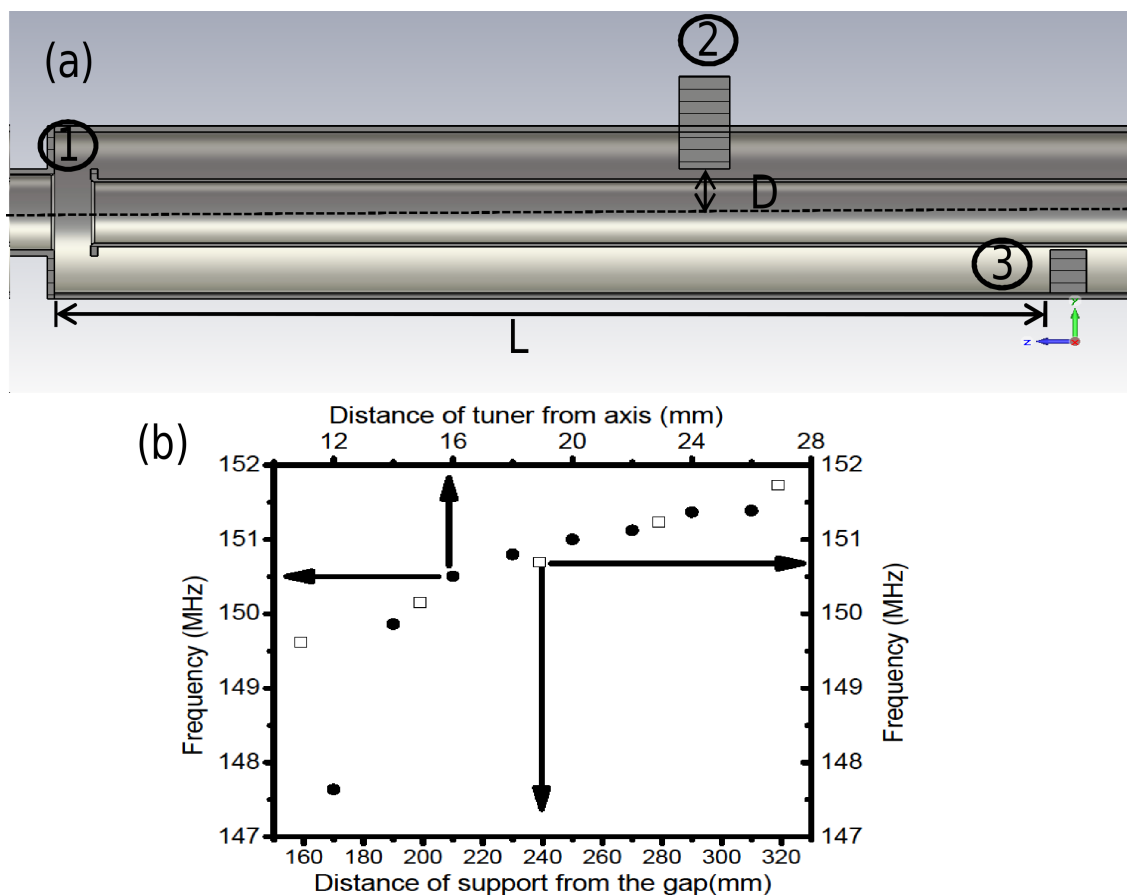


Figure 3. (a) CST setup of the main buncher. 1. Bunching gap. 2. Tuner 3. Alumina support. The distance of the tuner from the buncher axis is represented by D while the distance of the support from the gap is represented by L . (b) Variation of the resonant frequency as a function of the distance of support from the gap (L) and distance of tuner from axis (D).

(BaF_2 , ~ 200 ps), it is expected that this spectrometer will provide time resolution of ≤ 300 psec for depth dependent PALS.

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