TIME BUNCHING SYSTEM TO MODULATE LOW ENERGY POSITRON BEAMS

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ABSTRACT

A time bunching system to modulate low energy positron beams has been designed and is being constructed for high count rate lifetime measurements. The bunching system consists of a dual mode chopper (continuous-wave and pulse mode) and a single cavity double harmonic buncher. This paper describes the design procedure of the system.

INTRODUCTION

Lifetime measurement with a pulsed low energy positron beam is known to be a powerful method to study defects or electronic properties in solids at the surface or close to the surface.[1,2] Using this method, a depth dependence of the lifetime spectra can be obtained by means of controlling the mean penetration depth of the positrons with variable injection energy. Furthermore, very high count rate($>10^6$ cps) measurement is possible when an intense pulsed positron beam exists, because a start signal is derived electronically and the coincidence count rate is equal to the single count rate in one detector.

However, in the world, there exists only one system which can measure lifetime spectra using a pulsed low energy positron beam with a sufficient time resolution. This system has been developed by Schödlbauer *et al.*[2,3] The performance of the system is that the total time resolution is 225 psec and that the count rate is 30 — 70 cps with a 15 mCi ^{22}Na source. Since one time spectrum requires about 10^6 counts, this count rate is insufficient to measure precisely the depth dependence of the lifetime spectra.

The present authors plan to carry out high count rate($>10^3$ cps) lifetime measurements with an intense slow positron beam in the Electrotechnical Laboratory(ETL). An intense slow positron beam($>10^8$ positrons/sec) is generated from the electron beam(70 MeV, 50 pps, 4 μsec) of the linac in ETL by a Ta converter and a W moderator. The slow positrons are stored temporarily in a pulse stretcher or a linear-storage section.[4] The positrons can be extracted from the stretcher as a continuous or pulsed($\sim$10 nsec, 100 k — 5 Mpps) beam. The pulsed beam is used to measure long lifetime components(τ >1 nsec) such as positronium components.

We are constructing a bunching system to modulate the intense positron beam. The bunching system consists of two main pulsing devices, i.e. the chopper and the buncher, and the electronic system. In this paper, we discuss the design procedure of the bunching system.

TIME BUNCHING SYSTEM

Chopper

A chopper is used to suppress a part of the beam outside of the desired pulse by deflecting the beam across an aperture. Figure 1 shows a section of a chopper. This chopper has two deflectors. The second deflector is used to compensate the transversal energy of the beam, which is given by the firstdeflector. This chopper can be operated in both continuous wave(CW) mode and pulse mode. In the pulse mode, the pulsed beam extracted from the stretcher is synchronized with the chopper. Electronic power is supplied to the chopper from a linear amplifier through an impedance transformer.

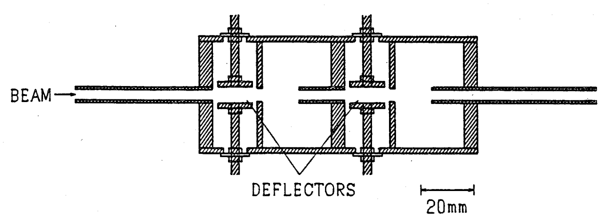

Figure 1. Cross sectional view of the chopper.

Buncher

Since low energy positrons are treated as non relativistic particles, the theory of bunching of low energy positrons is similar to that of the heavy ion bunching. The ideal modulation energy δE at the gap of the buncher is given as[5]

$$\delta E(t) = E_B[(1 - t/\tau_D)^{-2} - 1],$$

where E_B is the energy of the positron entering the buncher at the time t, and τ_D is the time interval during which the positron travels from the gap to the sample. However, because of the practical difficulty in applying the ideal waveform, bunchers generally use single sine-wave[3] or combined wave with two or more harmonics.[5]

We have chosen a single cavity buncher with two harmonics for the reason of the easier fabrication and operation. Several considerations have been involved in the judgment of the injection energy of the buncher and the operating frequency of the buncher.

1. In order to achieve total time resolution of the lifetime spectrum less than 200 psec, the pulse width of the beam at the sample should be less than 100 psec.
2. The energy acceptance of the buncher should be larger than 10 eV(FWHM) because there is an energy spread due to the longitudinal electric field of the chopper.
3. The chopper and the γ-ray detector should be separated each other as long as possible in order to reduce background γ-ray signals caused by positrons being annihilated in the chopper.

After the series of parameter surveys, taking into account the above conditions, it has been judged that the injection energy of the buncher is 250 eV and the fundamental frequency of the buncher cavity is 150 MHz.

Figure 2 shows the caluculated time spectra of the bunched positrons at the sample. In this calculation, we assumed that the pulse width at the chopper is 2.5 nsec(FWHM) and the energy spread of the positrons entering the buncher is 10 eV(FWHM), the distance between the second deflector of the chopper and the gap of the buncher is 500 mm, and the mean drift time from the gap of the buncher to the sample is 3.2 nsec. This result indicates that the bunching efficiency of the first and third order harmonic buncher is higher than that of the single wave buncher by 30%.

Figure 3 shows a section of the buncher cavity being fabricated. This cavity is a $1/4\lambda$ and $3/4\lambda$ coaxial resonator and the length is about 500 mm. This cavity has a tuner to match the third order harmonic to the resonant frequency. The fundamental resonant frequency is tuned by means of varying the frequency of the signal generator.

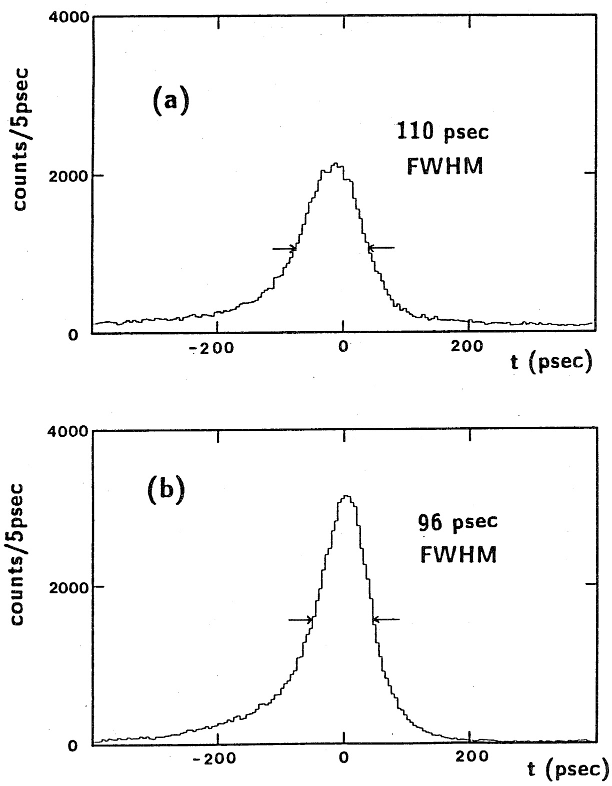

Figure 2. Caluculated time spectra of the bunched positrons at the sample (a) with only the fundamental wave; (b) with the first and third order harmonics. For each spectrum, 10^5 trajectories are calculated by means of Monte Carlo method.

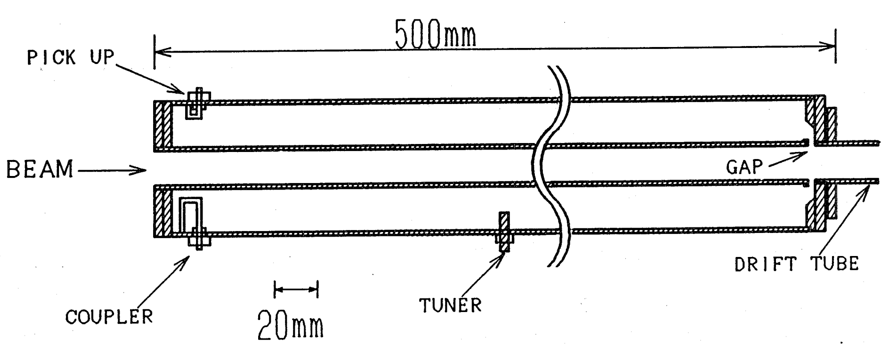

Figure 3. Cross sectional view of the buncher.

Electronic System

Figure 4 shows a block diagram of the electronic system. The signal generator generates a fundamental frequency signal which matches the resonant frequency of the buncher cavity. The signal is split to two signals:One is fed to the buncher control unit; The other is transformed to a $1/N$ (N=1,2,4,8,16,$\cdots$) frequency signal by a frequency divider, and then, connected to a timing pulse generator and the chopper. The buncher control unit consists of a harmonic generator, phase shifters, variable attenuators, and a combiner. The output signal of the control unit is amplified and coupled into the buncher. The outputs of the timing pulse generator are connected to a time to amplitude converter(TAC), a gate generator, and the beam stretcher through a delay unit, a function generator, and an amplifier. A positron lifetime spectrum is obtained by measuring the time interval between the timing pulse and the output signal of a fast γ-ray detector(BaF_2+PMT).

SUMMARY

In this paper, we present the design procedure of the bunching system of intense low energy positron beams. We have carried out a pleliminary test of the bunching system using a pliot model.[6] The performance of the lifetime measurements with this system is expected that the injection energy at the sample is variable from ~500 eV to 30 keV, total time resolution is less than 200 psec, and count rate is more than 1000 cps.

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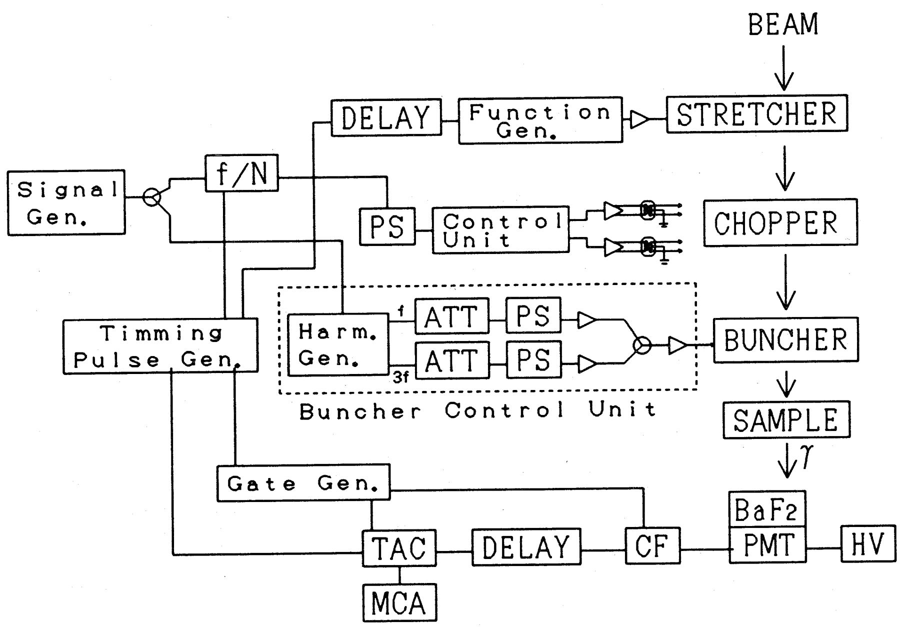

Fiqure 4. Block diagram of the electronic system.