Generation of an Intense Pulsed Positron Beam and Its Applications

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Abstract

A positron pulsing system for an intense positron beam generated by an electron linac has been developed at the Electrotechnical Laboratory. The pulsing system generates an intense pulsed positron beam of variable energy and variable pulse period. The pulsed positron beam is used as a non destructive probe for various materials researches. In this paper, we report the present status of the pulsed positron beam and its applications.

I. Introduction

Positrons have been established to be a very sensitive probe to study microstructural defects, electronic structure in solids, and surface or near surface phenomena.[1] In 1987, a facility to produce an intense slow positron beam was constructed at the Electrotechnical Laboratory (ETL) [2]. We have developed a pulsing system for the intense positron beam, which enables us to perform variable-energy positron lifetime spectroscopy (VEPLS) and time-of-flight(TOF) experiments with high peak-to-background ratio, high count rate, and wide measurable time range [3].

In this paper, we report the present status of the positron pulsing system and some application examples of the pulsed positron beam.

II. Positron Pulsing System

An intense positron beam of $\sim 10^7$ e^+/s is produced with a high energy ($\sim$70 MeV) electron beam of the ETL linac. The positron beam is initially a pulsed beam corresponding to the linac pulse. However, the repetition rate of the linac is too low (50 pps - 100 pps) and the pulse width is too wide (1 μs - 4 μs) for high count-rate positron experiments. Thus, the positron beam is stored temporarily in a linear storage section [4], and the pulse-stretched beam is used for the pulsing system. The pulsing system consists of a chopper, a sub-harmonic pre-buncher (SHPB) and a double harmonic buncher as shown in Fig.1 [5]. An axial magnetic field of $\sim$0.01 T is applied to the pulsing system by Helmholtz coils for beam guiding. The chopper

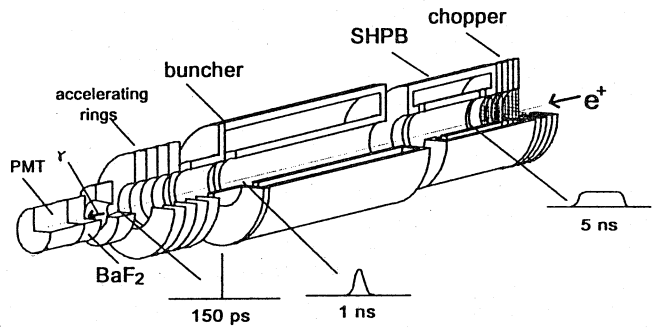

Figure. 1. The positron pulsing system.

consists of three grids, and utilizes a pulsed electric field longitudinal to the beam direction. This device generates a pulsed beam ($\sim$5 ns, $\sim$250 eV) of variable pulse period from the pulse-stretched beam. The SHPB compresses the pulse width of the chopped beam to $\sim$1 ns (FWHM). This beam can be used for time-of-flight experiments. For the positron lifetime spectroscopy, the positron pulse is further compressed to $\sim$150 ps at the sample position by the buncher. The fundamental frequency of the buncher, f_B, is 150 MHz; the operating frequency of the SHPB is a quarter of the buncher frequency, and the chopper frequency is $f_B/(4 \cdot n)$, (n=1, 2, ...). There are accelerating rings and a drift tube between the buncher and the sample. By adjusting the applied voltages to the drift tube and the accelerating rings, the incident positron energy at the sample can be varied from 0.5 keV to 30 keV. As a result, the positron pulsing system generates a pulsed beam of high intensity, variable energy, and variable pulse period.

III. Applications of the Pulsed Positron Beam

A. Positron Lifetime Measurement

A positron lifetime spectrum is obtained by measuring the time interval between the timing signal of the pulsing system and timing signal of an annihilation γ-ray de-

tected with a BaF_2 scintillation detector. At present, the count rate of annihilation γ-rays is 100-500 cps for the positron lifetime experiments. By using this system, we can measure both long lifetime and short lifetime components in near surface regions, surfaces, interfaces, and thin films. Several experimental results using the pulsed positron beam have proved the usefulness of variable-energy positron lifetime spectroscopy [6-9]. We observed long-lived o-Ps components of high intensity in many specimens, for example, a-Si:H [6], diamond films [8], SiO_2 films [7], porous Si (Fig.2), *etc.* These long-lived components are strongly influenced by the deposition condition, annealing temperature, and other conditions.

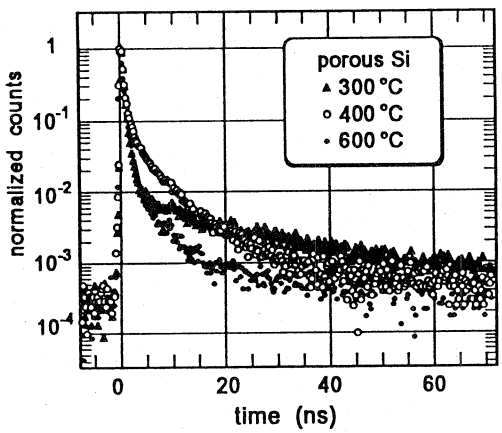

Figure. 2. Positron lifetime spectra of porous Si at the sample temperatures of 300 °C, 400 °C, and 600 °C.

B. Age-Momemtum Correlation Spectroscopy

Age-momentum correlation spectroscopy (AMOCS) is known to provide information which is unavailable from individual measurement of age (positron lifetime spectroscopy) and/or that of momentum (measurement of Doppler broadening or angular correlation of annihilation radiation)[10]. The conventional AMOCS system requires a triple coincidence technique for the start β^+ or γ ray signal and two annihilation γ-ray signals. Thus, the maximum count rate is limited to about 100 cps. On the contrary, an AMOCS system with a pulsed positron beam requires only a double coincidence technique, because the start signal can be obtained electronically from the pulsing system. Thus, it is possible to perform AMOCS with high count rate. We have developed a AMOCS system for the variable-energy pulsed positron beam [9]. The count rate of ~10 cps was achieved with the pulsed beam. If a higher-intensity positron beam is available, the count rate can be easily increased.

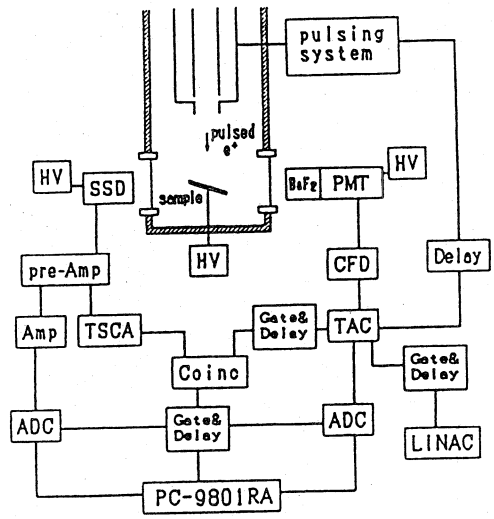

Figure. 3. Block diagram of the AMOCS system.

C. Positron Annihilation Induced Auger Electron Spectroscopy

Positron annihilation-induced Auger electron spectroscopy (PAES) is known to have significant advantages over conventional methods of Auger electron spectroscopy [11]. In PAES, core electrons are removed by annihilation with positrons. Therefore, the incident beam energy in PAES need not be larger than the core level ionization energy, permitting the elimination of the large secondary electron background. Furthermore, the PAES signal originates almost exclusively from the topmost atomic layer since the positrons are trapped in an image correlation well just outside the surface. Several works using a position sensitive or single slit energy analyzer have demonstrated the feasibility of PAES [11-13]. However, the energy resolution of these systems is lower than conventional Auger electron spectroscopy since the resolution is limited by the energy analyzer.

Recently, we have developed a PAES system which measures the energy of electrons by means of a TOF technique with the pulsed positron beam [9]. Figure 4 shows an example of PAES spectra from highly oriented pyrolytic graphite (HOPG). A significant peak at around 250 eV, corresponding to the Auger peak of carbon was observed in the spectrum of Figure 4. This measurement is preliminary, nevertheless, the resolution of the carbon Auger peak is significantly higher than that of previously reported Auger peak of the PAES experiment [13].

D. Positronium Time-of-Flight Measurement

Several experimental and theoretical results have shown that energy analysis of positronium emitted from solid surfaces gives valuable information on surface properties [14-15]. We have developed a Ps-TOF measurement system by using the pulsed positron beam [9].

Figure 5 shows the experimental set-up of the Ps-

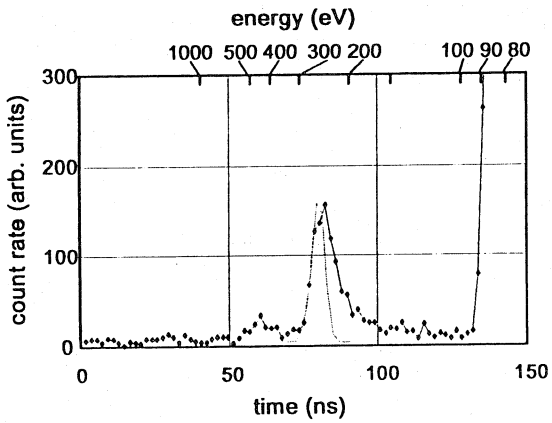

Figure. 4. TOF-PAES spectrum of HOPG.

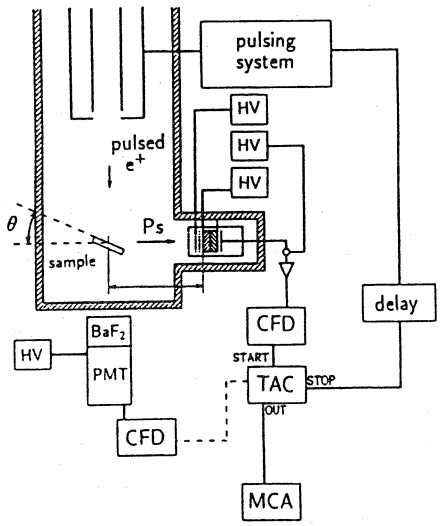

Figure. 5. Schematics of the Ps-TOF system.

TOF system. Positronium atoms are detected by a micro-channel-plate (MCP) detector of single anode type. TOF spectra are obtained by measuring the time interval between the signal of MCP detector and that of the pulsing system.

The present count rate of both the Ps-TOF system and TOF-PAES system is insufficient for high statistic measurements. One reason for this is that the pulsing efficiency of the present system, which is optimized for lifetime measurements but not for TOF measurement, is low (a few %). Therefore, if we construct an optimized pulsing system for TOF experiments, the pulsing efficiency will increase by about one order of magnitude.

IV. Conclusions

A slow positron pulsing system and application examples of the pulsed positron beam were described. By the use of the pulsed positron beam, it has become possible to carry out variable-energy positron lifetime spectroscopy, age-momentum correlation spectroscopy, TOF-PAES, and Ps-TOF measurements.

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VI. References

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