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A MULTI-PARAMETER ACQUISITION SYSTEM FOR POSITRON ANNIHILATION LIFETIME SPECTROMETER

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ABSTRACT

A positron annihilation lifetime spectrometer employing a multi-parameter acquisition system has been prepared for various purposes such as the investigation and characterization of solid-state materials. The fast-fast coincidence technique was used in the present spectrometer with a pair of plastic scintillation detectors. The acquisition system is based on the Kmax software and on CAMAC modules. The data are acquired in event-by-event list mode. The time spectrum for the desired energy windows can be obtained by off-line data sorting and analysis. The spectrometer for event-by-event data acquisition is an important step to construct a positron age-momentum correlation (AMOC) spectrometer. The AMOC technique is especially suited for the observation of positron transitions between different states during their lifetime. The system performance was tested and the results were presented and discussed.

Keywords: Positron Lifetime Spectrometer, List Mode, CAMAC

INTRODUCTION

A positron that has been injected into a material under study and has slowed down, in most cases annihilates with the emission of 2 or 3 γ rays. In the case of free positrons the cross-section for emission of 3 γ is only 1/379 of that of 2 γ cross-section. The measurements of properties of these γ rays; such as their energies, emission directions and time of emission which can all be measured; provide useful information about the material in which the positron annihilates. Hence, information of electron density and electron momentum (characteristic of the annihilation site) can be obtained.

Positron annihilation spectroscopy (PAS) was originally used to study the electronic structure and defects in solids. In connection with this, the physics of positron annihilation in condensed matter has been extensively developed. In general, the PAS has been applied to a wide variety of materials during the last decades [1-8].

The three experimental techniques used in PAS are the lifetime, angular correlation and the Doppler broadening. They are all based on nuclear spectroscopy.

Positron annihilation lifetime (PAL) spectroscopy is widely used for the investigation and characterization of different types of materials. Different positron states can be extracted from the timing spectrum. These states correlated to, for example, structural defects in material. Furthermore, the presence of phase transitions can be conveniently observed by monitoring the positron parameters (lifetime and intensity) as a function of the temperature. The PAL is measured as a time difference between two photons. The birth of the positron is marked by the emission of a γ ray from the daughter nucleus of the positron emitter (usually ^{22}Na), and the annihilation is revealed by the annihilation γ rays. The conventional measuring system for PAL is a fast coincidence spectrometer which consists of two scintillation detectors, two timing discriminators, a time-to-amplitude converter (TAC) and a multichannel analyzer (MCA). In some systems, a fast-fast coincidence technique is used by adding a fast coincidence unit for improving the time resolution. One of the detector-discriminator combinations (start) is set to detect the 1274.5 keV γ ray of ^{22}Na and the other (stop) is set to detect one of the annihilation γ rays.

Many efforts have been devoted to the improvement of the PAL spectrometer [9, 10]. Spectrometers having a time resolution (FWHM) from $\approx$ 300 ps down to $\approx$ 200 ps are commonly used nowadays. Also, PAL spectrometers using a fast digital oscilloscope and/or BaF_2 scintillation detectors have been constructed (see e.g. [11]). The time resolution of these spectrometers is < 200 ps FWHM. Recently, a multi-parameter acquisition system is used in some spectrometers to acquire data in event-by-event list mode. This acquiring system is convenient because it allows the correlation of the acquired data.

A PAL spectrometer employing a fast-fast coincidence technique has been constructed at Physics and Chemistry Department, Faculty of Education, Tanta University [12]. In this spectrometer, the data were acquired in histogramming mode using a MCA. The objective of this work is to prepare a multi-parameter acquisition system for event-by-event data acquisition. The details of the PAL spectrometer employing the multi-parameter acquisition system and the results of performance tests were presented. Also, this acquiring system will be used for constructing an AMOC spectrometer to measure the lifetime spectra of positrons as a function of an energy distribution of the annihilation γ rays.

EXPERIMENTAL TECHNIQUE

Positron Lifetime Spectrometer

A schematic diagram of the PAL spectrometer employing the multi-parameter acquisition system is shown in Fig. 1. This spectrometer consists of two Bicron

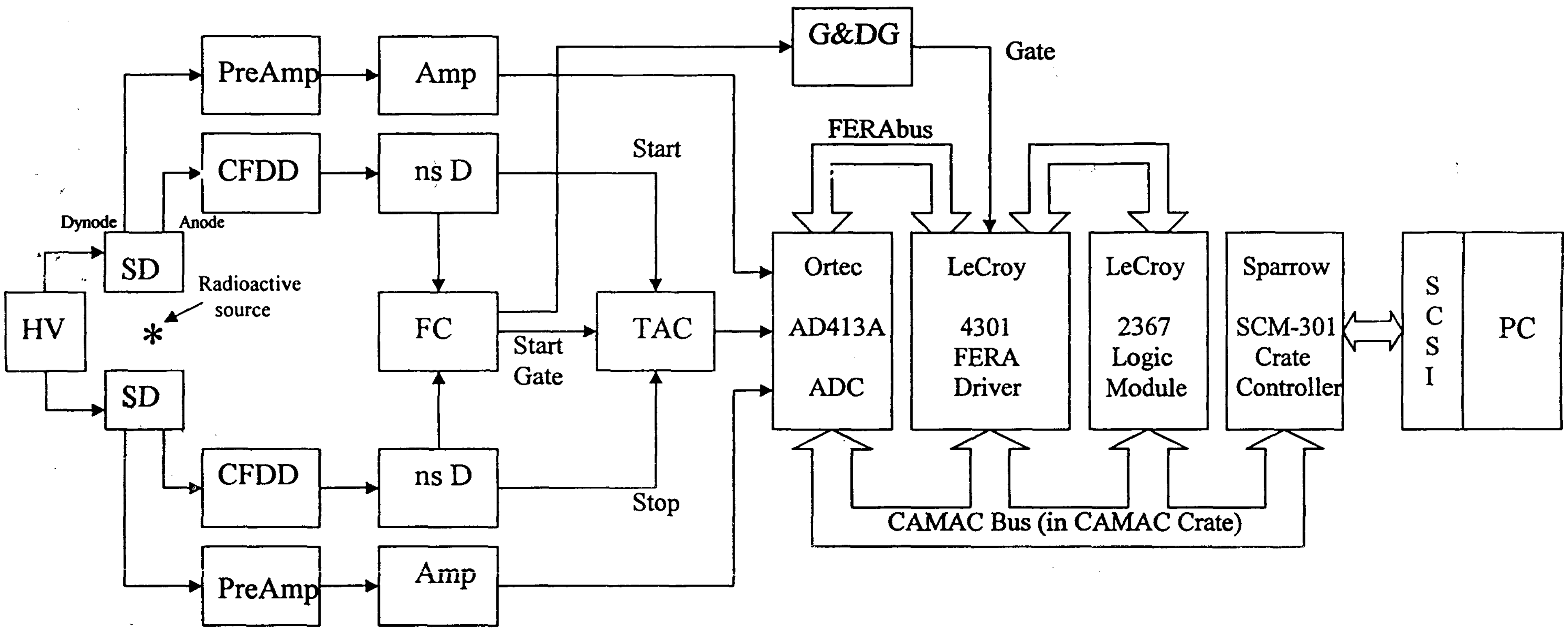

Fig. 1. A schematic diagram of the PAL multi-parameter spectrometer. HV: high voltage power supply, SD: scintillation detector, CFDD: constant fraction differential discriminator, ns D: nanosecond delay, FC: fast coincidence, TAC: time-to-amplitude converter, PreAmp: scintillation preamplifier, Amp: amplifier, G&DG: gate and delay generator, ADC: analog-to-digital converter, FERA: fast encoding and readout ADC, SCSI: small computer system interface.

BC–418 plastic scintillation detectors and NIM modules. The output signals from the photomultiplier (PM) anodes are processed by two Ortec 583 constant fraction differential discriminators, Ortec DB463 delay box, Ortec 414A fast coincidence and Ortec 566 TAC for time spectrum measurements. The signals of the PM dynodes are fed two scintillation preamplifiers (Ortec 113) followed by two amplifiers (Ortec 575A) for energy spectrum measurements.

Our PC-based acquisition system is based on the Kmax software [13] and on CAMAC modules with FERAbus capability, which allows fast downloading of the data from the ADCs. The FAST-CAMAC multi-parameter acquisition system considers a good choice due to its flexibility. This system includes Ortec AD413A CAMAC Quad 8k ADC, LeCroy CAMAC 4301 fast encoding and readout ADC (FERA) system driver and LeCroy 2367 FASTCAMAC universal logic module. The Sparrow SCM-301 crate controller is used to interface a CAMAC minicrate (Sparrow 1000) to the Pentium III 600 MHz PC. The small computer system interface (SCSI) cable is used to connect the SCM-301 crate controller to the SCSI connection that is located on the back of the PC. The Ortec 416A gate and delay generator is used to have the proper negative NIM gate signal that goes from the 414A fast coincidence to the 4301 FERA driver (see Fig. 1). The Kmax version 7.0 software was used to configure and operate data acquisition and process control acquisition system. The Kmax provides high-level features for data display and analysis.

Performance Measurements

In order to check the performance of the PAL spectrometer employing the multi-parameter acquisition system, the time resolution of the spectrometer was measured using ^{60}Co at ^{22}Na energy window settings. First, the energy spectra of both scintillation detectors have been measured using the ^{22}Na source to set the energy windows. Then, the energy and time spectra were measured using the ^{60}Co source. In these measurements, the 583 CFDDs were operated as an integral discriminators. The energy spectra of both start and stop detectors were acquired in event-by-event mode through channels 1 and 2 of the ADC, respectively (see Fig. 1). The ADC channel number 3 was used for acquiring the time spectrum in the same mode. The TAC was calibrated using the Ortec 462 time calibrator. The acquired event-by-event data were sorted and then data histogramming are performed with the National Instruments Laboratory Virtual Instrument Engineering Workbench (LabVIEW) version 6i software. The LabVIEW program (virtual instruments, VI) is prepared for this purpose. The event data was saved to a file in text format to process the data by the LabVIEW software.

RESULTS AND DISCUSSION

Figure 2 shows a time spectrum that was obtained from the output of the Ortec 462 time calibrator. The conversion factor of 6.85 ps/channel is obtained by linear regression of the peaks position of the previous time spectra.

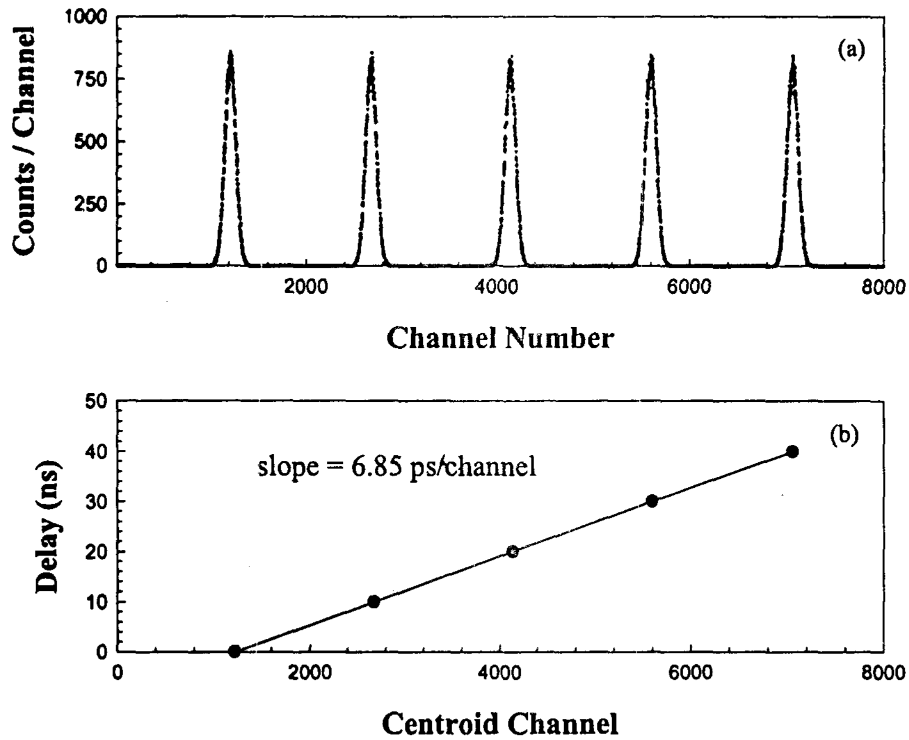

Fig. 2. (a) A typical time spectrum of the time calibrator measured using 8K ADC. (b) The calibration time/channel curve of the Ortec 566 TAC is also shown.

Table 1 shows a part of the event data file saved in text format (left-side column). On the right-side column of the Table 1, some comments are given about the structure of the data file. The file starts with the block header followed by information about the event type, event size and the number of events in each block of data. This would be then followed by the events. There are always four data words to be read from the AD413A ADC for each event. The contents of the first, second, third and forth channels of the ADC are separated by one space. The channel number 4 of the ADC had no input signals in this case, therefore, it reported zero.

The time spectra with different energy window settings can be obtained from only one measurement by employing the multi-parameter acquisition system. Asan example, the time spectra at different energy window settings (15, 20, and 30 %) for both start and stop channels are shown in Fig. 2. The time resolution (FWHM) of the

Table 1. A part of the event data file saved in text format.

Event Data File	Comments
Kmax Event File - Text Format	Block header
4 4 2048	Event type, size and number of events in the block
904 1131 2150 0	Event number 1
3360 2463 2199 0	Event number 2
4415 1357 2253 0	.
2297 822 2248 0	.
2469 574 2218 0	.

spectrometer shows the improvements of ≈ 10% in time resolution by decreasing the energy windows from 30 to 15%. On the other hand, the coincidence count decreased by a factor of about three. All these spectra were obtained by the off-line analysis of the event data file. The PAL spectrometer with event-by-event data acquisition showed somewhat better time resolution than that of the spectrometer with histogramming-mode data acquisition. This is mainly due to the fact that setting the energy windows in the software allows an exact selection of the events with certain energy range while in the case of doing this in the hardware, using the CFDD, the window limits are not a sharp cut.

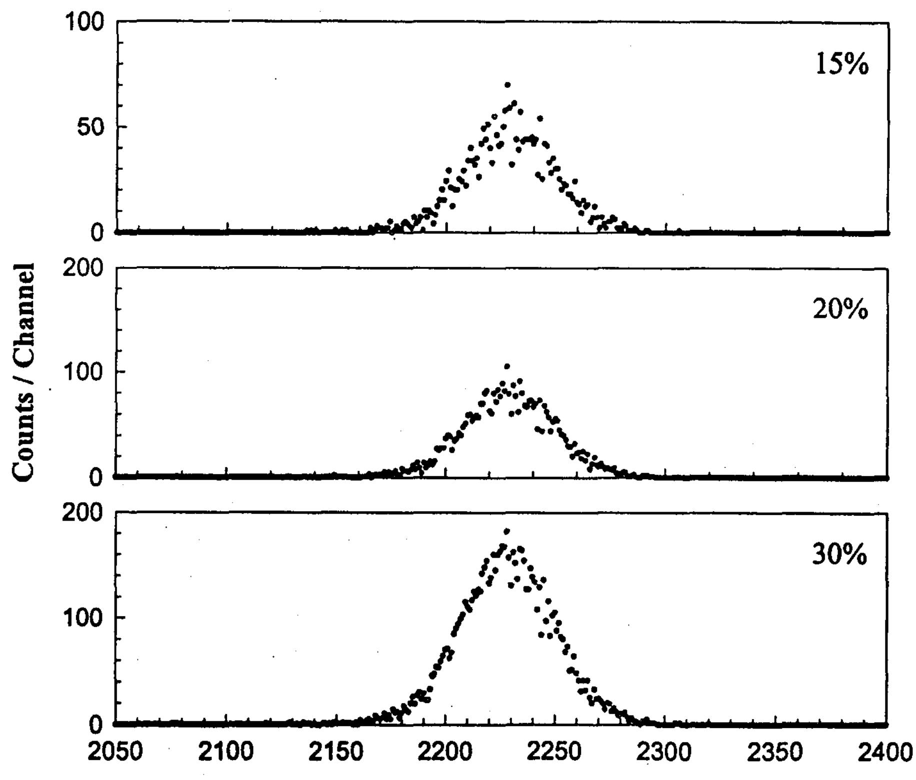

Fig. 3. A time spectra measured using ^{60}Co source at 15, 20 and 30% ^{22}Na energy windows of start (1274.5 keV) and stop (511 keV) γ rays.

The construction of the AMOC multi-parameter spectrometer to measure the lifetime spectra of positrons as a function of an energy distribution of the annihilation γ rays is now in progress. In this spectrometer, the lifetime of the positrons will be measured using the prepared PAL multi-parameter spectrometer. The energy distribution of the annihilation γ rays will be measured by a HPGe detector.

CONCLUSION

The positron annihilation lifetime multi-parameter spectrometer has been prepared for several purposes such as determination of the electron density in various materials. The spectrometer was found to work satisfactorily with a possibility to increase the acquired parameters such as Doppler broadening of the annihilation γ rays and temperature. This can be done through increasing the input channels of the ADC by using the available LRS 2249A 12-channel ADC.

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REFERENCES

[1] Schrader, D.M. and Jean, Y.C., *Positron and Positronium Chemistry*, Amsterdam: Elsevier, 1988.

[2] Hautojärvi, P., and Corbel, C., "Positron spectroscopy of Defects in Metals and Semiconductors", in *Proceeding of the International School of Physics*, Varenna, Italy, July 6-16, 1993, pp 491–532.

[3] Eldrup, M., *Journal de Physique IV* **5**, C1-93–C1-109 (1995).

[4] Jean, Y.C., "Characterizing Free Volumes and Holes in Polymers by Positron Annihilation Spectroscopy", in *Proceeding of the International School of Physics*, Varenna, Italy, July 6-16, 1993, pp 563–580.

[5] Hautojärvi, P. and Vehanen, A., in: *Positrons in Solids*, Berlin: Springer, 1979.

[6] Urban, J.M., Quarles, C.A. and Salaita, G.N., *Acta Physica Polonica A* **88**, 241–248 (1995).

[7] Dupasquier, A. and Mills Jr.A.P. (Eds.), *Positron Spectroscopy of Solids*, Amsterdam: IOS press, 1995.

[8] Krause-Rehberg, R. and Leipner, H.S., *Positron Annihilation in Semiconductor*, Heidelberg: Springer, 1999.

[9] Bečvář, F., Čížek, J., Lešták, L., Novotný, I., Procházka, I. and Šebesta, F., *Nucl. Instr. and Meth. A* **443**, 557–577 (2000).

[10] Moszyński, M., *Nucl. Instr. and Meth. A* **337**, 154–164 (1993).

[11] Saito, H., Nagashima, Y., Kurihara, T. and Hyodo, T., *Nucl. Instr. and Meth. A* **487**, 612–617 (2002).
[12] T. Sharshar and K.R. Mahmoud, to be published.
[13] See http://sparrowcorp.com.