Applied Surface Science 255 (2008) 111–114

Contents lists available at ScienceDirect

Applied Surface Science

journal homepage: www.elsevier.com/locate/apsusc

High-resolution positron lifetime measurement using ultra fast digitizers Acqiris DC211

F. Bečvář, J. Čížek *, I. Procházka

Faculty of Mathematics and Physics, Charles University in Prague, V Holešovičkách 2, CZ-180 00 Praha 8, Czech Republic

ARTICLE INFO

Article history:
Available online 15 May 2008

Keywords:
Positron lifetime spectroscopy
Ultra fast digitizer

ABSTRACT

This work demonstrates that a significant improvement of the timing resolution, simultaneously keeping coincidence count rate high enough, can be achieved by use of the state-of-the-art ultra fast 8-bit digitizers which replace the traditional analog timing modules. Performance of the digital spectrometer in conditions of a routine measurement is compared with that of the same detectors connected to the analog setup. It was found that employment of the digital setup leads to an improvement of timing resolution from 169 ps for the traditional analog setup down to 146 ps for the digital setup.

1. Introduction

Time resolution power is one of the most important parameters of any positron lifetime (PL) spectrometer. The timing information from detector pulses is derived by analog NIM units, i.e. constant fraction (CF) discriminators and time-to-amplitude converter. In the fast–fast setup, constant fraction differential discriminators (CFDD's) are used also for pulse height selection. The analog timing introduces uncertainties into CF timing and amplitude selection. Moreover, random pile-up effects which cause distortions of PL spectra cannot be completely eliminated by the analog timing. Recent development in the sampling rate of 8-bit ultra fast digitizers opened a new possibility for timing in PL spectroscopy. The detector pulses can be directly sampled by (i.e. digitized) by a digitizer which replaces all the analog timing electronics. The digitized pulses are stored in computer and analyzed off-line. This new digital approach has several undisputable advantages compared to the traditional analog setup: (i) all detector signals are directly accessible for the analysis, i.e. the amount of information is much higher, (ii) the timing analysis can be repeated many times and one can find the optimal strategy how to derive the timing information and to eliminate the distorted pulses, and (iii) time consuming adjustment of the analog NIM devices is not necessary anymore.

However, it is not clear yet whether the digital setup provides better timing resolution power then the traditional analog setup. Saito et al. [1] achieved excellent timing resolution of 144 ps by employing fast digital oscilloscope with sampling rate 4 GS/s. However, the same timing resolution was obtained with traditional analog setup [2]. Digital PL spectrometer equipped with ultra fast digitizers was described in Ref. [3]. The authors achieve moderate timing resolution of ≈200 ps and reported no improvement in timing resolution compared to the analog setup. On the other hand, testing measurements with ultra fast digitizer connected to detectors of the spectrometer described in Ref. [2] demonstrated an improved timing resolution [4].

The power of digital and analog timing was compared in this work. Detectors equipped with BaF_2 scintillators were connected to (i) ultra fast digitizers and (ii) traditional analog setup. Performance of PL spectrometer in the two configurations (i) and (ii) was compared.

2. Experimental details

Schematic diagram of PL spectrometer in the configuration (i) and (ii) is shown in Fig. 1. The detectors consist of Hamamatsu H3378 photomultipliers optically coupled with truncated cone (∅ 18–36 mm, thickness 12 mm) BaF_2 scintillators. The detector pulses were taken from the anode using a standard high voltage divider supplied by the producer.

In the digital setup, the output detector pulses were divided into two parts by impedance balanced passive splitters. The larger parts of signals were lead to input channels of two ultra fast 8-bit digitizers Acqiris DC 211 with the sampling rate 4 GS/s. The

* Corresponding author at: Department of Low-Temperature Physics, Faculty of Mathematics and Physics, Charles University, V Holešovičkách 2, CZ-180 00 Praha 8, Czech Republic. Tel.: +420 2 2191 2788; fax: +420 2 2191 2567.
E-mail address: jakub.cizek@mff.cuni.cz (J. Čížek).

0169-4332/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.apsusc.2008.05.184

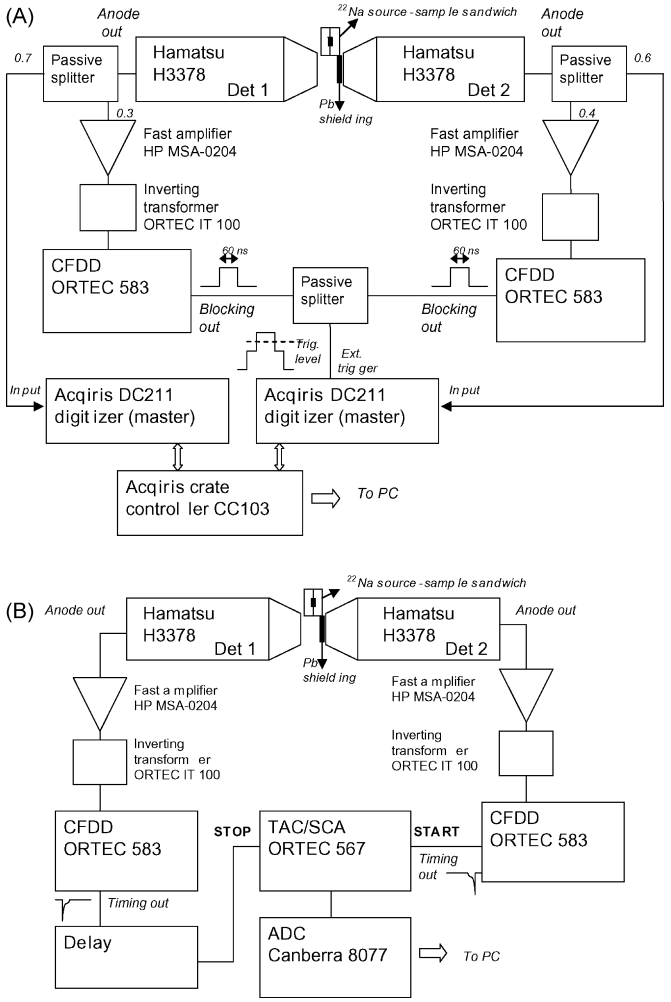

Fig. 1. A schematic diagram of (A) digital setup, and (B) traditional fast–fast analog setup.

digitizers shared a common crystal controlled time base. The smaller fractions of signals were amplified by a single chip-inverting amplifier HP MSA-0204 to feed CFDD's Ortec 583. The rectangular blocking out signals with duration of ≈60 ns produced by CFDD's were passively mixed to form an input signal for triggering the digitizers. The discrimination level was adjusted so that *only coinciding* detector signals are processed. Further restriction is imposed by adjusting the lower level of CFDD's pulse height window to a level corresponding to γ-ray energy of ≈380 keV. Contrary to the analog setup, CFDD's are not used for timing. Their purpose is to ensure that only coincidence events are digitized while uninteresting single track events are filtered out.

Each acquired waveform was formed by 300 sample points with spacing of 250 ps covering thus a time interval of 75 ns. The waveforms were subsequently analyzed off-line by software developed by us [5]. The timing information was derived by *true* CF method at a level of 7% applied to integrated waveforms. A detailed description of the CF method with integrated waveforms can be found in Ref. [5]. The shape of the integrated waveforms was controlled by digital filters [5] which excluded distorted signals. The software analysis was performed in two modes (i) "stop–start" (det 1 is "stop detector" and det 2 "start detector"), and (ii) "start–stop" mode, where the roles of detectors were reversed. Application of these two modes doubles the count rate.

A conventional fast–fast configuration was used in the analog timing setup. The CFDD's were fed by detector signals amplified by the single chip amplifiers, i.e. no signal splitting was applied in this setup.

Testing measurements were performed on a well-annealed α-Fe sample using ^{22}Na positron sources with activity of 1.2 and 2.5 MBq sealed between two 2 μm thick mylar foils.

3. Results and discussion

Results of testing measurements are summarized in Table 1. Fig. 2 shows a fit of the spectrum obtained in run #A1-a-i. The reference α-Fe exhibits a free positron component with lifetime τ_1 = 107 ps which agrees well the bulk Fe lifetime reported in the literature [6]. Two additional weak components with lifetimes τ_2 and τ_3 come from positron annihilations inside the positron source itself and in the covering mylar foils. The lifetimes and intensities obtained in the "stop–start" and the "start–stop" mode are practically identical. Virtually the same lifetimes and intensities were obtained also in the analog setup measurement with 1.2 MBq source (run #B1).

The resolution function for the digital setup is well described by two Gaussians, see Table 1. The timing resolution achieved in the "stop–start" and the "start–stop" mode, respectively, is 147 and 145 ps. The "start–stop" mode exhibits slightly better timing resolution because the two Gaussians are closer to each other.

The widths of the two main Gaussians and their separation for the analog setup are larger than in the digital setup. In addition, a weak and broad third Gaussian, which accounts for pile-up effects, must be added to describe well the resolution function. The timing resolution in the analog setup is 169 ps. Thus, the timing resolution achieved in the digital setup is about of 23 ps better than in the corresponding analog configuration. It clearly demonstrates that digital timing does improve timing resolution.

The count rate with 1.2 MBq source was 940 s^{-1} (including storage into PC hard disk). It testifies a high throughput of the digitizers. The fraction of waveforms which felt into the imposed energy windows and passed through the digital filters lies around 4% in each mode. Thus, the total fraction of processed waveforms is 8%. It corresponds to the effective count rate of ≈80 s^{-1}, which is comparable with the analog setup.

Although this count rate is sufficient for most applications, in cases when a high count rate is of primary importance, one has two straight options how to increase it: (i) slight expansion of the digital filters (i.e. the shape requirements imposed onto the pulses are not so strict), or (ii) use of a source with higher activity.

The run #A1-b was processed with the filters expanded by a factor of 1.3. One can see in Table 1 that the lifetimes and intensities obtained with the expanded filters and virtually the same as in the case of the standard processing procedure. The expanded filters increased the effective count rate by a factor of ≈1.5. The cost for it is a slight worsening (2–3 ps) of timing resolution.

The performance of the spectrometer was tested further with a stronger source of doubled activity (2.5 MBq). The higher activity increases not only the number of coincidences, but also the number of random pile-ups. Thus, measurement with the stronger source tests the efficiency of digital filters in recognizing and rejecting the waveforms damaged by pile-ups. The digital timing measurement (run #A2) with stronger source gives virtually the same lifetime for the reference α-Fe as that measured with standard source. The source component intensities are higher because they depend on the source preparation procedure [2]. Thus, we can conclude that the digital filters work well also with the stronger source. Timing resolution becomes slightly (1–2 ps) worse when the stronger source is used, but the count rate is doubled.

Table 1
Summary of the results of the testing measurements

Quantity	Digital setup					Analog setup	
Run-id	#A1-a-r	#A1-a-i	#A1-a	#A1-b	#A2	#B1	#B2
Mode	Stop–start	Start–stop	Averaged			–	
Parameters of measurement							
^{22}Na source activity (MBq)			1.2		2.5	1.2	2.5
Count rate (s^{-1})			940		2040	70	139
Accumulated coincidences			200×10^6		148×10^6	10×10^6	9×10^6
Accepted coincidences (%)	4.0	4.2	8.2	12.8	7.6	100	100
Effective count rate (s^{-1})	38	40	78	120	155	75	129
Expansion factor	1.0	1.0	1.0	1.3	1.0	–	–
Energy windows							
Stop energy window (keV)			460–590			≈450–600[a]	
Start energy window (keV)			1080–1550			≈1100–1600[a]	
Lifetimes and intensities							
τ_1 (ps)	106.9 (3)	107.0 (3)	107.0 (2)	107.0 (2)	107.1 (2)	107.0 (3)	105.0 (5)
α-Fe sample							
τ_2 (ps)—source	358 (6)	371 (5)	365 (4)	365 (4)	369 (2)	370 (5)	369 (3)
τ_3 (ns)—source	1.20 (4)	1.38 (5)	1.29 (5)	1.28 (2)	1.89 (2)	1.35 (3)	1.93 (2)
I_2 (%)	8.5 (1)	8.4 (1)	8.45 (7)	8.45 (7)	9.5 (5)	8.7 (2)	9.6 (7)
I_3 (%)	1.31 (8)	1.15 (5)	1.23 (5)	1.24 (4)	1.70 (4)	1.24 (4)	1.68 (8)
Resolution function							
w_1 (ps)	137.2 (7)	137 (1)	137.2 (7) 137 (1)	141.3 (6) 139.2 (8)	138 (1) 138 (1)	151.3 (3)	155.1 (6)
w_2 (ps)	155 (1)	153 (1)	155 (1) 153 (1)	159 (1) 155.4 (9)	160 (2) 154 (1)	187 (1)	188.5 (9)
δ_{12} (ps)	21 (1)	12 (1)	21 (1) 12 (1)	20 (1) 9 (1)	17 (2) 5 (2)	28 (1)	30 (1)
w_3 (ps)	–	–	–	–	–	600 (30)	520 (30)
I_{g3} (%)	–	–	–	–	–	1.5 (1)	4.9 (4)
w (ps)	**147 (1)**	**145 (1)**	**147 (1)/145 (1)**	**151 (1)/147 (1)**	**149 (1)/145 (1)**	**169 (1)**	**172 (1)**
Quality of fit							
χ^2/ν	1.02 (2)	1.00 (2)	1.01 (2)	1.01 (2)	1.03 (2)	1.07 (2)	1.12 (2)

The "stop–start" and the "start–stop" mode results for the run #A1-a are compared in the second and third column. The next columns show averaged results obtained in both modes. Meaning of the symbols: τ_1—lifetime of the α-Fe specimen, $\tau_{2,3}$, $I_{2,3}$—lifetimes and intensities of the source contributions. Parameters of the resolution function in the averaged mode are given first for the "stop–start" mode followed by those for the "start–stop" mode; w_1, w_2, δ_{12}—FWHM's and separation of the first and the second Gaussian, the weight of the Gaussians was fixed at the ratio $I_{g1}/(I_{g1} + I_{g2}) = 0.5$. In the analog setup, the resolution function contains an additional weak and broad Gaussian with FWHM w_3 and normalized intensity I_{g3}; w is the total FWHM of the resolution function (i.e. timing resolution of the spectrometer); the χ^2 value reduced to number of degrees of freedom is shown in the last row.

[a] The energy windows in the analog setup were adjusted approximately at these energies using an oscilloscope.

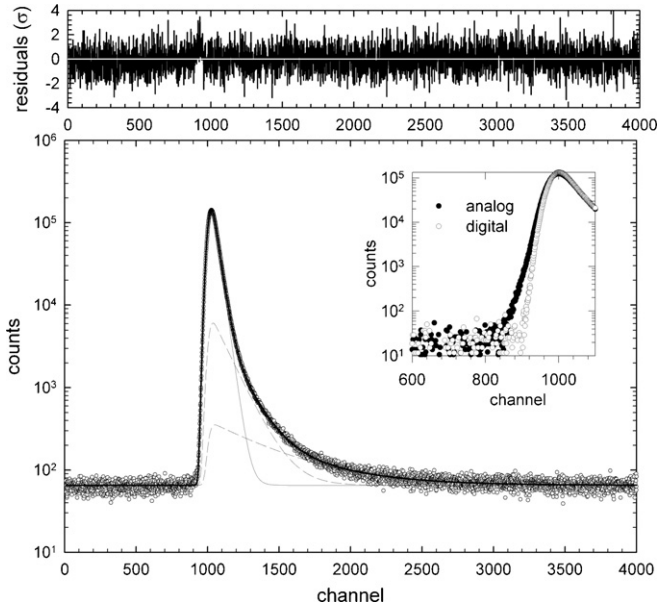

Fig. 2. The PL spectrum obtained from run #A1-a-i. The inset shows the impact of random pile-ups on the leading edge of PL spectra measured with a stronger positron source. The spectrum obtained with the digital setup (run #A2, stop–start regime) is plotted by open circles, while that measured with the analog setup (run #B2) is shown by full circles.

A testing measurement with the stronger source was performed also with the analog setup (run #B2). The impact of pile-ups on the PL spectrum can be directly seen in the inset in Fig. 2 as a tail foregoing the leading edge of the spectrum. The pile-up effects cause a shortening of the lifetime τ_1 and an increase of intensity I_{g3} of the wide Gaussian constituent of the resolution function.

4. Conclusions

Performance of digital PL spectrometer equipped with two ultra fast digitizers was compared with the traditional analog setup connected to the same detectors. The timing resolution of 146 ps was achieved in the digital setup. It was demonstrated that the digital spectrometer can be operated in the "stop–start" and "start–stop" mode which doubles the count rate at no cost. Digital timing results in ≈20 ps better timing resolution than analog timing performed under similar conditions, keeping the count rate comparable. Moreover, an additional increase in the count rate up to 150 s^{-1} accompanied only by a very slight decrease of timing resolution can be easily achieved with the digital spectrometer.

Acknowledgement

Financial support from The Ministry of Education, Youth and Sports of the Czech Republic (Project No. MS 0021620834) is highly acknowledged.

Reference

[1] H. Saito, Y. Nagashima, T. Kurihara, T. Hyodo, Nucl. Instrum. Methods A 487 (2002) 612.
[2] F. Bečvář, J. Čížek, L. Lešťák, I. Novotný, I. Procházka, F. Šebesta, Nucl. Instrum. Methods A 443 (2000) 557.
[3] J. Nissilä, K. Rytsölä, R. Aavikko, A. Laakso, K. Saarinen, P. Hautojärvi, Nucl. Instrum. Methods A 538 (2005) 778.
[4] F. Bečvář, J. Čížek, I. Procházka, J. Janotová, Nucl. Instrum. Methods A 539 (2005) 372.
[5] F. Bečvář, Nucl. Instrum. Methods B 261 (2007) 871.
[6] A. Seeger, F. Banhart, Phys. Status Solidi (a) 102 (1987) 171.