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Alpha energy resolution enhancement of a Si surface barrier detector

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Abstract In this work, alpha energy resolution of a Si surface barrier detector was improved. For this purpose, we used constant fraction timing method. Energy resolution enhancement of about 1 % was achieved for alpha peak of ^{210}Po. In order to prove the validity of the timing method, it was applied to the alpha spectrum of ^{226}Ra. It was concluded that proposed method was successful on the energy resolution improvement.

Keywords Si surface barrier detector · ^{210}Po · ^{226}Ra · Constant fraction timing method

Introduction

Semiconductor detectors are solid-state devices. They operate like ionization chambers, but the charge carriers in semiconductors are electrons and holes not electrons and ions as in the gas counters. Si and Ge are the most preferred materials for semiconductor detectors [1].

The most important parameter of the energy measurements is the energy resolution. The energy resolution is usually given in terms of the full width at half maximum of a peak (FWHM). ΔE is this width and the relative resolution at the energy E_0 can be defined as follows [2] (Fig. 1).

$$\text{Resolution} = \Delta E/E_0. \quad (1)$$

The energy resolution is usually expressed in percent [2].

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The measurement of the time relationship between two events is carried out by means of timing spectroscopy. A signal which is related to these events is accurately acquired in timing spectroscopy [3]. The FWHM is the figure of merit of a spectroscopy system [4].

Fast timing signals were obtained by using leading edge and constant fraction timing (CFT) methods from a Si surface barrier detector by Vogler et al. [5]. Geretschlager [6] carried out noise reduction measurement through timing method in a surface barrier detector. Pulse shape discrimination on a Si surface barrier detector was achieved through constant fraction discriminator and timing single analyzer by Li et al. [7]. Yalcın and Gurler [8] determined the mass attenuation coefficient of aluminum for beta particles by using Si surface barrier detector. The energy spectra of ^{210}Po, which were achieved by using both Si surface barrier detector and time of flight spectrometer (TOF), were compared by Cetiner et al. [9].

In this work, we obtained the alpha energy spectrum of ^{210}Po by using a Si surface barrier detector. Enhancement of its energy resolution value was achieved via CFT method. Positive effect of the timing method on the alpha peak was tested by applying it to the alpha spectrum of ^{226}Ra.

Experimental

First, the alpha energy spectrum of ^{210}Po was acquired by a Si semiconductor surface barrier detector. The energy resolution of the detector was calculated on the alpha peak of this spectrum. In order to obtain time spectrum of the source, then, CFT method which is one of the timing methods was used. Time resolution value of the detector was obtained from the time spectrum. Eventually,

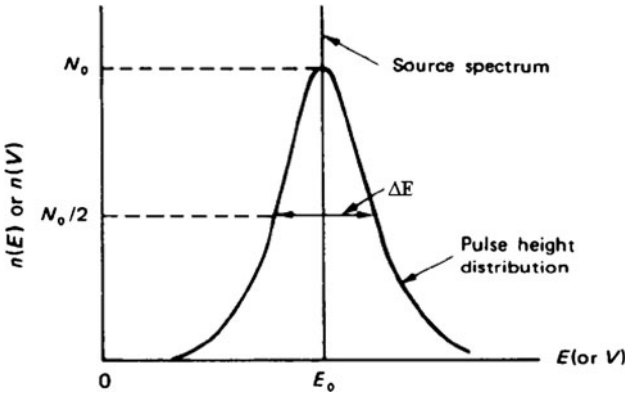


Fig. 1 Definition of the energy resolution [1]

coincident energy spectrum gated with the time spectrum was accumulated in a multichannel analyzer (MCA). Finally, we compared the obtained spectra without and with the timing method.

^{210}Po radioisotope emits 5.407 MeV-energy alpha particles. The radioisotope has half-life of 138.376 days [10]. A 0.1 μCi-activity point source was used in the measurements. The used Si surface barrier detector (Ortec, model no: CA-18-50-100) has an active area of 50 mm^2 and 100 μm thickness. Data acquisition time of 900 s was chosen for all measurements. The measurements were carried out at a constant room temperature (20 °C) to stabilize the detector noise. During the measurements, the used detector was placed into a vacuum chamber because the range of alpha particles is very small in the air. The vacuum level is about 500 μm during the data acquisition.

Used experimental setup is given in Fig. 2.

The output of the detector was connected to a preamplifier (PA, Ortec 142). Its energy output was sent to a delay line amplifier (DLA, Ortec 460). Its bipolar output was connected to the input of a multichannel analyzer (MCA, Ortec Trump 8K), through a delay amplifier (DA, Ortec 427A). Thus, energy spectrum of the used isotope was obtained. Time output of the PA was split into two branches. Each branch was forwarded to two constant fraction discriminators (CFD, Ortec 463). While one of these branches was directly connected to the start input of a time to amplitude converter (TAC, Ortec 566), the other branch was sent to the stop input of the TAC via a delay unit (D, Ortec 425A) in order to generate a time difference between start and stop inputs of the TAC. Time interval between the two pulses is transformed into a voltage pulse whose amplitude is converted from 0 to 10 V by the TAC [1]. Time spectrum was obtained by connecting the TAC output to the MCA input. Then, the energy signals from the delay unit and the time signals from the TAC were forwarded to the MCA. Eventually, energy resolution

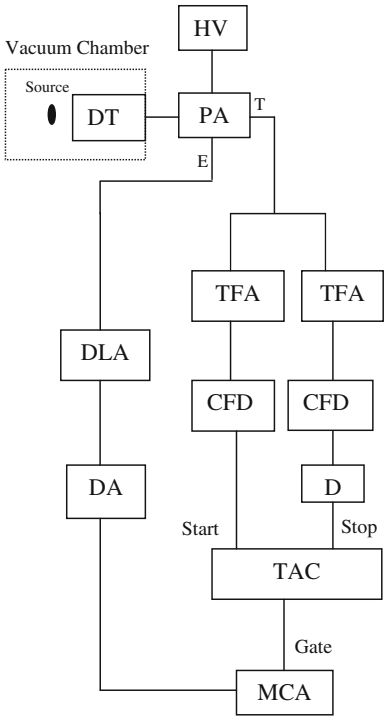


Fig. 2 Block diagram of the used spectrometer

improvement of the detector was achieved through this coincidence connection.

In Figs. 3, 4, the output signal shapes of the DLA, TFA, CFD, and TAC are shown.

The peaking time is the required time for the shaped pulse to reach its maximum amplitude [11]. Sixty-one percent of the peak value is called as shaping time. The peaking time is about 3–5 times greater than the shaping time (Fig. 5) [12].

In the present work, shaping and peaking times were found as 30 and 90 ns, respectively, from Fig. 6. Peaking time was obtained three times greater than the shaping time as stated above.

In order to determine the time per channel of the MCA, the time calibration of the MCA was initially carried out before the calculation of the time resolution value. The time calibration graph was obtained as shown in Fig. 7 by plotting the channel number of the time spectrum peak versus various delay times. The inverse of the slope of this graph gives time per channel of the MCA as well. This value was calculated as 24.62 ± 0.19 ps.

We also investigated the dependence of the time resolution values to the various delay times. We found that the minimum time resolution which means the best resolution was obtained when the delay time was chosen as 13 ns as shown in Fig. 8. Therefore, the delay time was set to this value during the all measurements.

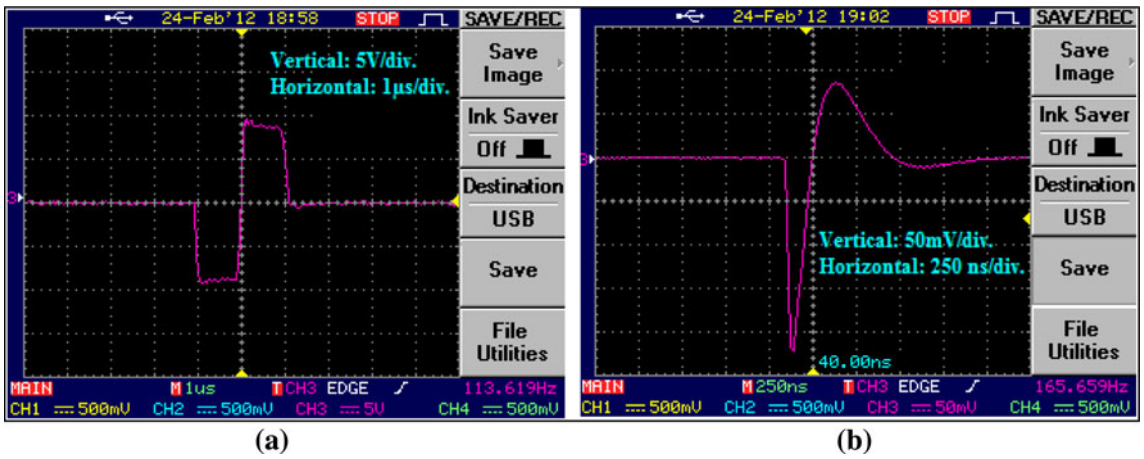


Fig. 3 Output signal shapes of: **a** DLA, **b** TFA

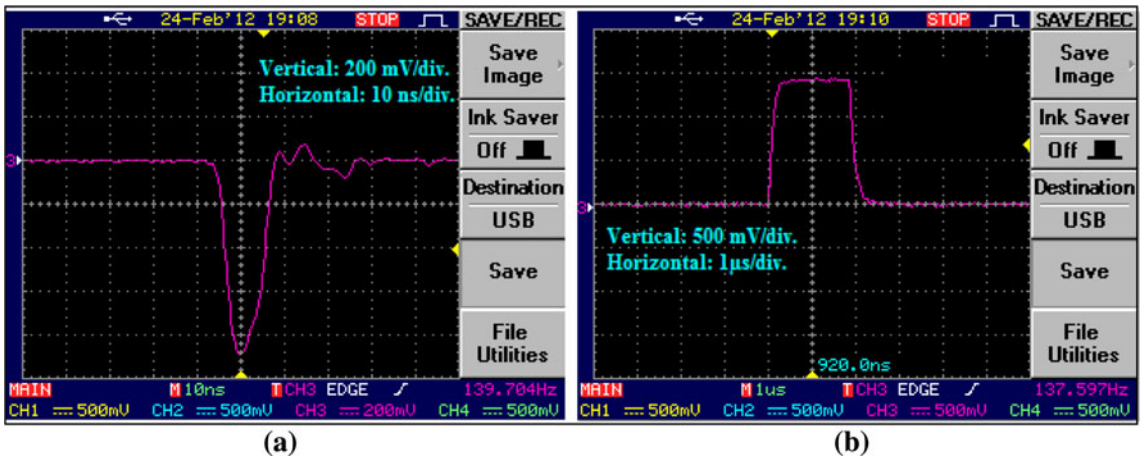


Fig. 4 Output signal shapes of: **a** CFD, **b** TAC

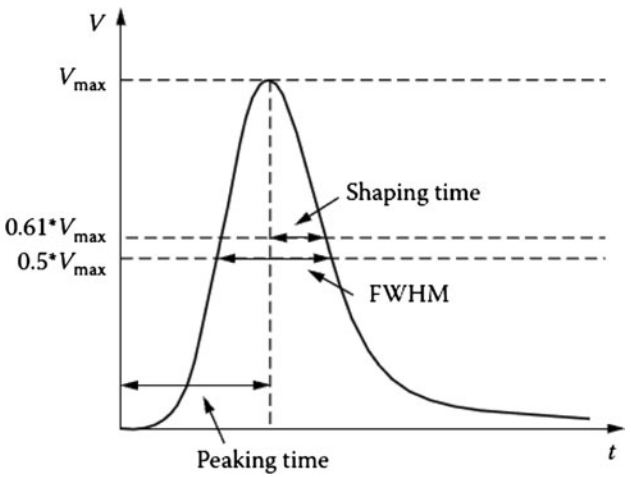


Fig. 5 Definitions of shaping and peaking times [12]

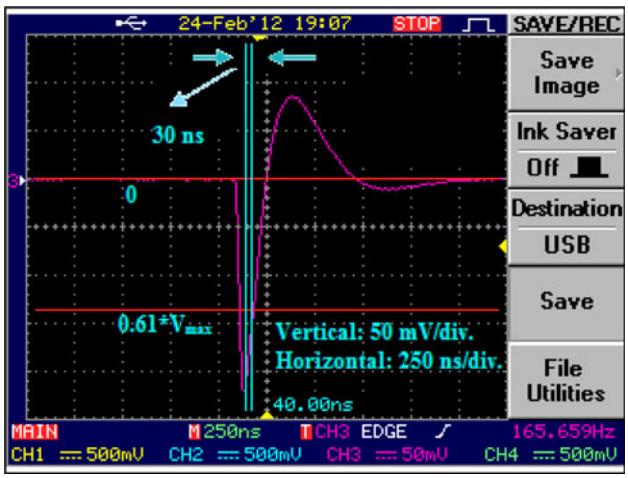


Fig. 6 Shaping time on the TFA output signal

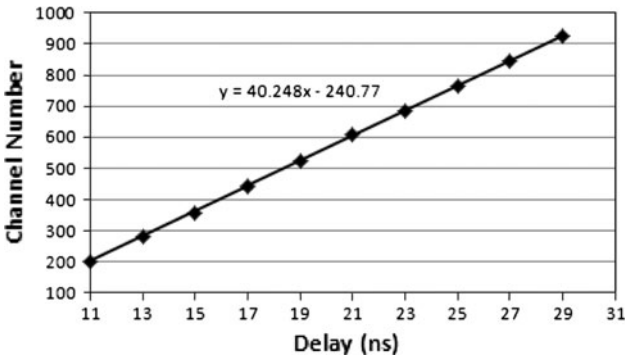


Fig. 7 Time calibration graph

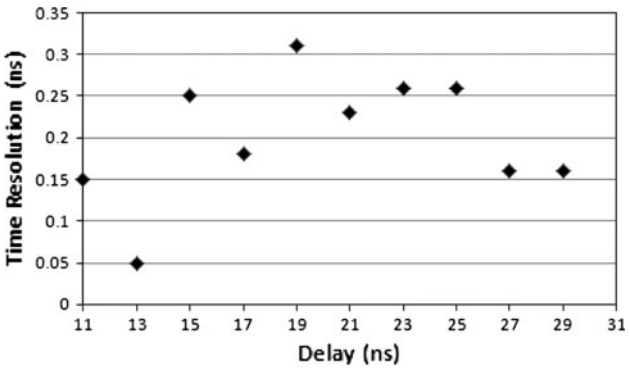


Fig. 8 Dependence of the time resolution to the delay time

In CFT method, the input signal (original signal) is firstly attenuated by a constant fraction (f) and delayed (T_d). Then, this signal is inverted. Finally, resulting signal and original signal is summed in order to produce a bipolar signal [13]. This method is shown as in Fig. 9.

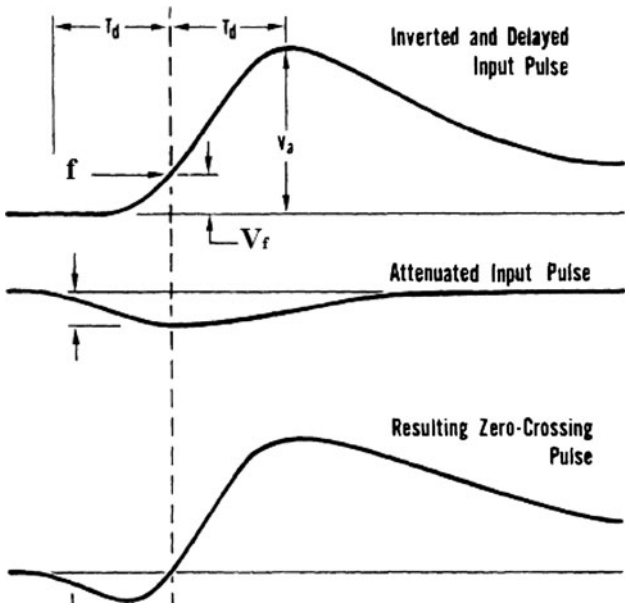


Fig. 9 Constant fraction timing method [14]

Results

Before timing application, the energy spectrum of ^{210}Po was acquired as shown in Fig. 10.

The obtained time spectrum via CFT method of the used isotope is given in Fig. 11.

Time per channel of the MCA was obtained as 24.41 ps from the time spectrum. This value was calculated as 24.62 ± 0.19 ps as stated above. These results are compatible with each other as expected. The time resolution value from the time spectrum was found as 160 ps. Similar time resolution calculation was carried out from the time calibration graph and time resolution value of 164.21 ± 1.26 ps was obtained.

Coincident energy spectrum with the timing application of the used isotope was obtained as shown in Fig. 12.

The energy resolution values before and after the timing application were found so as to be 1.66 and 1.55 %, respectively.

Comparison of the obtained energy spectra of ^{210}Po with and without timing process is given in Fig. 13.

Gross count rates under the alpha peaks of the isotope before and after the timing application were found as 133.33 and as 56.69 s^{-1} from Figs. 10, 12, respectively.

To check the validity of used timing method for ^{210}Po, this timing method was applied to alpha spectrum of ^{226}Ra. Figure 14 shows the spectra of ^{226}Ra acquired before and after timing process. Obtained energy spectrum of ^{226}Ra was compatible with the spectrum given in the literature [15].

Vertical and horizontal axes in the figures above correspond to counts and the number of channels, respectively.

Discussion and conclusion

The improvement of the energy resolution of the Si surface barrier detector was achieved of about 1 % for ^{210}Po by means of CFT method.

The energy spectrum of ^{210}Po was investigated by Cetiner et al. by means of Si surface barrier detector and TOF spectrometer. When compared the obtained energy spectrum of ^{210}Po with that of Cetiner et al. it is deduced that both spectra are compatible with each other.

Since time resolution value is quite effective parameter on the energy resolution improvement of the detector, we tried to have the best time resolution for maximum performance. Therefore, we investigated the effect of delay time on the time resolution value as stated in the previous section. Since the minimum time resolution value (i.e., the best time resolution) was obtained in delay time of 13 ns, all measurements were carried out by choosing this delay time.

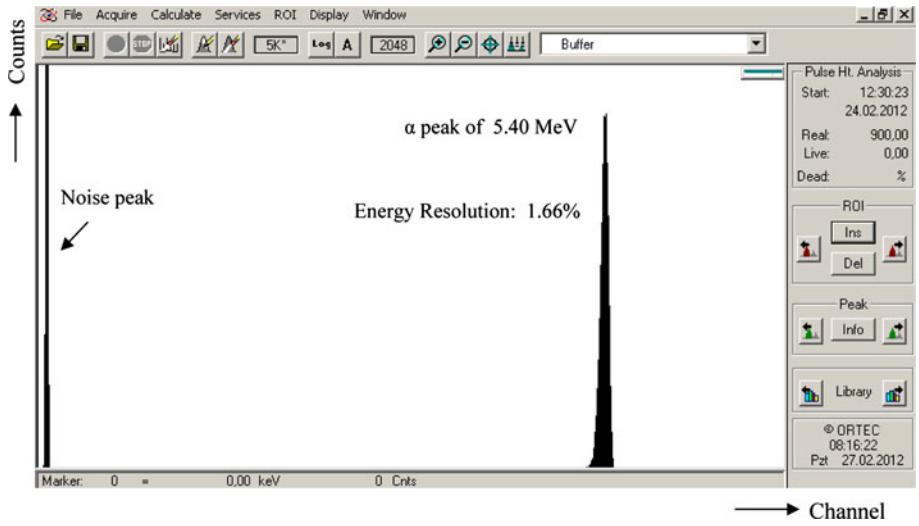


Fig. 10 The energy spectrum of ^{210}Po before timing process

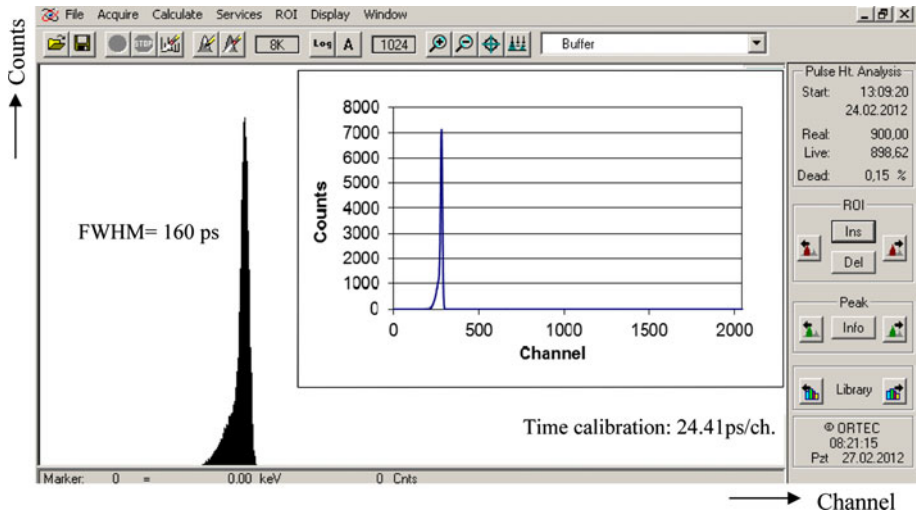


Fig. 11 The time spectrum of ^{210}Po

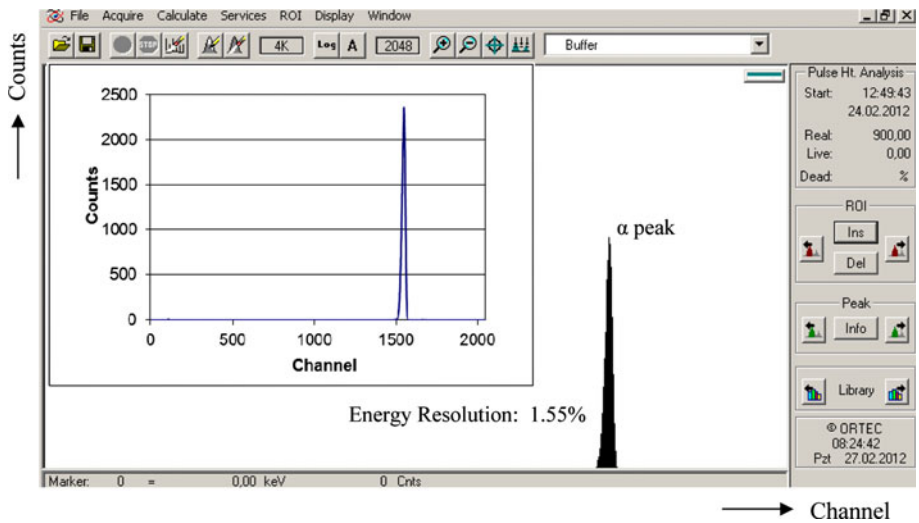


Fig. 12 Coincident energy spectrum of ^{210}Po through timing process

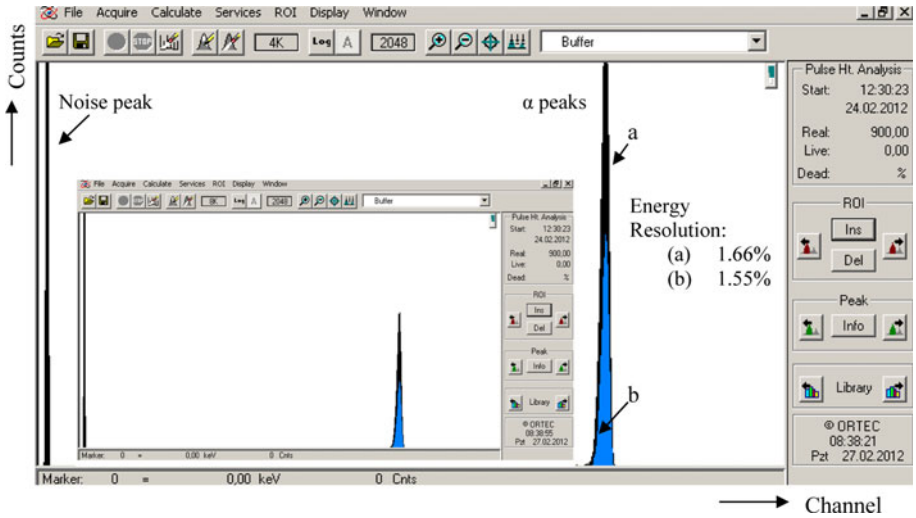


Fig. 13 Comparison of the energy spectra of ^{210}Po: (**a**) before (*black*), (**b**) after (*blue*) timing application. (Color figure online)

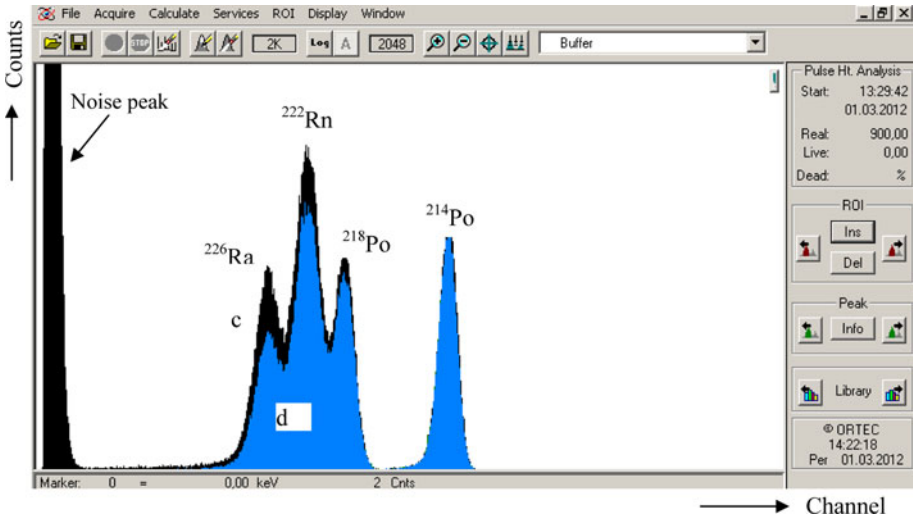


Fig. 14 Comparison of the energy spectra of ^{226}Ra (**c**) before (*black*), (**d**) after (*blue*) timing process. (Color figure online)

As shown in Fig. 12, counts in low energy region together with the noise peak were discriminated by means of the used timing process. It can be deduced that the timing method can be used to enhance the energy resolution of a detector. To check the validity of the timing method, it was applied to the alpha spectrum of ^{226}Ra as shown in Fig. 14. In the overall comparison, the method was prosperous in this energy spectrum, too. But it is conspicuous that the method was quite effective in the low energy region (noise, ^{226}Ra and ^{222}Rn peaks) but not effective in the high energy region (^{214}Po peak).

The count rates before and after the timing application for ^{210}Po were calculated and found slower than 5,000 s^{-1} (Figs. 10, 12). This means that we studied at low count rates [16]. Low count rates were chosen to experience the effect of the timing method. If the method was even successful at low count rates, it was thought that it would be prosperous at high count rates, too. The dead time value of the MCA was nearly zero as shown in Figs. 10, 11, 12, 13, 14. Thus, it can be concluded that pulse pile-up, pulse distortion, and spectrum distortion effects did not appear in our spectra [2, 11].

From the discussion above, it can be concluded that energy resolution of a Si semiconductor detector can be improved by eliminating noise, background, and spurious pulse effects through timing application even though it has high energy resolution capability at room temperature.

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