Improving energy resolution in an α-TOF detector†

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The alpha-TOF[1)] detector is a commercial MagneTOF ion detector with a silicon PIN diode embedded in the impact plate. We have developed the device for use in multi-reflection time-of-flight (ToF) mass spectrometry of radioisotopes, in particular superheavy elements. The alpha-decay signals provide a succinct means to identify that an implanted ion was indeed from a radioisotope ion. Until now, however, inherent noise in the detector limited the energy resolution to $\sigma_E \approx 150$ keV full-width at half-maximum (FWHM), which was insufficient for precise identification from E_α. By selectively shutting off the high-voltage bias applied to the detector's dynode, we have significantly reduced the noise in the detector and achieved a resolution of $\sigma_E \approx 20$ keV FWHM. This will allow precise identification of the nuclide and nuclear state of each decay-correlated ToF event.

The electric field needed for the electron isochronous trajectory in the MagneTOF is produced using Zener diodes. Whenever more than ≈700 V is applied between the detector anode and cathode, these diodes produce considerable noise which we have determined to cause the observed poor energy resolution. This is confirmed by Fig. 1 wherein similar numbers of ^{185}Hg were implanted on the detector with either the detector bias on (black histogram) or off (red histogram). With the bias off, the energy resolution is improved by nearly an order of magnitude and the low-intensity contributions of ^{185}Au and ^{184}Hg can be observed. A low-energy tail is presumably the result of differential energy loss from the dead layer depending on the alpha-particle's incident angle; those alpha-particles impinging the detector at far from normal angles lose significant energy to the dead layer.

With this in mind, we developed a relatively slow high-voltage switch to allow shutting off the detector bias without damaging the detector or causing a dangerous spike in the capacitively-coupled detector anode signal. The design uses high-voltage photodiodes to produce a switch that swings 2 kV in ∼1 ms with a smooth, linear transition (see Fig. 2). The timing generator was modified to produce a pulse spanning $\Delta t = \pm 50$ ns relative to the expected TOF of the radioactive ions of interest. These pulses and the TOF signals were applied to a digital gate generator, and whenever they were coincident the gate generator produced a 10 s duration pulse to trigger the aforementioned switch and shut down the high-voltage bias applied to the detector. In an initial test, we successfully observed the loss of reference ion detection for 10 s following a TOF event in the region of interest.

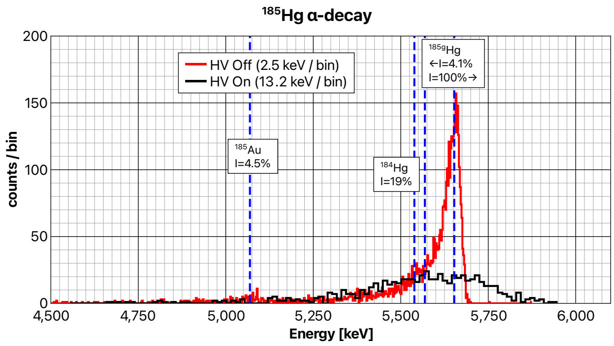

Fig. 1. Alpha-decay energy spectrum with and without detector dynode bias bias applied. Each spectrum had the same acquisition duration and has approximately the same number of events. The full-width at half-maximum is reduced from 318(10) keV to 30.2(1.2) keV with the detector bias off. The low-energy tail is presumed to be the result of energy loss in the dead layer, particularly from alpha-particles striking the detector obliquely. The incoming beam is a cocktail of several nuclides; the dominant alpha-decay energies are indicated by the dashed blue lines.

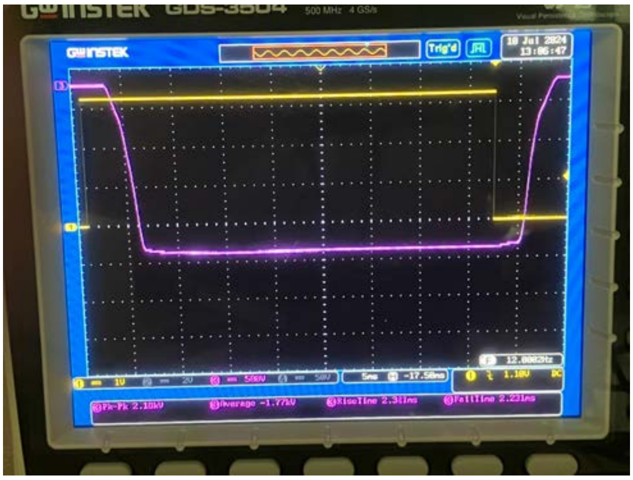

Fig. 2. Oscilloscope trace showing the rising and falling transition of the slow photodiode switch used to gently turn the detector bias on and off. Yellow trace is the switch trigger signal, purple trace is the switch output signal. Time scale is 5 ms per division.

† Condensed from the article in Nucl. Phys. A

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Reference

1) T. Niwase *et al.*, Nucl. Instrum. Methods Phys. Res. A, **953**, 163198 (2020).

DOI:10.34448/RIKEN.APR.58-128