LAWRENCE LIVERMORE NATIONAL LABORATORY

LLNL-TR-809262

MagMicro with Ultra-High Energy Resolution (FY20 Q2 Report)

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Quarterly Progress Report: Q2 FY20 – January to March 2020

Project: MagMicro with Ultra-High Energy Resolution

Project Number: LL16-MagMicro-PD2La

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HQ Project Manager: Chris Ramos

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Progress this quarter

Task 15 (Fabricate 32-pixel Ag:Er MMC Arrays): Completed ✓

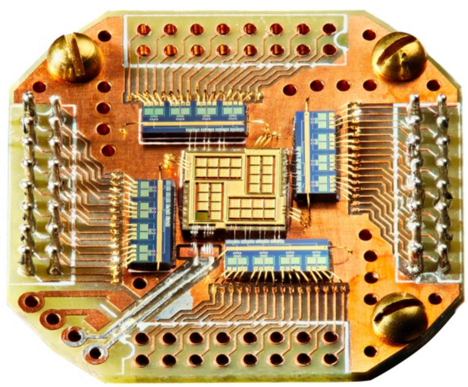

Fig. 1: Picture of the 32-pixel MMC gamma detector array. The central detector chip contains four 4 x 2 sub-arrays of MMCs with gold absorbers, each of which is read out by four SQUID preamplifiers on a separate (blue-ish) chip.

Task 16 (Demonstrate energy resolution <50 eV FWHM): Completed ✓

We have already achieved an energy resolution of 38 eV FWHM in FY17.

Task 17 (Integrate Compton Veto with MMC in Dilution Refrigerator): Abandoned ×

Task 18 (Operate 32-MMC array in LLNL dilution refrigerator): ✓

We had initially planned to test the remaining 32-pixel array (which has a slightly different design that may allow higher energy resolution) to see if we can improve the energy resolution beyond the tests we conducted in Q1. However, due to the Convid-19 pandemic, this work could not be completed.

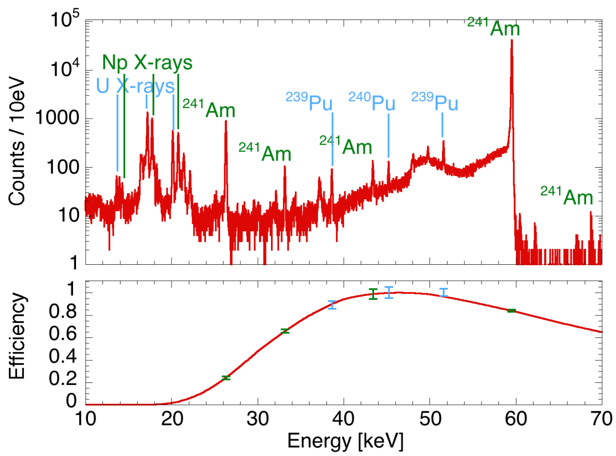

Figure 2 (top): The sum spectrum of a WGPu source shows the gamma emissions from the three dominant isotopes in the sample. Since we did not use a Cd foil, the Am-241 line at 60 keV dominates the spectrum.

Figure 3 (bottom): The four Am-241 gamma-emissions can be used to extract an efficiency curve at low energies. The accuracy of the Pu-240/Pu-239 isotope ratio is limited by statistical errors due to the large number of counts in the Am-241 line at 60 keV.

Instead, we have extracted the efficiency curve of our MMCs at low energies from the measurements we did in Q1 (Figure 2), because that is one of the quantities that will ultimately determine the NDA accuracy of isotope measurements and thus the range of applications MMC will be used in. Since MMCs are small and multiple-scattering inside the MMC is negligible, the efficiency curve $\eta(E)$ can be described accurately as a function of the energy E with an analytical expression that accounts for the self-absorption in the source and attenuation in the Al windows between source and MMC:

$$\eta(E) = \eta_0 \left(\frac{1 - e^{-\mu_{Pu}(E) d_{Pu}}}{\mu_{Pu}(E) d_{Pu}} \right) e^{-\mu_{Al}(E) d_{Al}} \left(1 - e^{-\mu_{Au}(E) d_{Au}} \right) \quad (1)$$

The term in the first brackets in Equation (1) describes the self-absorption of the radiation in the Pu source, the second term the attenuation in the Al windows with total thickness d_{Al} between source and detector, and the term in the second brackets the absorption in the Au absorber of the MMC with thickness d_{Au}. The elemental mass absorption coefficients μ_{Pu}, μ_{Al} and μ_{Au} can be obtained from various data bases, e.g. https://www.nist.gov/pml/x-ray-mass-attenuation-coefficients. The scale factor η_0 accounts for the solid angle that the MMC covers for a particular experimental setup. Equation (1) can be used to fit the measured detection efficiency well within the accuracy of the literature branching ratios for Am-241, with the thicknesses slightly adjusted from the nominal design values to account for fabrication uncertainties and variations in density from the literature values (Figure 3). The measured isotope ratio Pu-240/Pu-239 = 6.25(36) % agrees with the specifications for WGPu. So far, this NDA accuracy of ~5.8% is still limited by the statistical uncertainty of the Pu lines due to the strong Am-241 line at 60 keV. With improved statistics, it would ultimately be possible to determine this isotope ratio by NDA with an accuracy of 2.2%, currently limited by the uncertainties of the associated branching ratios of 0.0447(9) % and 0.02722 (22) % for the strong Pu-240 and Pu-239 lines at 45.244 and 51.624 keV, respectively. Improving these branching ratios and thus the NDA accuracy of the Pu-240/Pu-239 ratio would be possible with MMCs by using the better-known branching ratios of Am-241 (Figure 3).

Task 19 (Acquire Gamma Spectrum from Safeguards-Relevant Sample): Completed ✓

Task 20 (Present paper at INMM and report to NA-22): Completed ✓

Outlook

This completes our work on this project. A final report will summarize the results from this LCP.

For a follow-up project, we are currently funded by NA-241 to build a decay energy spectrometer based on the MMC technology developed in this LCP. The IAEA is specifically interested in accurate isotope analysis of small particles that decay energy (Q) spectroscopy is well-suited for. We have established an SP-1 collaboration with the IAEA that is expected to continue beyond FY20.

Publications

Both MMC papers that we have submitted for the 18th International Workshop on Low Temperature Detectors (LTD-18) have been published in the Journal of Low Temperature Physics. The first paper is by Steve Boyd (UNM) on "Metallic Magnetic Calorimeters for High-Accuracy Nuclear Decay Data" and the second one is by Geon-Bo Kim (LLNL) on "A New Measurement of the 60 keV Transition in Am-241 Decays using Metallic Magnetic Calorimeters".

Lab Program Manager Comments [optional]: