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MagMicro with Ultra-High Energy Resolution (Report Q2 FY19)

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Disclaimer

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Quarterly Progress Report: Q2 FY19 – January to March 2019

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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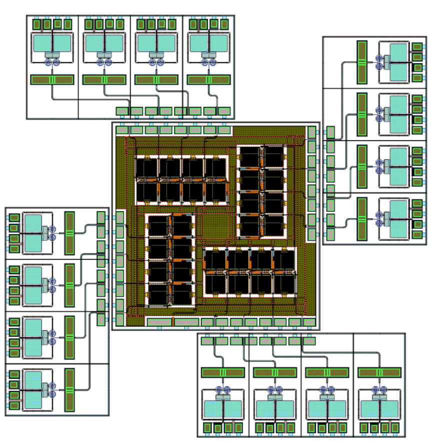
Progress this quarter

Task 15 (Fabricate 32-pixel Ag:^{166}Er MMC Arrays):

We have finalized the designs of the MMC detectors and the mask layout for our 32-pixel MMC gamma-detector arrays. The optimized layout separates the MMC detector chip from the SQUID preamplifier chips that are coupled to the MMCs through Al wire bonds (Figure 1) so that the power dissipation of the SQUIDs no longer heats the MMC above the temperature of our dilution refrigerator. The MMC geometry is optimized to that the detectors are estimated to have a limiting resolution of ~20 eV FWHM for gamma energies up to >100 keV and ~1 ms decay times for maximum count rates of several tens of counts/s per pixel. Pixel sizes will range from (0.5 mm)^2 to (2mm)^2, with the large pixels offering higher efficiency at the cost of a slightly lower speed and energy resolution. In practice, the detector performance will also depend on the quality of the photolithographic fabrication, for example the quality of the SiO_2 insulator between the magnetic Ag:Er sensor and the Nb pick-up coil. Thinner SiO_2



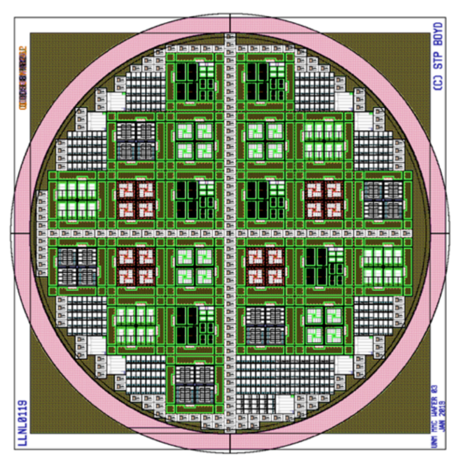


Figure 1 (left): Layout for the 32-pixel MMC detector array. The central detector chip contains four 2 x 4 arrays of MMC detector pixels (black), each of which is coupled to a separate chip with four SQUID preamplifiers. Figure 2 (right): The layout of the entire 4" wafer contains several different detector designs and test structures.

improves the magnetic coupling and therefore increases the signal and energy resolution, but may have pin-holes that cause the detector to fail. We have therefore included different detector designs in the mask to allow good detector performance under different conditions (Figure 2). The photolithographic masks have been ordered. Unfortunately, since the design ended up taking much longer than expected, the fabrication has only begun recently. We will therefore have to request a no-cost extension of the project to September 30, 2019.

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

Since we have already achieved an energy resolution of 38 eV FWHM in FY17, we will not focus on this task until the optimized 32-pixel MMC arrays are available.

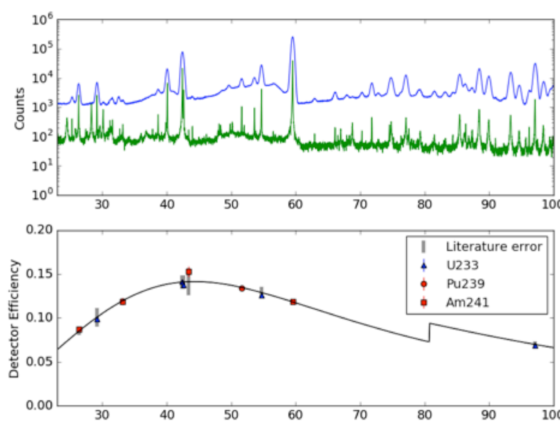
Task 17 (Integrate Compton Veto with MMC in Dilution Refrigerator): Abandoned ×

Task 18 (Operate 32-MMC array in LLNL dilution refrigerator): Not yet started

Our dilution refrigerator is equipped with the wiring and with 16 SQUID preamplifiers to be able to read out the new MMC arrays in Q3.

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

Our earlier experiments on $^{233}U/^{239}Pu$ had shown that the accuracy of our MMC measurements is limited by the literature values of the available calibration sources. This is reflected in our attempt to calibrate the MMC quantum efficiency for energies up to 100 keV based on the literature values of the branching ratios for ^{233}U, ^{239}Pu and ^{241}Am (Figure 3). The efficiency can be modeled to an accuracy of ~±1%, but not better (bottom). This is sufficient for standard non-destructive assay (NDA) of nuclear materials, but not to improve nuclear data or make NDA accuracy competitive with the ±0.1% accuracy of destructive analysis (DA) by mass spectrometry. Such an accuracy requires better calibration sources such as Yb-169, which we had generated at the 88" Cyclotron at LBL in Q1. In Q2, we have taken MMC gamma-spectra of this Yb-169 source with a resolution of 60 eV FWHM to test how well we can calibrate MMC energies and



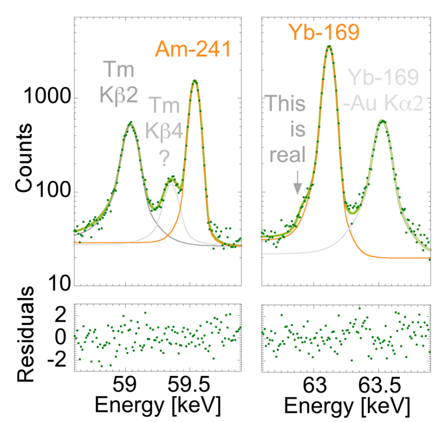


Figure 3 (left): MMC spectra (green) of a custom $^{233}U/^{239}Pu$ source have ~10 higher energy resolution than the Ge spectra (blue) of the same source. They allow calibrating the quantum efficiency of our MMC detectors to an accuracy of ±1 %, limited by the literature errors of the gamma-ray branching ratios for ^{233}U, ^{239}Pu and ^{241}Am. Figure 4 (right): High-accuracy spectra of Yb-169 allow very accurate energy and efficiency calibration of gamma-rays and X-rays. They show e.g. that the literature value of the Tm Kβ4 X-ray is off by ~140 eV (Figure 4a), and that the possible Yb-169 gamma-ray at 63.01 keV does in fact exist (Figure 4b).

and efficiencies. In this context it is becoming increasingly obvious that even the literature values for decay radiation of Yb-169 can be of insufficient accuracy, especially for the weaker lines. For example, while the energies of the Am-241 gamma and the Tm Kβ2 X-ray match with the literature values, the Tm Kβ4 centroid is off by ~140 eV (!) (Figure 4a). On the other hand, a Yb-169 gamma-ray at 63.01 keV that is listed with a question mark in the NNDC data base seems to be real (Figure 4b). We expect the literature values of the decay radiation from actinides to be affected by similar problems, which in turn likely limits the accuracy of actinide NDA by gamma spectroscopy.

We are currently continuing the analysis of our MMC and Ge spectra of Yb-169 to address HQ recommendations to identify the best experimental procedure to improve the nuclear data and experimental procedures needed for high-accuracy NDA. We do believe that MMCs are the best technology to do these measurements, although one needs to pay attention not only to the detector performance but also to the experimental setup and the pulse-processing equipment. We are working with several senior colleagues at different DOE laboratories to tap into their extensive knowledge of NDA. We hope to be able to make well-founded recommendations by the end of this project and publish them in a reference paper as a basis for future cross-laboratory comparisons.

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

Outlook

We expect the 32-pixel MMC detector arrays to be completed in Q3 so that we can test them at LLNL. This will require a no-cost extension of the project to 09/30/19, which we will request from HQ.

Publications

Lab Program Manager Comments [optional]: