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Magnetic Microcalorimeters with Ultra-High Energy Resolution (FY17 Q2 report)

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Quarterly Progress Report: Q2 FY17 – January to March 2017

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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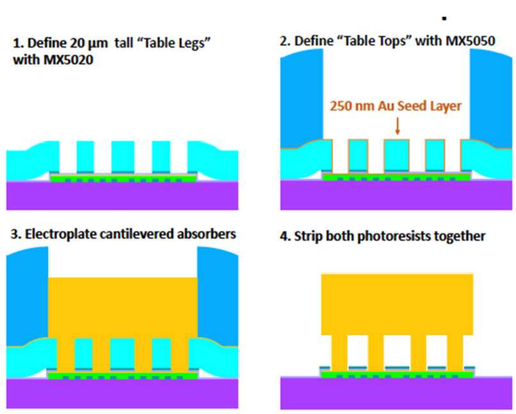
Progress this quarter

Tasks 1, 7 (Finalize design, order, build, install and debug dry dilution refrigerator):

We have installed, commissioned and tested the new liquid-cryogen-free dilution refrigerator from BlueFors, and its performance exceeds specs considerably. (BlueFors is known to under-promise and over-deliver.) We have attained a base temperature of 7 mK (specs: <10 mK), a cooling power of 21 µW at 20 mK (specs: >12 µW) and a cooling power of 710 µW at 100 mK (specs: >575 µW). It's a beautiful instrument (Figure 3)!

Task 9 (Fabrication of Ag:Er MMC detector arrays at the University of New Mexico)

We have fixed the problem with the Au gamma-absorber fabrication on our MMCs by switching the photoresist material used for the absorber mold from a (standard) liquid spin-on to an (unusual) dry-film roll-on photoresist (DuPont MX5000 Series). This photoresist film (Figure 1, dark blue) is rolled onto the wafer with the Ag:Er sensor with a heated roller on a hot plate at ~90 ˚C, and several layers of photoresist can be added to increase the thickness of the absorber.



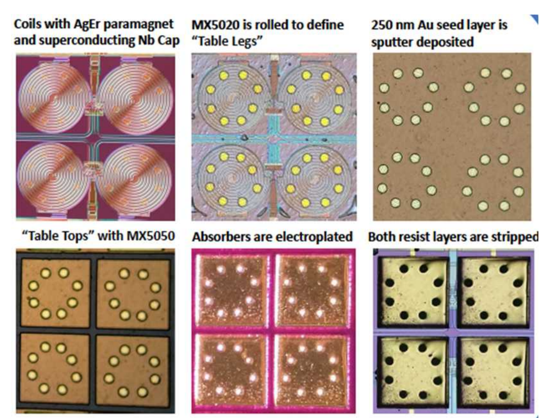
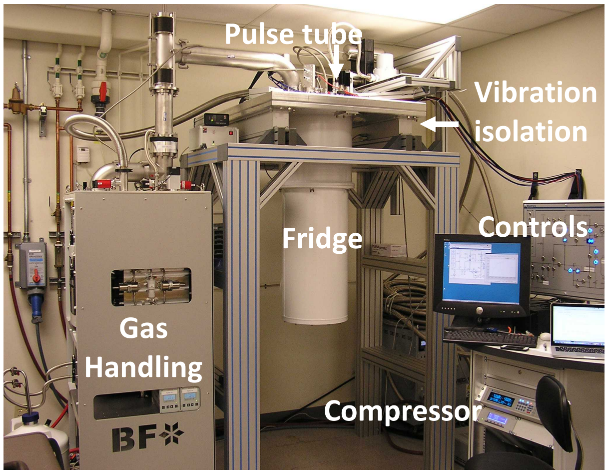


Figure 1 (left): Schematic of the absorber fabrication process using two different photoresists (light and dark blue) to define the "legs" and the "top" of the absorber. Figure 2 (right): Top view of four absorbers in an MMC detector array on top of the circular pick-up coil and paramagnetic sensor during the corresponding stages of fabrication.



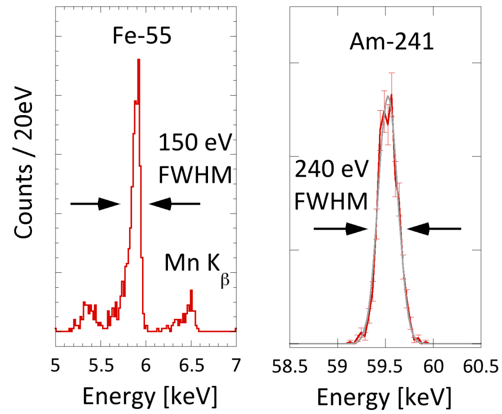


Figure 3 (left): Liquid-cryogen-free dilution refrigerator installed in our lab at LLNL. Figure 3 (right): First spectra taken with MMC gamma detectors fabricated at the University of New Mexico.

The advantages of this roll-on photoresist are that more produces reliable results over a wider parameter space than the AZ-125-nXT spin-on photoresist we used in the past, and that it is easier to remove without damaging the detector than the SU-8 photoresist that other groups are using. Changing to this photoresist has increased the reliability of the fabrication process significantly. Pictures of four absorbers in an MMC detector array during the different stages of fabrication are shown in figure 2. Initial tests of the new devices at a comparably "high" temperature of 50 mK in the ADR refrigerator at UNM have shown an energy resolution of 150 eV at 6 keV and 240 eV at 60 keV (Figure 4).

Task 10 (Fabricate MMC detector arrays at the Heidelberg University):

We have received two tested and several untested 8 pixel gamma detector arrays from our collaborators at Heidelberg University. These are the first gamma-detector arrays that Heidelberg has fabricated with Ag:Er (as opposed to traditional Au:Er) sensors, which should improve performance since Ag does not have a nuclear contribution to the heat capacity. We will test their gamma response in Q3.

Task 11 (Demonstrate Cryogenic Compton Veto Operation):

The simplest way to passivate a high-purity Ge detector so that it no longer loses resolution over time when used as a Compton veto at ~10 mK is by illuminating them with light from an LED. Interestingly, cheap "low"-quality LEDs work best at temperatures <1K, probably because they contain sufficient impurities in the junction area to prevent a complete carrier freeze-out. We have modified the housing for our Ge test detector to be able to install one of these LEDs in it an operate it at T ≈ 0.1 K.

Task 12 (Gamma Spectrum from Safeguards-Relevant Sample):

Due to current interest by NA-241 in U-233, we are preparing a sample that contains U-233 and Pu-239. Both isotopes have many gamma emission lines at low energy, and the Pu-239 will serve as an internal calibration standard for U-233. We will initially measure its spectra with high-purity Ge detectors at the LLNL counting facility, and then compare them with the spectra from MMCs.

Task 13 (MMC Array Operation with an Energy Resolution <100eV): (No work yet.)

Task 14 (Presentation of Results at LTD-17 Workshop and Publication of Report):

We have submitted three different abstracts for the LTD-17 Conference: One on the MMC design with Steve Boyd as the lead author, one on the gamma-ray absorber fabrication with graduate student Ruslan Hummatov as the lead author, and one on uranium measurements with post-doc Geon-Bo Kim as the lead author.

Outlook

We will continue to characterize the Ag:Er MMC in detail to compare it with existing models and understand its limiting performance, both in New Mexico and at LLNL. For best resolution, it will be important to reduce external electromagnetic interference and ensure good thermal coupling to the cryostat. Improved resolution will be important for our presentations at the LTD-17 conference in Japan in Q3.

We have also hired Cameron Flynn, a junior in physics at the university of New Hampshire, as a summer student to work on the MMC detector project. If he turns out to be as smart and as strong in the lab as his letters of recommendation and his interview performance suggests, we will try to attract him into one of the bay area universities for his Ph.D. and recruit him to LLNL for his thesis research.

Publications

Our FY16 paper "Tantalum Passive Persistence Shunts for On-Chip Current Trapping in Metallic Magnetic Calorimetry", by R. Hummatov, L. N. Le, J. A. Hall, S. Friedrich, R. A. Cantor, and S. T. P. Boyd, has been published as *IEEE Trans. Appl. Superconductivity* **27**, 2200205 (2017).

Lab Program Manager Comments [optional]: