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Fabrication of Absorbers with Dry Film Photoresist for Gamma Ray Spectroscopy with Metallic Magnetic Calorimeters

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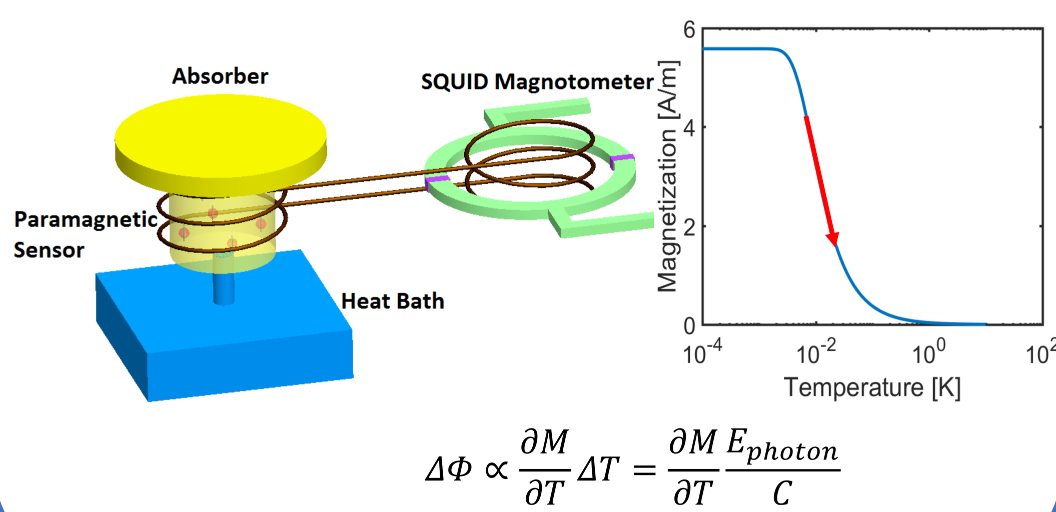
1. Abstract

We are developing metallic magnetic calorimeters (MMCs) for high resolution gamma-ray spectroscopy for non-destructive assay of nuclear materials. Absorbers for these higher-energy photons can require substantial thickness ~100 µm to achieve adequate stopping power. We have previously reported successful electroforming of gold absorbers for these devices using a sacrificial Cu layer as the mask for the posts and Az125nXT photoresist to pattern the tops [1]. In this report, we describe a new absorber fabrication process using dry film photoresist for both posts and tops. As with the copper process, the dry-film process is completely compatible with the STARCryo "Delta 1000" SQUID microfabrication process, enabling future commercial deployment of our integrated SQUID/sensor detector designs. The dry film approach produces well-defined absorbers with fewer and much-simpler process steps and improved yield (100% to date). Absorber adhesion is excellent, with 100% survival to date against vigorous ultrasound and repeated rapid immersion in liquid nitrogen. Using this approach we have completed fabrication of 14-pixel arrays of integrated SQUID/sensor MMCs with attached absorbers. At present the absorber thickness has been tested to < 50 µm with the dry-film approach. Process development is ongoing to increase the maximum thickness by layering the film. In this report we describe the post-"Delta 1000" fabrication steps used to complete the new MMC devices and initial performance results.

2. Metallic Magnetic Calorimeters



$$\Delta\Phi \propto \frac{\partial M}{\partial T}\Delta T = \frac{\partial M}{\partial T}\frac{E_{photon}}{C}$$

3. Layers of UNM MMCs

#	Layer	Description	Thickness
1	Nb/Al-AlO$_x$/Nb	Josephson Junction Definition[2] & First Wiring	400 nm
2	NbTa62	Passive Persistence Switch Shunts	220 nm
3	SiO$_2$	Insulation	130 nm
4	AuPd	SQUID Shunt Resistor	170 nm
5	Nb	Second Wiring	480 nm
6	SiO$_2$	Insulation	150 nm
7	Nb	Third Wiring	480 nm
8	Au	Pads	330 nm
9	AgEr	Paramagnet	1.5 µm
10	Au	Thermalization Layer	220 nm
11	SiO$_2$	Insulation	200 nm
12	Nb	Superconducting Cap	370 nm
13	Au	Posts + Absorbers	20 + 30 µm

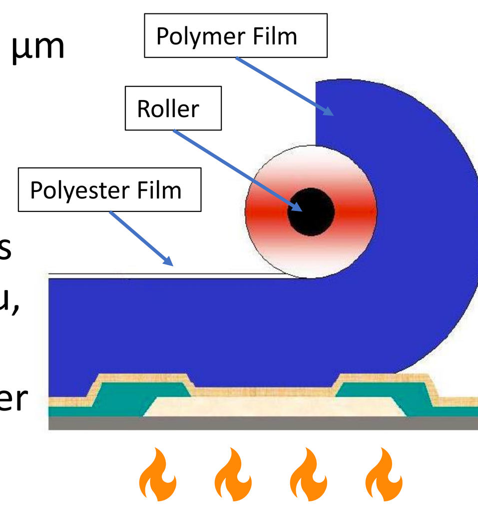
Wafer-level Fabrication
CM-scale chip fabrication

4. Advantages of Dry-Film Photoresist

- For thick structures AZ125nXT or SU-8 is used.
  - AZ125nXT needs delicate handling.
  - It is hard to remove SU-8.
- Dry-film photoresists are easier to process and give high yield.
- No harsh conditions are involved in processing, safe for SQUIDs!
- Rolled on chip, instead of spin coating: no edge bead!
- The thickest film is 50 µm, but it can be layered!

5. Dry film Photoresist – MX5000[3]

- Thicknesses: 15, 20, 30, 40, 50 µm
- Compatible with:
  - Acid and alkaline etchant solutions
  - Au electrolytic plating baths
  - Si, SiO$_2$, Si$_3$N$_4$, sputtered Cu, Au, polymers etc.
- Can be rolled with heated roller or on hot plate

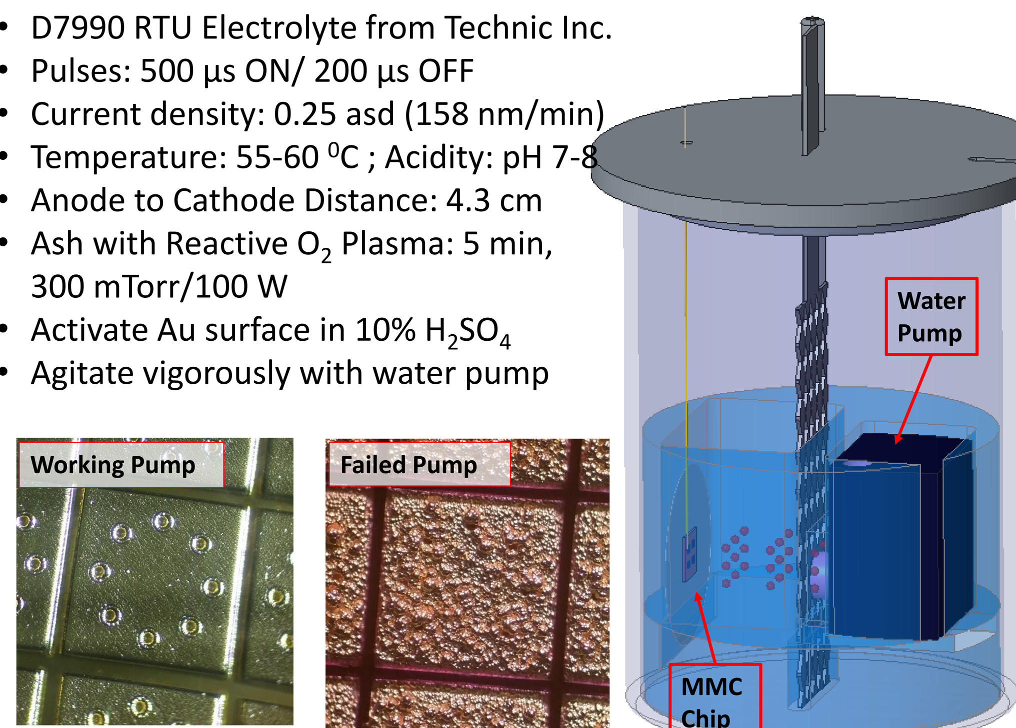


6. Dry Film Processing Steps

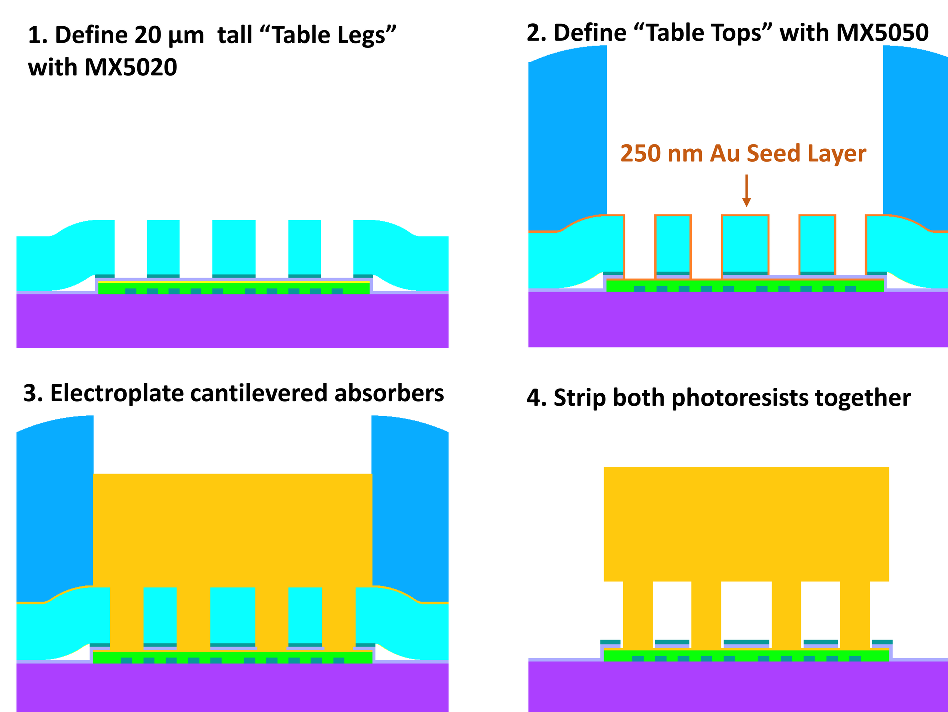
1. Chip on hot plate (90-100 ^{0}C)
2. Roll film on
3. Post Lamination Bake (optional)
4. Expose with 365 nm UV light
   - >20 mW/cm^2 for high resolution
5. Post Exposure Bake (optional)
6. Develop in 0.75 %wt K$_2$CO$_3$ solution at 27-32 ^{0}C; flow established with water pump.
   - MX5020 1 min; MX5050 3 min
7. Post Development Bake (optional)

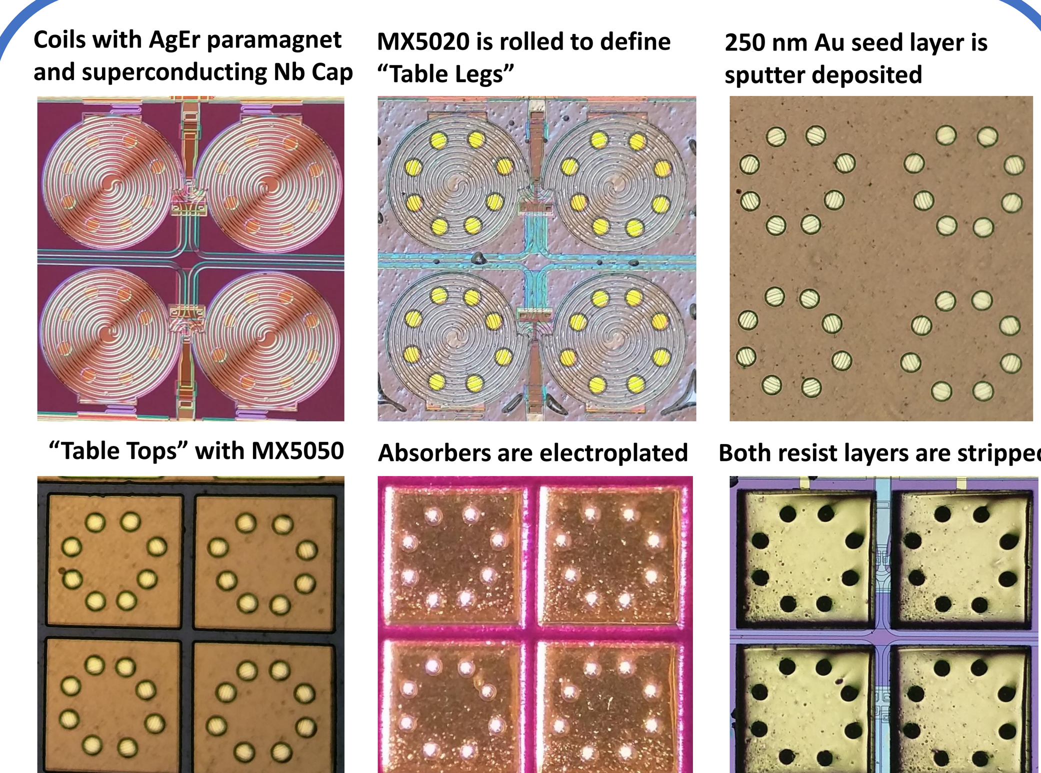
7. Au Electroplating

- D7990 RTU Electrolyte from Technic Inc.
- Pulses: 500 µs ON/ 200 µs OFF
- Current density: 0.25 asd (158 nm/min)
- Temperature: 55-60 ^{0}C ; Acidity: pH 7-8
- Anode to Cathode Distance: 4.3 cm
- Ash with Reactive O$_2$ Plasma: 5 min, 300 mTorr/100 W
- Activate Au surface in 10% H$_2$SO$_4$
- Agitate vigorously with water pump



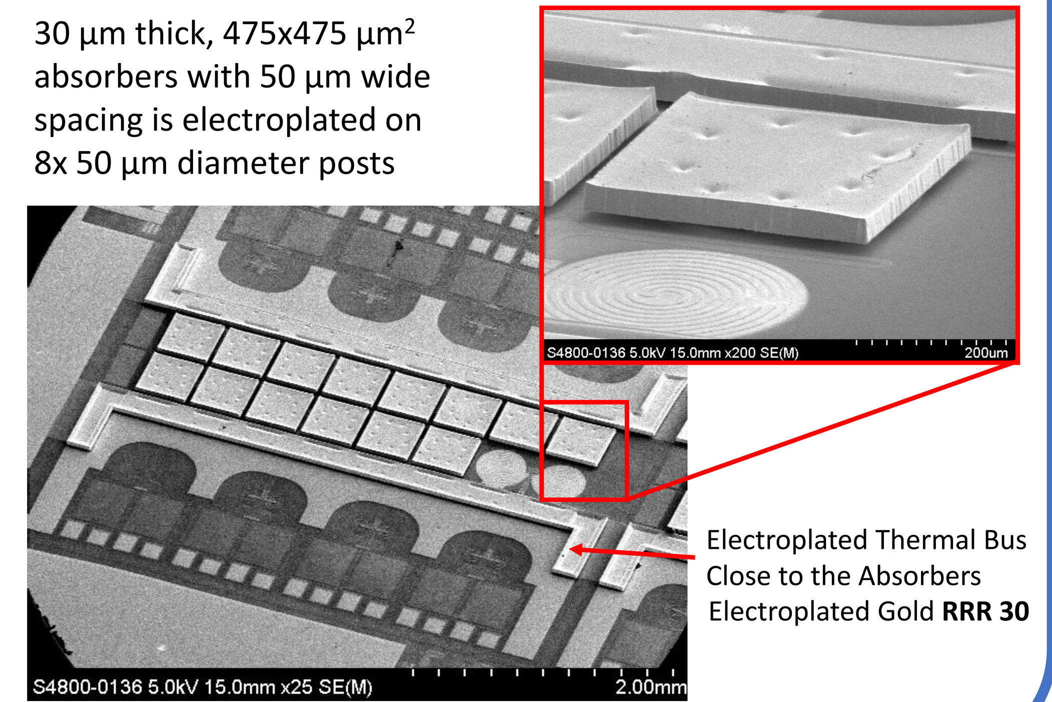
8. Absorber Fabrication Steps



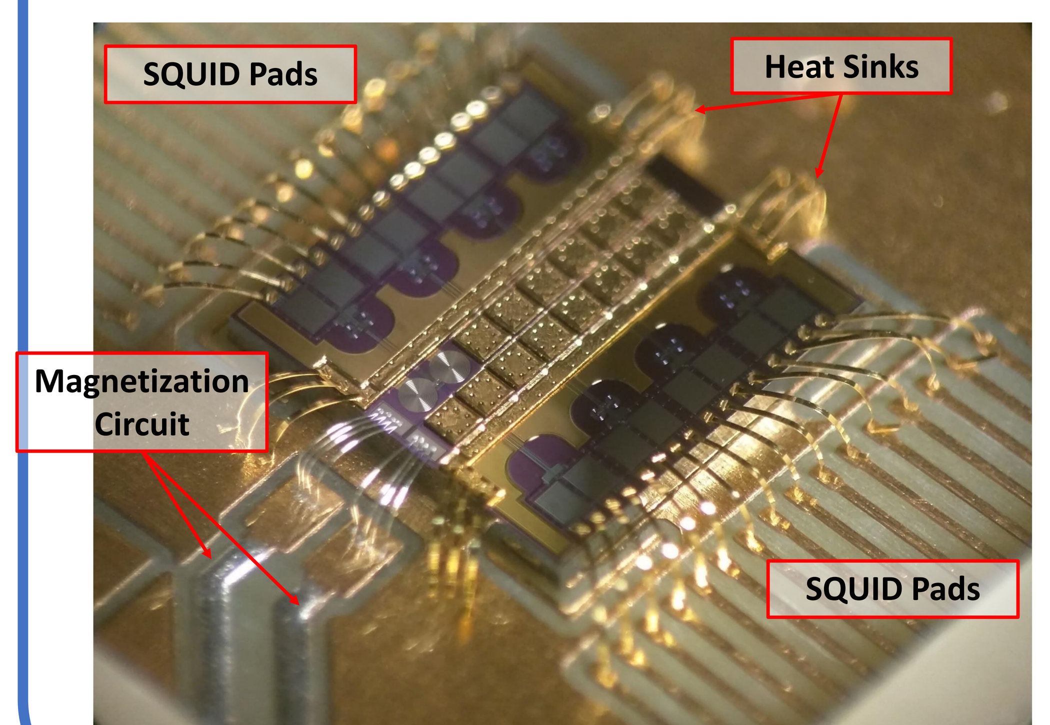


9. Cantilevered Absorbers

30 µm thick, 475x475 µm^2 absorbers with 50 µm wide spacing is electroplated on 8x 50 µm diameter posts

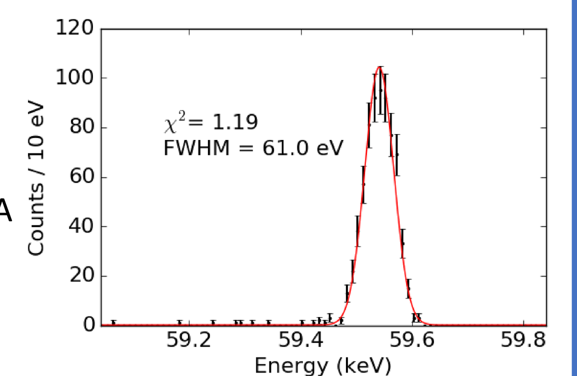


10. Array-chip ready for testing



11. Performance

Initial data taken at LLNL
- Source: ^{241}Am
- Temperature: 10 mK
- Magnetization current: 55 mA
- Total number of pulses: 700
- FWHM 61 eV @ 60 keV

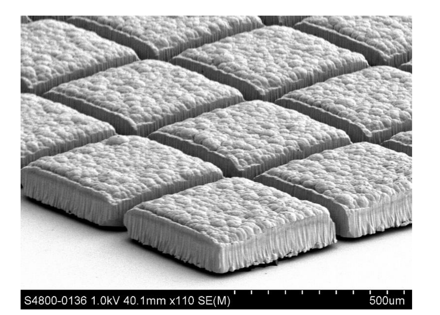


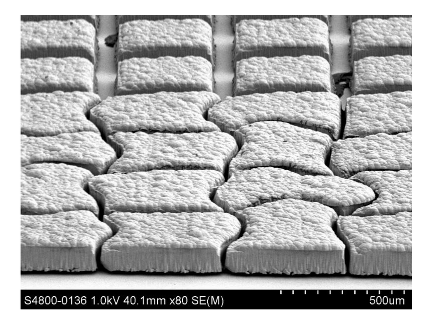
Operation temperature and magnetization current is not optimized yet, even better performance may be achieved.

12. 100 µm attempt – "Brownies"

1st attempt:
- two MX5050 rolled on top of each other and exposed/ developed together in one run
- Target thickness is achieved but finish is not smooth
- 25 µm walls deformed while drying with N2 gun

2nd attempt:
- 1st MX5050 rolled/ exposed/ developed, then 2nd MX5050 rolled/exposed/developed.





13. Acknowledgements

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14. References

1. L. N. Le, R. Hummatov, J. A. Hall, R. C. Cantor and S. T. P. Boyd, "Development of Metallic Microcalorimeters for Gamma-Ray spectroscopy", *J Low Temp Phys*, **184**, 108 (2016).
2. R. Cantor and J. Hall, "Six-Layer Process for the Fabrication of Nb/Al-AlO$_x$/Nb Josephson Junction Devices", *IEEE Trans Appl Supercond*, **15**, 82 (2005).
3. "DuPont^{TM} MX5000^{TM} Series Data Sheet & Processing Information", available online at http://www.micro-resist.de/daten/dupont/mx5000.pdf (July 2017)