Development of large-scale magnetic calorimeter arrays

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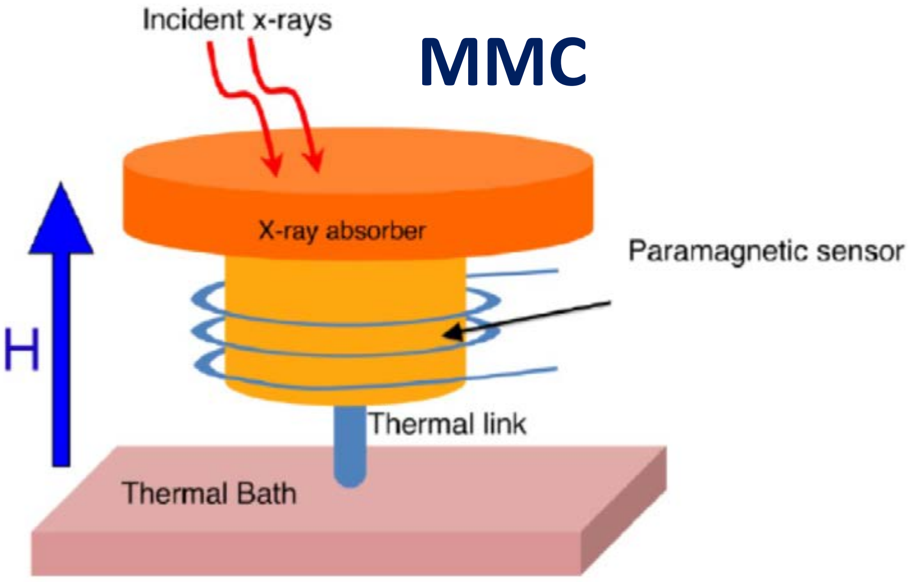
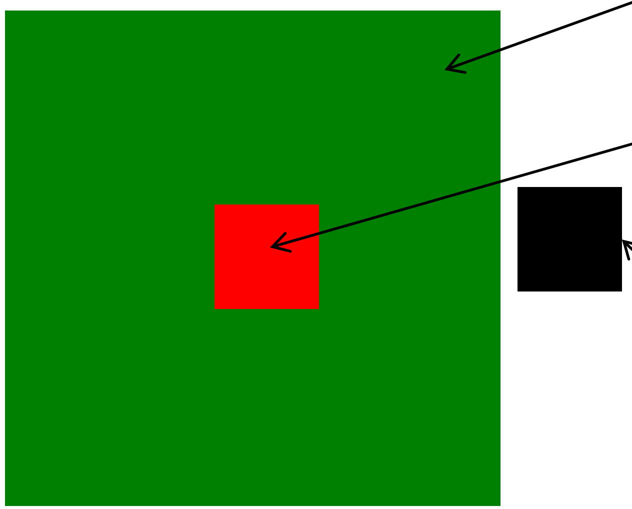
Introduction

- Metallic magnetic calorimeters (MMCs) can be used to measure the energy of individual x-ray photons with high precision by sensing the changes in the magnetic susceptibility of a paramagnetic metal film (Au:Er) as its temperature rises in response to the absorbed photon energy
- MMC is a leading contender for detectors for the Lynx X-ray Microcalorimeter (LXM) instrument on the Lynx mission concept. LXM is designed to consist of a very large array of MMCs with > 100K pixels



LXM array baseline configuration



Main array
- 1” pixels (50 µm), 5’ FOV, 5x5 hydra
- ΔE ~ 3 eV
- Up to 7 keV
- 86400 pixels

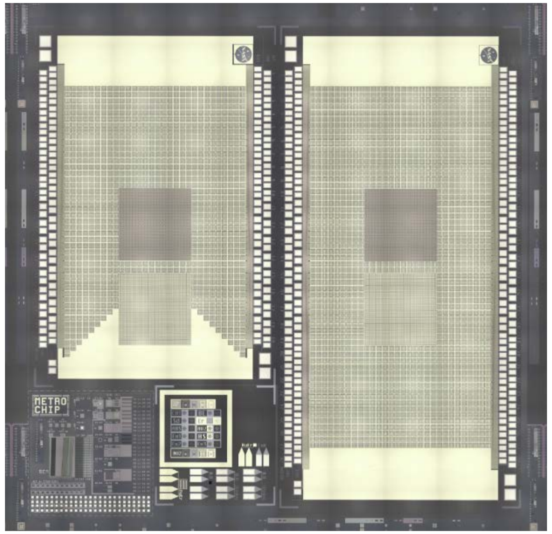
Enhanced array
- 0.5” pixels (25 µm), 1’ FOV, 5x5 hydra
- ΔE = 2 eV
- Up to 7 keV
- 12800 pixels

UHR array
- 1” pixels (50 µm), 1’ FOV
- ΔE = 0.3 eV
- Up to 0.75 keV
- 3600 pixels

Motivation

- As array size increases
  - Stray inductance of the wiring increases both between pixels and in the fanout to amplifiers
  - Routing of wiring between pixels and readout, on a planar scheme, becomes technologically challenging due to requirements of low inductance, low crosstalk, high critical currents and high yield
- MMCs can be scaled to large array sizes by,
  - maximizing the sensor inductance by decreasing the sensor meander coil pitch
  - maximizing the magnetic coupling by scaling the sensor (Au:Er) and sensor insulator thicknesses with pitch
  - maintaining the Nb thickness with pitch in order to keep sufficient critical current/width
- Buried layers can be used to achieve large scale, high density wiring
  - Well suited for connecting thousands of pixels on a large focal plane to readout chips
  - Planarization allows top surface of wafer to be exclusively available for pixels and heat sinking, opening up the possibility for new pixel geometries
  - Can alleviate crosstalk between high density, fine pitch wiring

Fabrication of high inductance MMC arrays with buried Nb layers

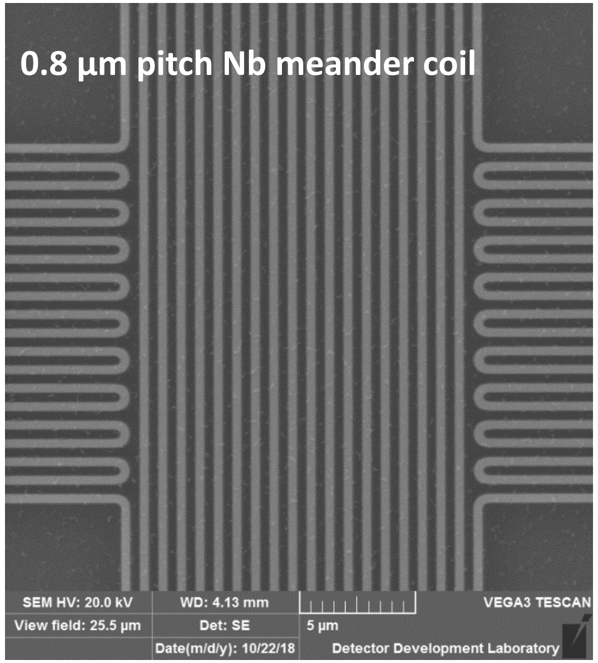


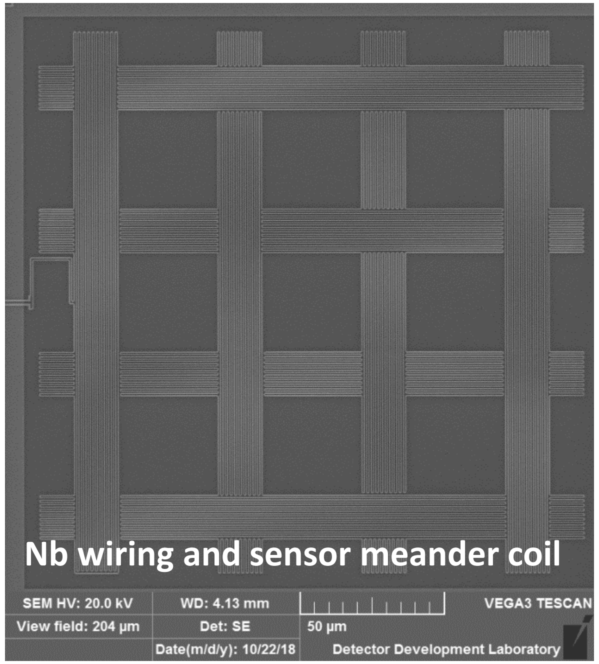
- Large size MMC arrays implementing Lynx concepts are fabricated with 4 buried Nb layers
- Die layout consists of two chips each comprising of Main array, Enhanced array and UHR array

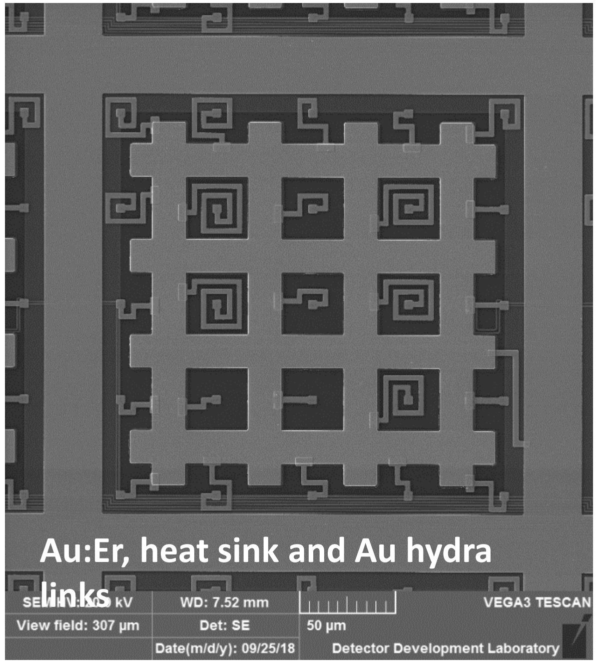
- All buried wiring and sensor meander coil layers are processed as follows
  - Nb deposition by dc magnetron sputtering
  - Patterning of Nb by deep UV (DUV) lithography (248 nm) and plasma etch
  - SiO2 interlayer dielectric (ILD) deposition by PECVD
  - Chemical Mechanical Planarization of ILD to desired thickness
  - Patterning of ILD by DUV lithography and plasma etch
- MMC sensor (Au:Er) deposition by sputtering and patterning by lift-off
- Au heat sink deposition by e-beam evaporation and patterning by lift-off
- Stems electroplating through photoresist mold on Au seed layer
- Absorbers electroplating and etch by ion milling

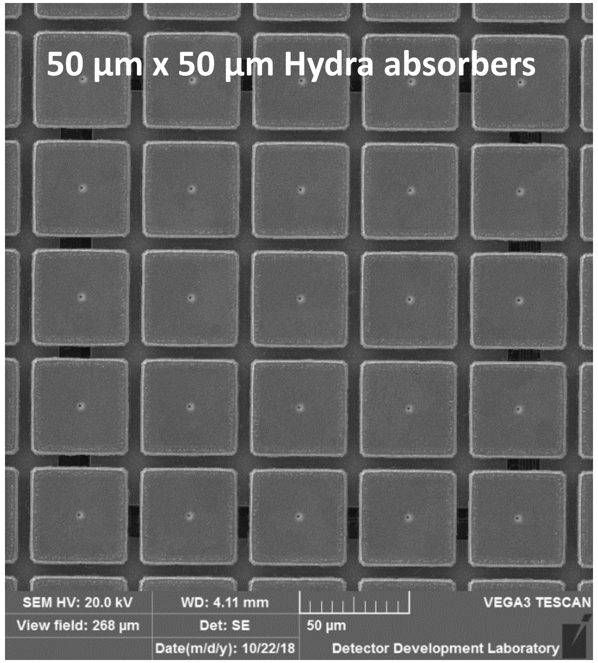
Array Components – Main Array

- 60 x 30 sensor array with waffle shaped, multi absorber sensors (5 x 5 Hydra)
- Sensor meander coils and twin microstrip wiring are both patterned on topmost Nb layer



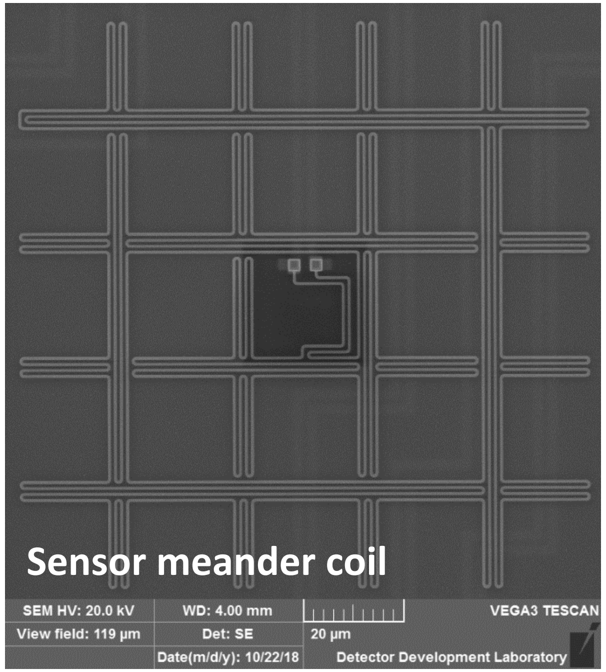


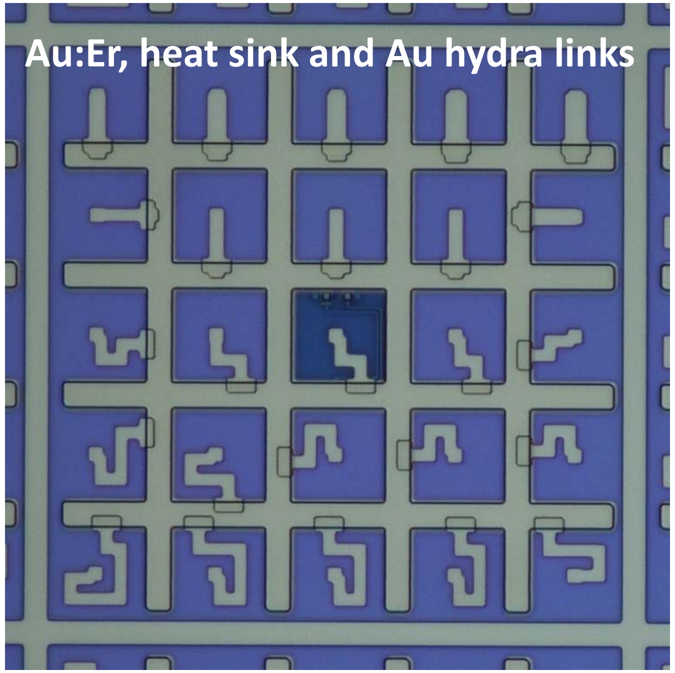


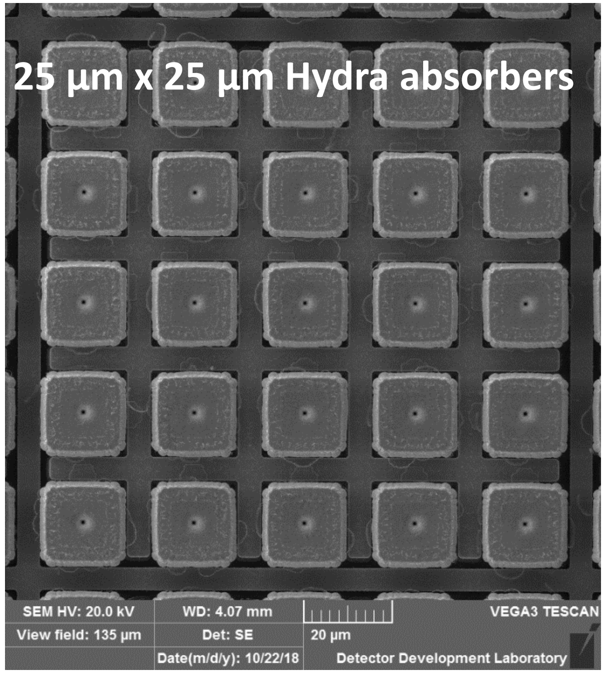


Array Components – Enhanced array

- 24 x 24 sensor array with waffle shaped sensor and a 5 x 5 Hydra design
- Sensor meander coils are patterned on topmost Nb layer
- Ability to use multiple layers of buried wiring allows twin microstrip wiring to be laid out on bottom most Nb layer without the need for aggressive packing of wiring on one layer. This reduces crosstalk between pixels.
- Sensor meander coils are connected to wiring through superconducting vias near the center of the Hydra

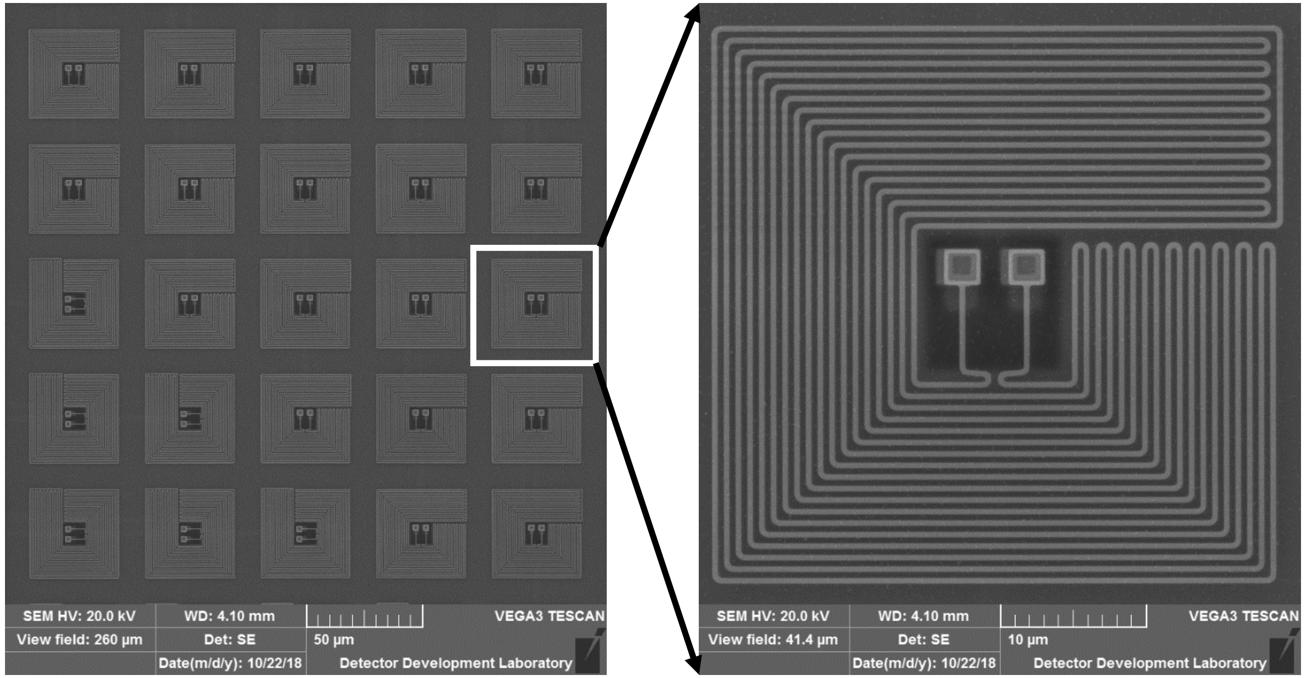


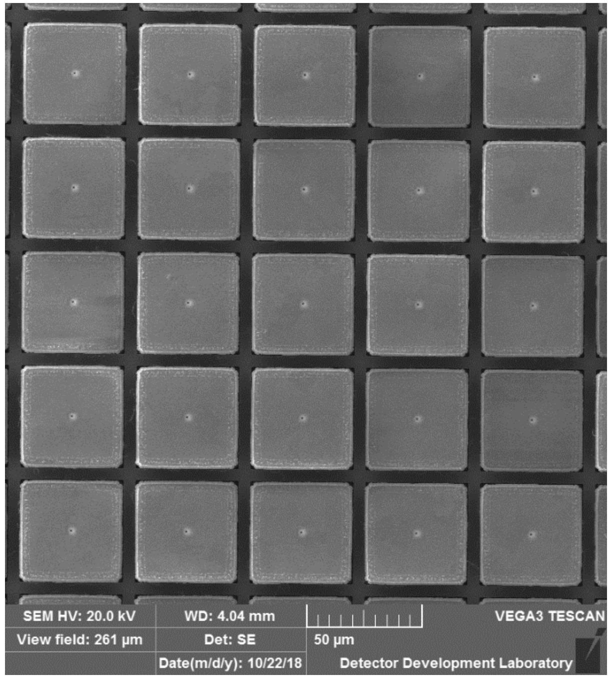




Array Components – UHR array

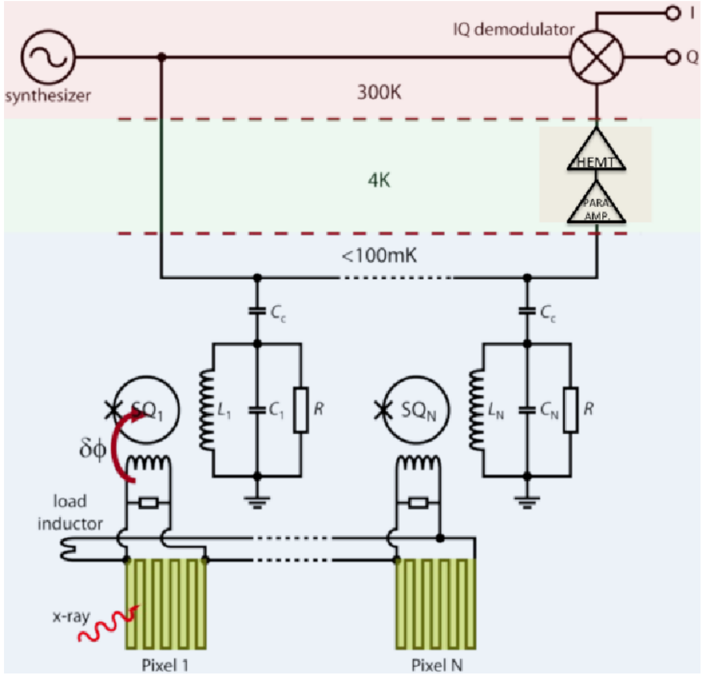
- 60 x 60 sensor array with a square annulus shaped sensor
- Sensor meander coils are on the topmost Nb layer
- Twin microstrip wiring is patterned on the bottom most Nb layer



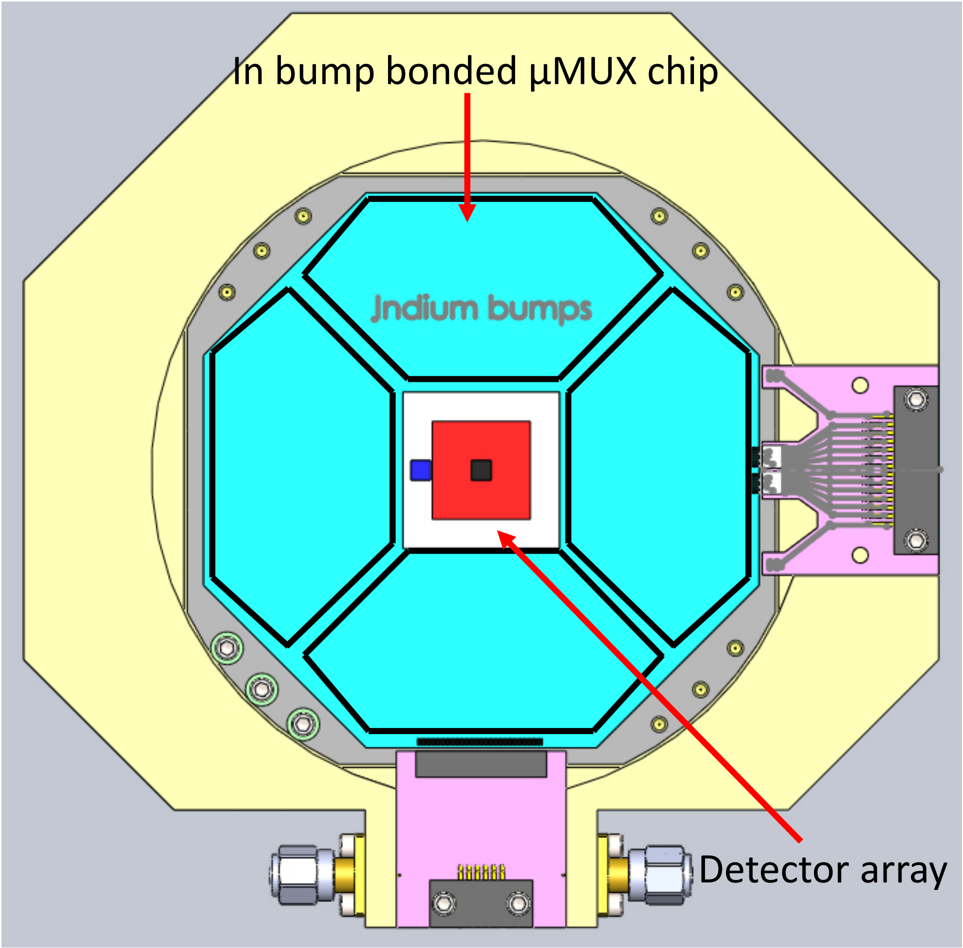


Readout for MMC arrays

- Changes in the MMC temperature induce changes in the magnetization, and thus inductance of meander coil
- This produces a change of current through the meander and also through the input coil to the rf-SQUID, thus changing the magnetic flux coupled to it
- This in turn induces a change in the SQUID inductance and L_N and consequently also the frequency of the microwave SQUID resonator



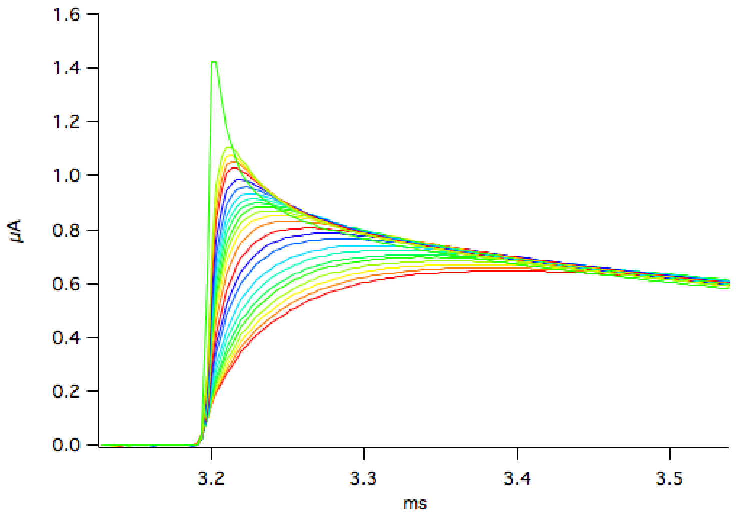
- The change in resonance frequency is sensed from changes in the microwave transmission and is amplified by a parametric amplifier and a low noise HEMT
- A technique called flux-ramped modulation uses a high frequency triangle wave to modulate the signal being input to the rf-SQUID over many φ_0's at high frequency. This provides a linear net response after demodulation in the room temperature electronics. The μSQUID provides microwave bandwidth with power dissipation less than 10 pW per sensor.

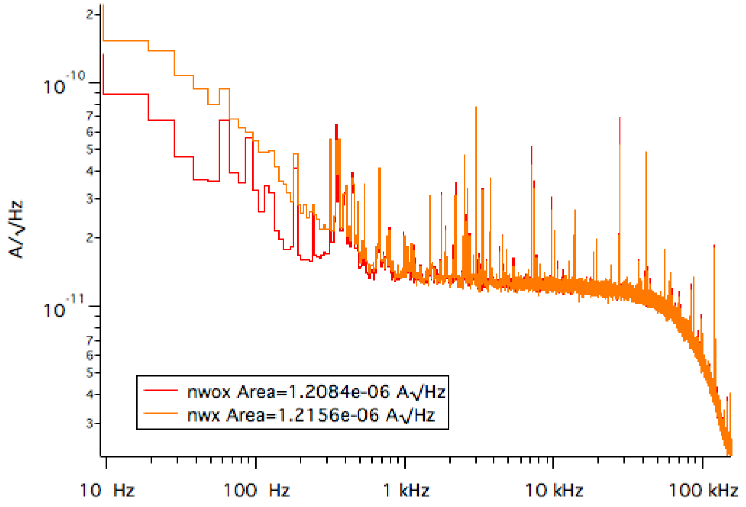


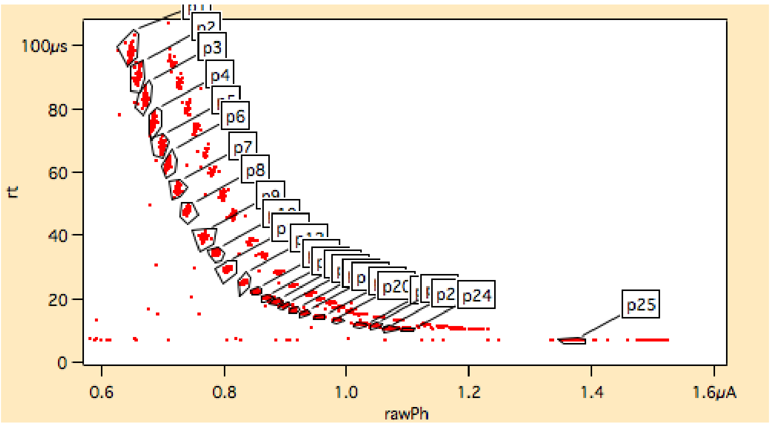
Concept for fanout of 100K pixels and 7568 sensors

Measurement Results

Main array pixel with 0.8 µm pitch meander coil, 15 mA bias current at T = 50 mK







NEP at T = 50 mK

Enhanced array 0.8 µm pitch pixel	1.96 eV – 1.99 eV
Main array 0.8 µm pitch pixel (with noisy SQUID)	10.5 eV – 12.5 eV
Main array 0.8 µm pitch pixel (noise corrected)	3 eV