Prototype Magnetic Calorimeter Arrays with Buried Wiring for the Lynx X-ray Microcalorimeter

LTD-18 #193

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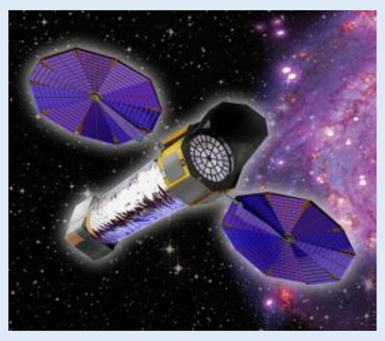
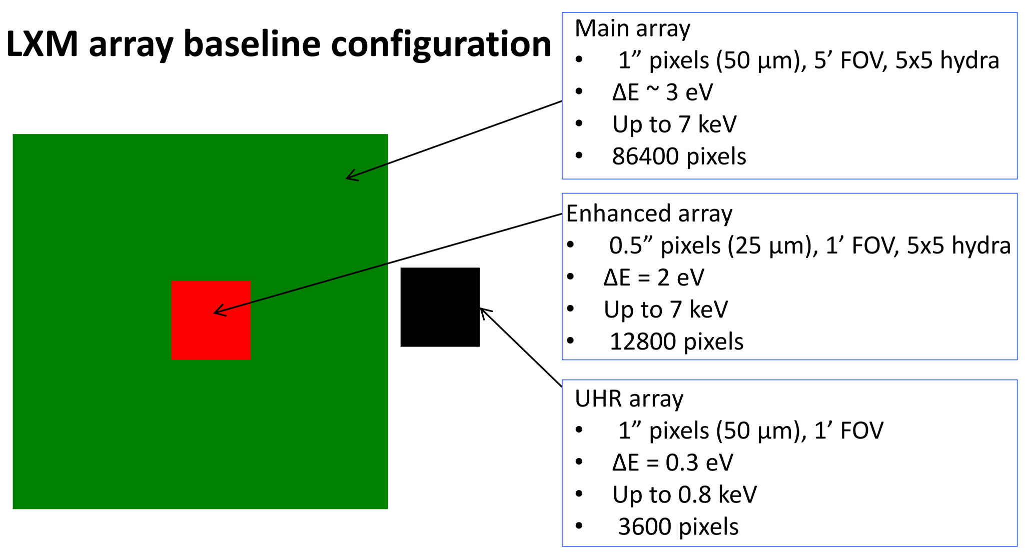
Introduction



- Lynx is a large mission concept under development by NASA for the Astro 2020 Decadal survey
- One of the key Lynx instruments is an imaging spectrometer called the Lynx X-ray Microcalorimeter (LXM) which comprises of a very large detector array with > 100K pixels

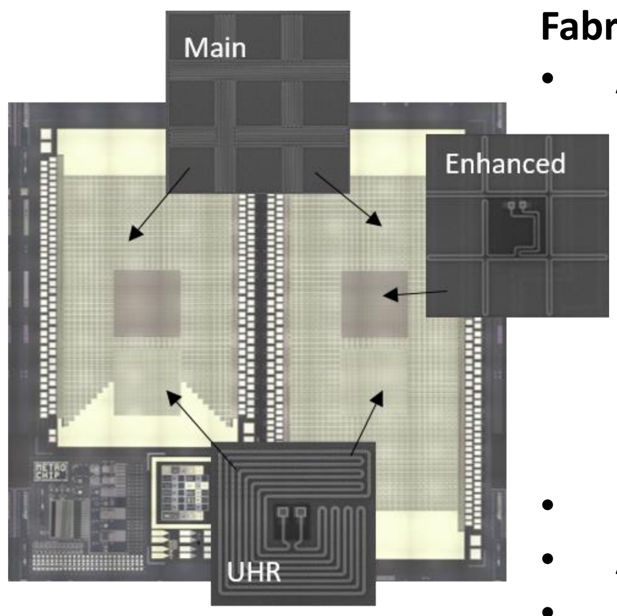
- Metallic magnetic calorimeter (MMC) technology is a leading contender for detectors for the LXM
- MMCs can be used to measure the energy of individual X-ray photons with high precision by sensing changes in the magnetic susceptibility of a paramagnetic metal film (Au:Er) as its temperature rises in response to the absorbed photon energy



Motivation

- Design and fabrication challenges for large size arrays
  - 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 sensor inductance by decreasing sensor meander coil pitch
  - Maximizing magnetic coupling by scaling sensor (Au:Er) and sensor insulator thickness with pitch
  - Maximizing 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

MMC Arrays with Four Buried Nb Layers



Fabrication Summary

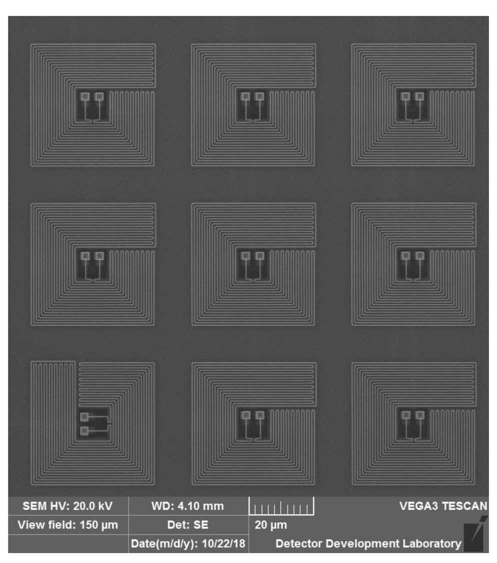
- All buried wiring and sensor meander coil layers are processed as follows
  - Nb deposition by dc magnetron sputtering
  - Patterning of Nb by deep UV (DUV) lithography (248 nm) and plasma etch
  - SiO_2 interlayer dielectric (ILD) deposition by PECVD
  - Chemical Mechanical Planarization of ILD to desired thickness
  - Patterning of ILD by DUV lithography and plasma etch
- MMC sensor (Au:Er) deposition by sputtering and patterning by lift-off
- Au hydra link deposition by e-beam evaporation 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

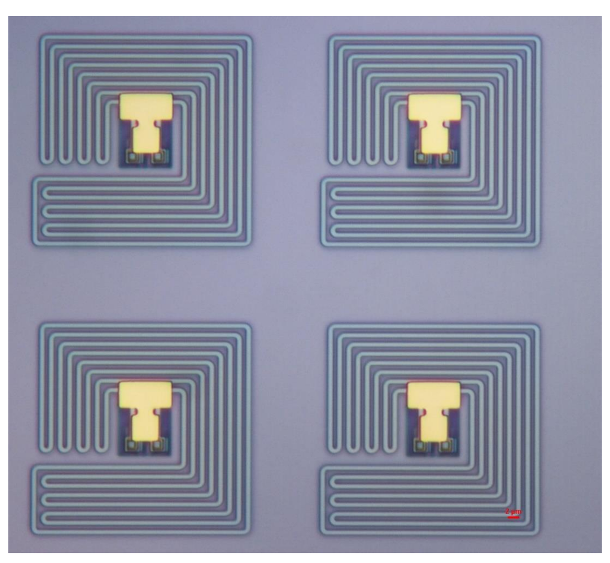
Fabricating High Inductance MMCs

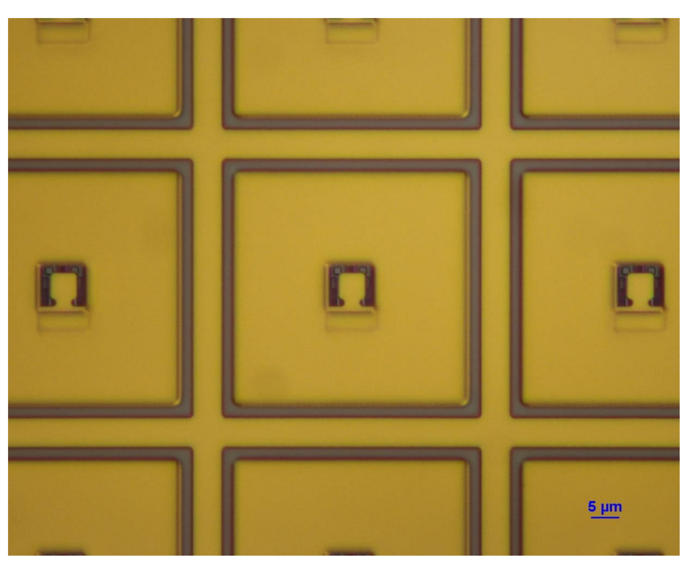
- Sensor meander coil pitch is reduced to 800 nm to increase sensor inductance
- To maintain good magnetic coupling with the reduced pitch, thickness of Au:Er is scaled to 128 nm
- To maintain a large critical current per unit width in the wiring and the sensor meander coils, Nb is anistropically etched to produce vertical edges, resulting in an approximately square cross section
- By using multiple layers of buried wiring, larger wiring linewidths are maintained, resulting in a decrease in the wiring inductance

UHR array

- Square annulus shaped sensor with non-hydra design
- Superconducting vias at the center of the sensor connect sensor meander coils on the topmost Nb layer to twin microstrip wiring on the bottom most Nb layer
- Au thermal link connects sensor to absorber stem in order to control size of slew rate at readout


Nb sensor meander coils


After addition of Au hydra links



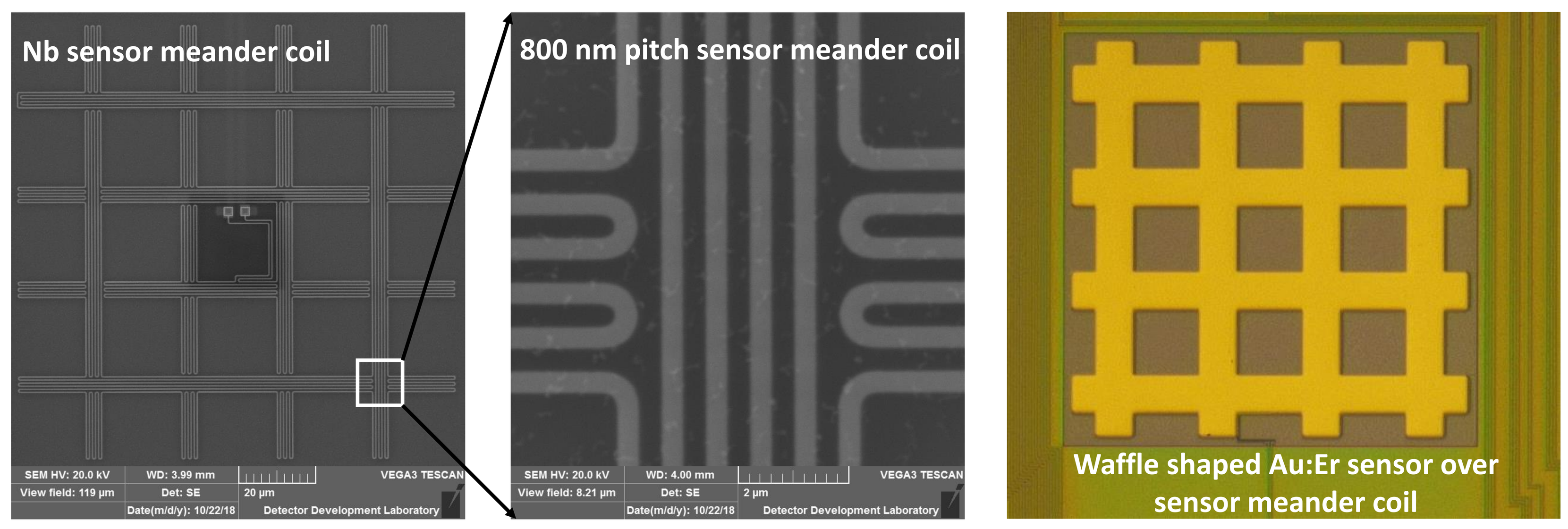
With Au:Er sensor and Au heat sinking grid deposited

Prototype Highlights

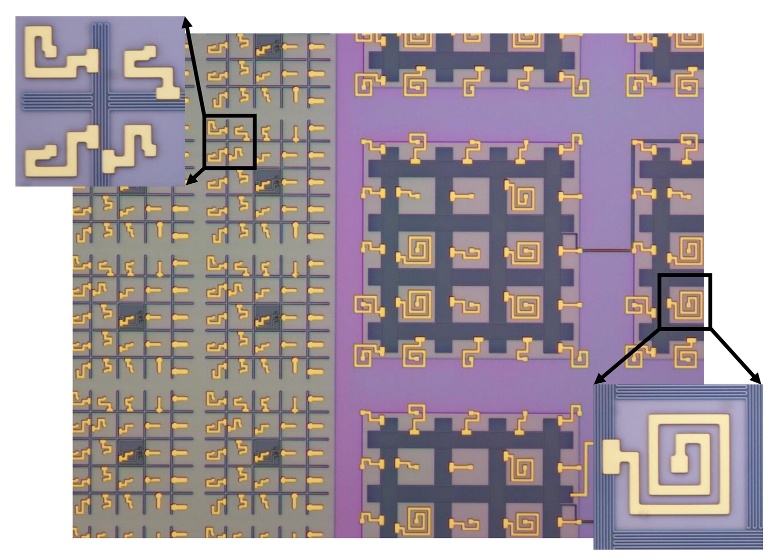
- 55800 pixels thermally linked to 5688 sensors
- 4 buried Nb layers
  - high yield, low inductance, high density wiring
  - reduced cross-talk through the use of shielding ground planes
  - precludes need for aggressive packing of wiring on one layer by allowing the fanout of wires from sub-arrays under Main array pixels

Main and Enhanced arrays

- Arrays of waffle shaped, multi absorber sensors in a 5 x 5 hydra configuration

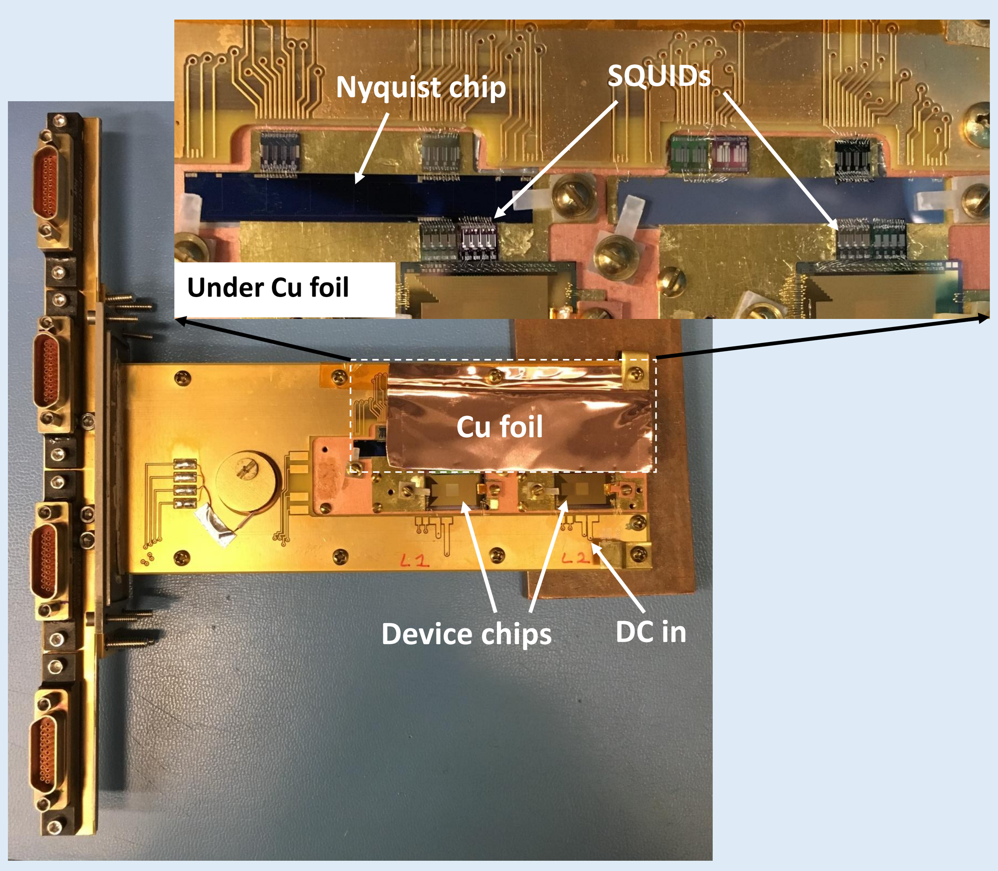


- Main array sensor meander coils and twin microstrip wiring are patterned on top Nb layer
- Enhanced array sensor meander coils on topmost Nb layer are connected through superconducting vias to twin microstrip wiring on the bottom most Nb layer.
- Hydra design allows 25 different pixels to be read using a single sensor. 25 absorbers are coupled to a single sensor through Au thermal (hydra) links of varied thermal conductance.


Enhanced array (left) and Main array (right) hydra link design


20 µm x 20 µm hydra absorbers for Enhanced array pixels (top left), 50 µm x 50 µm hydra absorbers for Main array pixels (bottom and right)

Test Results



Test setup

- Measured critical current at 4K on pixels with 400 nm wide sensor meander coils is better than 30 mA
- Issues with cooling system limited operating temperature to 50 mK
- Each sensor is not coupled to an optimized SQUID
- NEP at T = 50 mK

Enhanced array 800 nm pitch pixel	1.96 eV – 1.99 eV
Main array 800 nm pitch pixel (with noisy SQUID)	10.5 eV – 12.5 eV
Main array 800 nm pitch pixel (noise corrected)	2.8 eV – 3.7 eV

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