Cryogenic X-ray Detector R&D at APS

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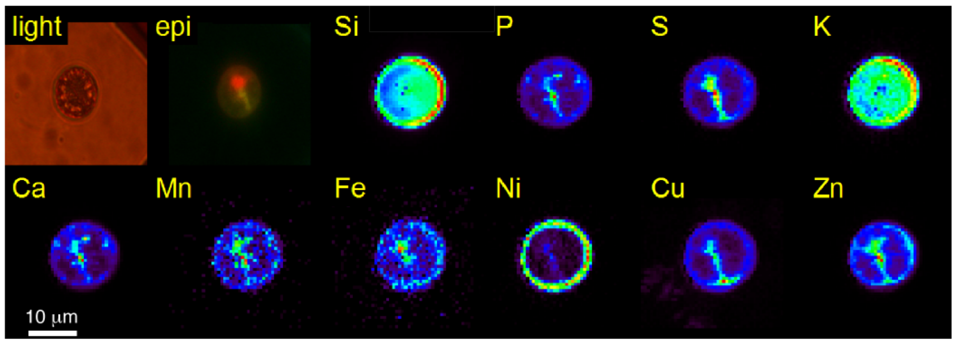
Cryogenic X-ray Detector R&D

- **Energy dispersive semiconductor detectors have almost reached their theoretical limits**
  - e.g., Silicon Drift Diodes have energy resolution ~ 150 eV at 6 keV
- **Limited R&D on spectroscopic detectors**
  - Only effort is Silicon array detector of Peter Siddons (BNL) and Chris Ryan (Australia)
    - Using Silicon arrays to achieve large collection solid angles for micro-probe XRF experiments
- **Leverages local facilities and existing projects**
  - Argonne's Nanocenter (CNM) for device fabrication
  - Transition Edge Sensors for UChicago/ANL cosmology

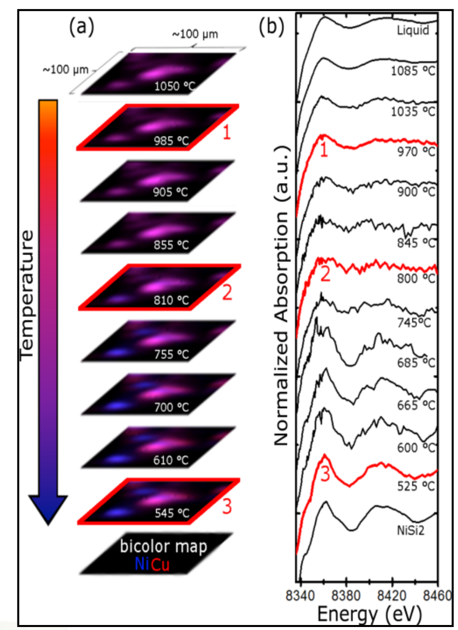
Example Application: X-ray Microscopy

- **Mapping the distribution of elemental composition**
  - 100 eV resolution is sufficient
  - Need more solid angle, count rate, and P/B to reduce minimum detectable limits



B. Twining, S. Baines, N. Fisher, J. Maser, S. Vogt, C. Jacobsen, A. Tovar-Sanchez, and S.Sañudo-Wilhelmy, *Anal.. Chem.* **75**, 3806 (2003)

- **How to map chemical states at nanometer-scale?**
  - "Nano-spectroscopy"
  - Today: XANES with no spatial resolution
  - *Are there alternatives?*



S. Hudelson, D. Newman, S. Bernardis, D. P. Fenning, M. I. Bertoni, M. A. Marcus, S. C. Fakra, B. Lai, T. Buonassisi *Adv. Materials 22, 3948 (2012)*

X-ray Emission Spectroscopy Imaging

- 2D mapping of chemical states the same way we acquire elemental maps today
- Detector Requirements
  - eV resolution
  - Broadband (multiple elements at the same time)
  - Count Rates > 100 kcps
- ***This may be the only way one could consider doing spectroscopy with < 20 nm spatial resolution on radiation sensitive materials (e.g., organic photovoltaics).***

Non-resonant XES spectra

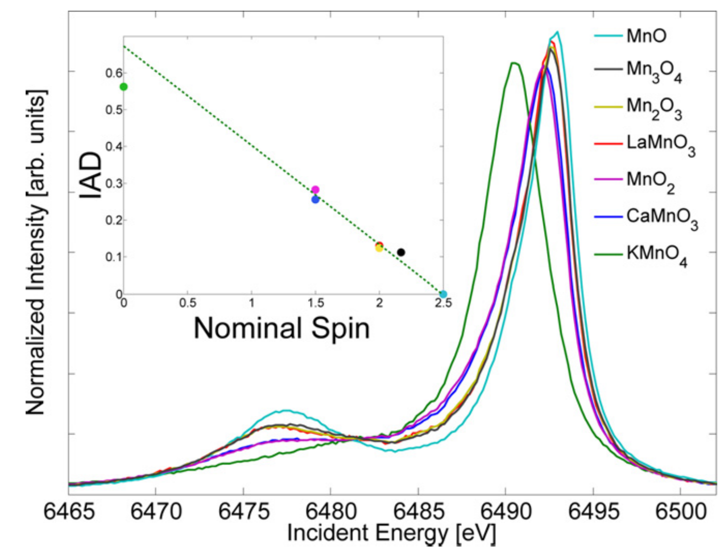
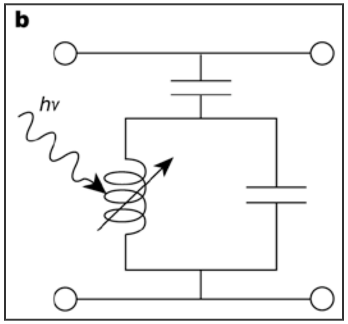


Fig. 6. Kβ main X-ray emission spectra normalized to the spectral area of manganese oxides, $K^{VII}MnO_4$ and perovskites $CaMn^{IV}O_3$ and $LaMn^{III}O_3$; (inset) IAD values with MnO as reference as a function of formal spin state with linear fit that considered MnO, MnO_2 and perovskites. The statistical error is smaller than the symbols.

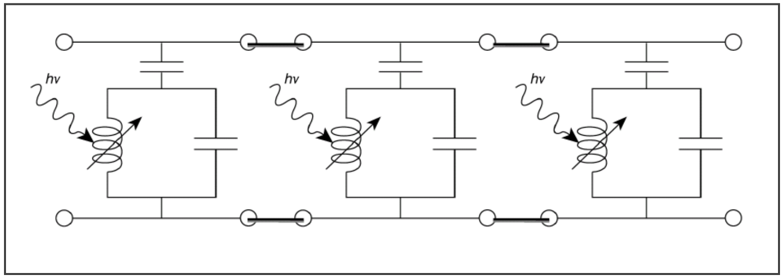
Taken with crystal analyzer (Pieter Glatzel et al)

Microwave Kinetic Inductance Detectors

- Excess quasiparticles or ΔT generated by x-ray causes an inductance increase (i.e., "kinetic inductance")
  - Measure inductance change in a LC resonating circuit

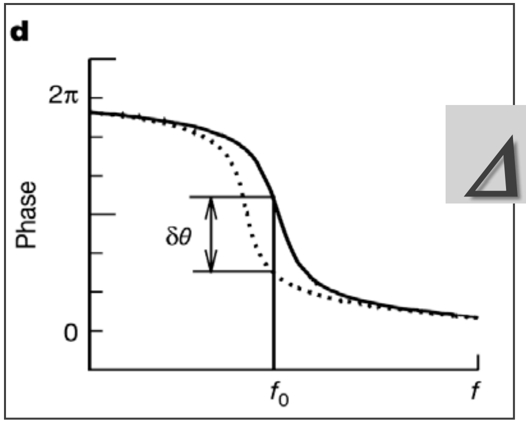


Multiplexing: Lithographically vary geometric inductance/resonant frequency…

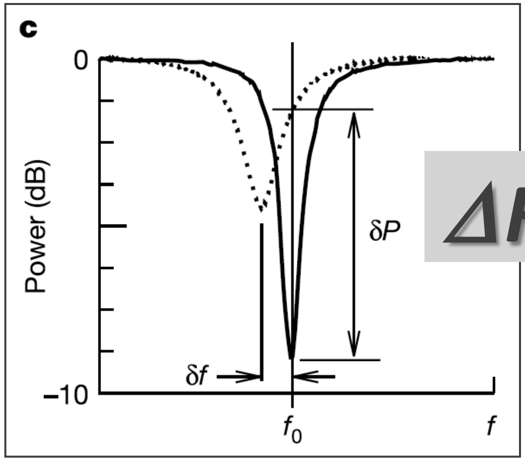


- ➢ ***2024 pixels demonstrated in 2013 (UCSB/JPL)***
- ➢ ***Groups are contemplating 10-100k pixels today (FNAL)***
  - *Limited by room temperature electronics*

Observables….



ΔL_s

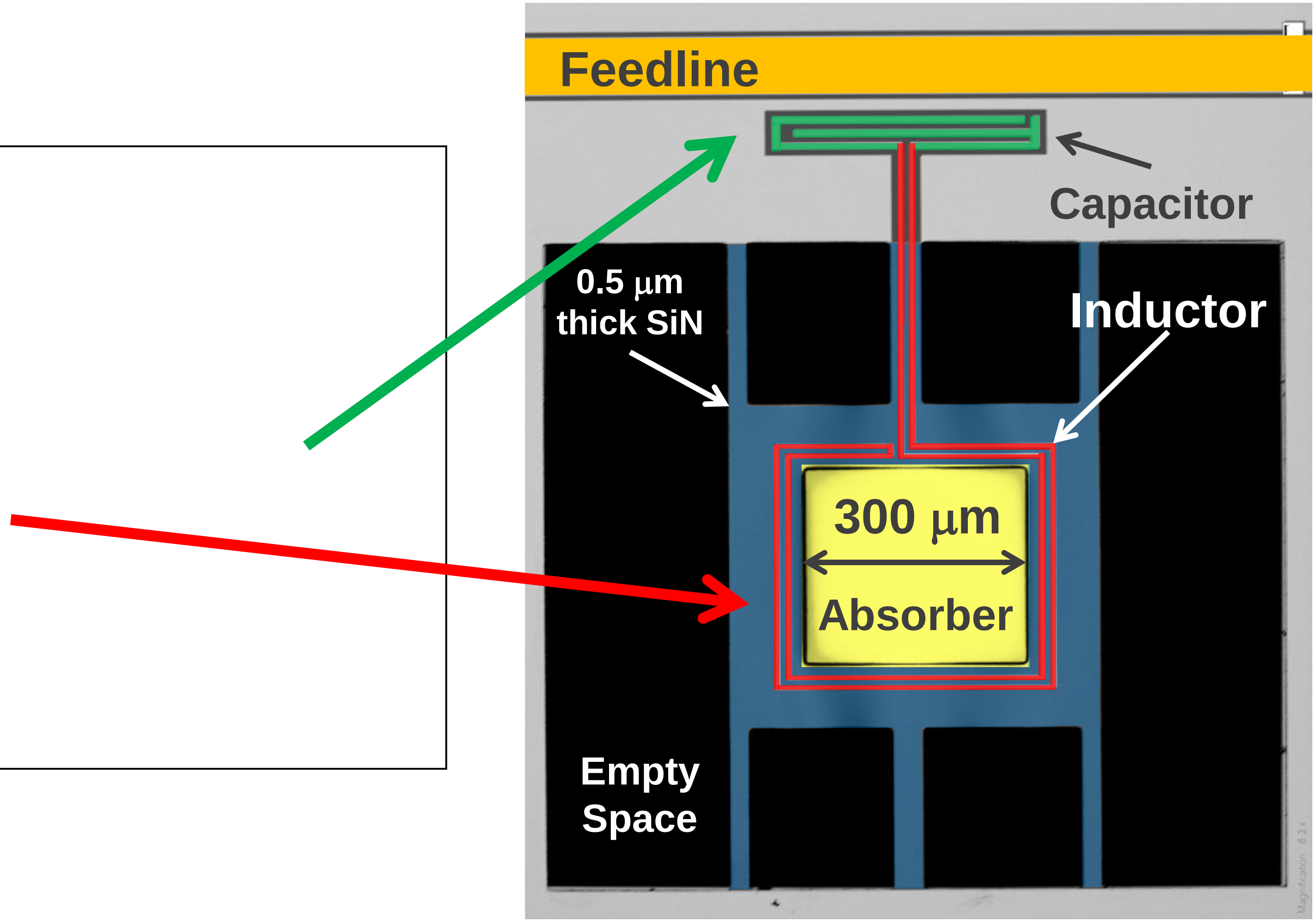


ΔR_s

MKIDs @ APS for synchrotrons

- The goal is energy resolution < 5eV with good count rate capabilities (> 100kcps)
- Three Main Aspects:
  1. **Device Fabrication**
     - Completely in-house with dedicated deposition chamber
  2. **Cryogenics and Device Characterization**
     - Turnkey 100 mK cryostat (cryogen-free)
  3. **Readout electronics**
     - Multi-pixel implementation in progress (Tim Madden)

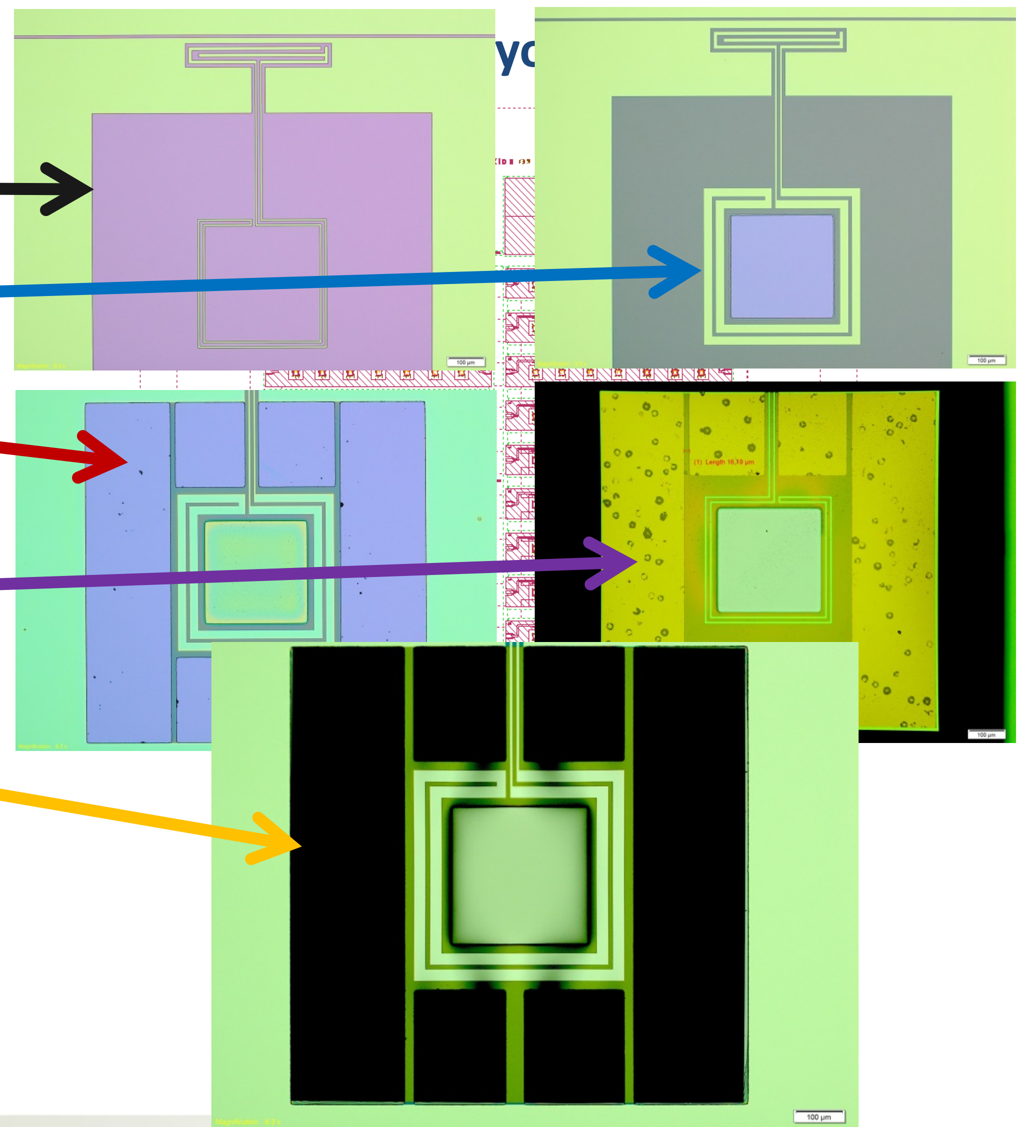
Anatomy of a thermal MKID (i.e., calorimeter)



0.5 x 300 x 300 μm Tantalum Absorber
100 nm WSi_2 resonator

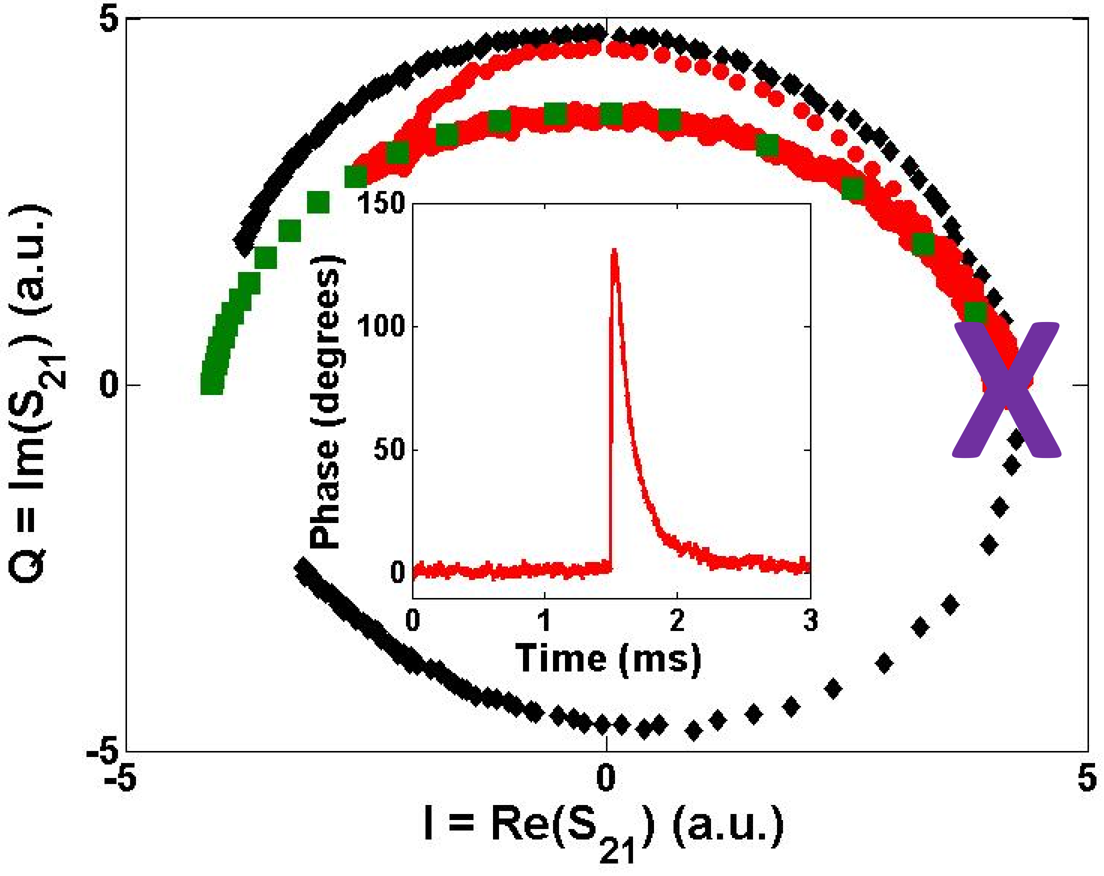
Fabrication Process

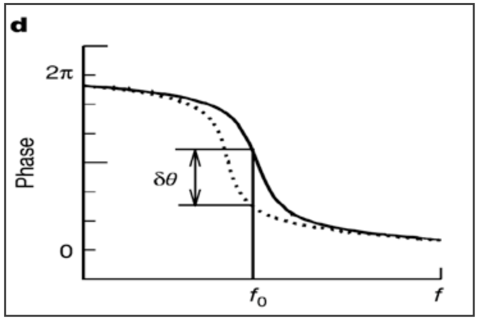
1. 0.5 μm SiN + 300 μm Silicon wafer
2. Resonator deposition (@ APS)
3. Resonator Lithography (MA-6, CNM)
4. Resonator Etch (Oxford RIE, CNM)
5. Resist strip (1165 remover, CNM)
6. Absorber Lithography (MA-6, CNM)
7. Absorber deposition (@ APS, CNM)
8. Absorber liftoff (1165 remover, CNM)
9. SiN bridge lithography(MA-6, CNM)
10. Backside SiN membrane lithography (MA-6, CNM)
11. Backside SiN etch (March etcher, CNM)
12. Bulk Si etch (KOH, CNM)
13. Backside protective Al depositions (@ APS)
14. SiN bridge etch (March etcher, CNM)
15. Al wet etch (CNM)
16. Resist strip (1165 remover, CNM)

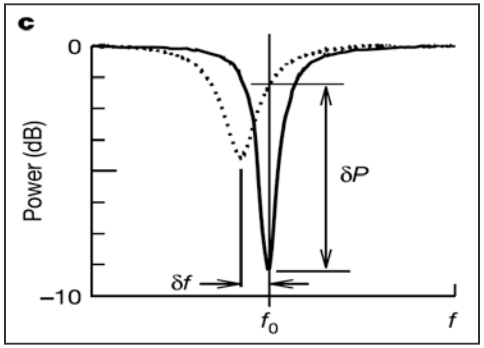


Measurements

- Find resonance frequency and monitor changes in phase (and amplitude)
  - Using mixing techniques







Current status & future work

- **Measured energy resolution = 90 eV with Fe-55**
  - This is the first version of this device.
  - Limited by rise-time variation
    - Need to weaken thermal coupling between resonator and absorber or improve thermalization with a normal metal underlayer.
- **Baseline Resolution = 45 eV**
  - This device is considerably noisier than most given SiN under capacitor, especially at low frequencies.
  - SiN mesa design to be fabricated next week.
- **Future Work**
  - Reduce noise (iterating between testing and fab)
  - Thicker absorbers (e.g., mushroom absorbers on SU-8 posts)
  - Implementation of 256-pixel readout electronics

The Team

- Tom Cecil (XSD Staff)
- Lisa Gades (XSD staff)
- Orlando Quaranta (Post-doc)
- Tim Madden (XSD Staff)
- Antonino Miceli (XSD Staff)

Thank you for your attention!