Science in seconds

the bigger, faster future of superconducting detectors

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microwave kinetic inductance detectors (mkids)

Photon absorption breaks cooper pairs, varies the kinetic inductance of a microwave resonant circuit

- Natural frequency-domain multiplexing
- Difficult to make high resolution X-ray, gamma ray detectors

metallic magnetic microcalorimeters (mmcs)

Magnetization of paramagnetic material in weak B-field used to measure temperature change due to photon absorption

• Demonstrated excellent energy resolution, good linearity with energy
• Difficult to multiplex
transition-edge sensors (tes)

Superconducting resistive transition used to measure temperature change caused by photon absorption

- Many techniques for multiplexing
- Good energy resolution over a wide range of energies (x-ray to gamma ray)
Superconducting detectors are already enabling science

emission spectrum of Pu

Bennett et al., RSI 83, 093113 (2012)
Superconducting detectors are already enabling science
We need to do

Science*

* collect and analyze a useful energy spectrum
We need to do

Science in seconds
Counting more photons

ASC 2020
\(10^2\) pixels
\(10^2\) cps/pix

ASC 2026
\(10^4\) pixels
\(10^3\) cps/pix

ASC 2040
\(10^6\) pixels
\(10^4\) cps/pix
64-pixel MMC array

S. Kempf et al., AIP Advances 7, 015007 (2017)
Challenges:

- Limit number of readout channels at room temperature
- Make better use of microwave readout bandwidth
- Compact, efficient packaging

megapixel arrays
larger multiplexing factors

**hybrid multiplexing:**
stage 1: code-division multiplexing (CDM)

larger multiplexing factors

**hybrid multiplexing:**

stage 2: high-bandwidth microwave SQUID mux

Mux factors
Microwave: $10^3$
CDM: $10^1 - 10^2$
Combined: $10^4 +$

C Yu et al, Engineering Research Express, 2-1 (2020)
larger multiplexing factors

"hydra": one thermometer connected to multiple pixels

- "mux" factor: \( \sim 10^1 \)
- Increases spatial resolution for imaging

S.J. Smith, et al., JLTP 199:300-338 (2020)
more efficient use of microwave bandwidth

kinetic inductance traveling-wave amplifier

Lower amplifier noise temperature

Decreased resonator coupling

More resonator channels / bandwidth

see also: talk by M. Malnou, ASC 2020
compact, efficient array packaging

20,000-pixel near-IR mkid array for MEC
https://microdevices.jpl.nasa.gov/capabilities/superconducting-devices/ole-mkids/

more compact arrays

multi-wafer integration
Nanoscale IC screening for defect analysis, process development

- IC manufacturers are already making features on ~10 nm scales
- Difficult to 3D image multi-layer chips: contributes to expense of chip development

https://en.wikichip.org/wiki/File:intel_interconnect_10_nm.jpg
X-ray tomography for nanoscale IC screening

- All-in-one tool for finding, imaging defects in chips at nm scales
- Replaces multi-step, typically destructive techniques currently in use
- Entire chips could be imaged to look for unwanted structures

see talk by P. Szypryt, ASC2020
Realistic chemistry, biology at X-ray light sources

- Many interesting metalloproteins create a weak X-ray signal of interest among a huge background
- Powerful X-ray sources (synchrotrons, XFELs) are used to create enough signal to measure
Realistic chemistry, biology at X-ray light sources

Large arrays of superconducting detectors can make measurements of important biological and chemical systems under real-world conditions possible.

- unrealistic high concentrations
- radiation damage
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let's take superconducting detectors from
"enabling" to "transformative"

Astronomy
Materials science
Dilute biological systems
Laboratory-based light sources
Nuclear safeguards
Neutrino mass measurements
Tomographic imaging
Industrial process monitoring
Neutrinoless double-beta decay
Time-resolved chemistry
Radiation-sensitive materials
Catalytic chemistry
Nuclear fuel processing
Decay-energy spectroscopy