Phonon-Mediated MKIDs for Dark Matter

DM detection down to fermionic thermal relic mass limit of a few keV requires sensitivity to eV-scale depositions.

Phonon-mediated Microwave Kinetic Inductance Detector (MKID) microcalorimeters measure meV-scale quanta.

- Athermal: faster than thermal sensors
- Frequency multiplexed: massively scalable
- Energy resolution limited by detector noise

Energy absorbed by the superconductor depends on the phonon collection efficiency \( \eta_{\text{ph}} \).

![Energy deposition in detector substrate produce phonons lead to breaking of Cooper pairs in Al superconductor.](Image 1)

Detection Mechanism

Energy deposit in substrate \( \rightarrow \) phonons \( \rightarrow \) quasiparticles

1. Momentary increase qP density inside LC resonator
2. Time-dependent kinetic inductance \( \rightarrow \delta f_p, \delta Q \)
3. Change in transmission spectrum of circuit
4. Modulation of amplitude, phase of RF probe tone

Energy Resolution Calibration

Following measurement of energy resolution from [2,3] using photon shot noise to infer absolute energy.

LED pulses: 470 nm light with 1-2 μs widths.

Tunable DC bias up to 6.0 V at 75 mA.

Incident on rear of chip via optical fiber.

Variance of pulse amplitude has contributions from zero-energy noise of MKID as well as photon shot noise

\[
\sigma^2(\mu) = \sigma_0^2 + h \nu \eta_{\text{ph}} \frac{d \nu}{d E_{\text{abs}}} \mu \tag{1}
\]

Device Response to Optical Photon Pulses

Broadening of pulse amplitude distributions apparent beyond zero-energy MKID noise contribution.

- Resolution, energy deposited in substrate \( \sigma_{E_{\text{dep}}} = 316 \) eV
- Phonon collection efficiency \( \eta_{\text{ph}} = 0.8\% \)
- Resolution, quasiparticle density in SC \( \eta_{\text{qp}} = 0.22 \mu \text{m}^{-3} \)

NEXUS Low-Background Facility

MINOS cavern at FNAL

- Dilution refrigerator
- 10 mK base
- 107 m rock overburden
- Moveable lead shielding
- 10(100) dru background
- RF & DC payloads
- Optical calibration platform
- DD neutron generator

References:

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