Contact-less phonons-mediated KID with massive absorber for rare events search

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Introduction
General principle

"Direct"

Incoming particles

Particles/Photons break Cooper-Pair

“Phonons-mediated”

Incoming particles

Phonons break Cooper-Pair

CALDER project [2, 1]
Caltech KIDs R&D [3]
Others ...
Why a contact-less design?

Main advantages

- No phonons loss in the feedline
- More R&D flexibility:
  - decoupling between readout and sensor
  - less constraints on sensor manufacturing
Method
The materials

- **Resonator and Feedline** = thin film Aluminum (Lumped Element)
- **Resonator thickness** = approx. 40nm and 20nm (2 prototypes)
- KIDs fabricated at CNRS Grenoble, e.g. NIKA/NIKA2
- **Massive absorber** = 30g crystalline silicon (36*36*10 mm)

Cryogenic

- Dilution refrigerator
- Base **temperature** = 200mK

Radioactive source

- $^{241}$Am $\rightarrow \alpha$ 5.45MeV, $\gamma$ 60keV, ...
- $\alpha$ **activity** $\approx$ 3kBq
Detector design

Resonator’s **filling factor** $\approx 0.2\%$
Absorber held in place by small clamp

Special thanks to Lionel Vagneron from IPNL for the holder design! (drawing not to scale)
Simulation - Misalignment/Spacing

Misalignment
not a big issue on X and Y axis
Z axis may be more problematic ...

This simulation is done by considering a 40nm thick resonator.
Results
Electrical measurements - IQ circle and resonances

Keypoints

- High Q-factors
- Good response
- Fair agreement simul./meas. [4]

\[ Q_{i}^{\text{simu}} \approx 2.1 \times 10^5 \]
\[ Q_{i}^{\text{exp}} \approx 4.1 \times 10^5 \]

\[ f_{r}^{\text{simu}} \approx 560\text{MHz} \]
\[ f_{r}^{\text{exp}} \approx 564.7\text{MHz} \]

Design is controlled

These are the data for the 20nm thick resonator.
Detuning as a function of $T$

\[ \delta f/f_0 = -\alpha \tanh(\Delta/2k_B T)^{-1/2} - 1 \]

- Very good agreement with MB theory
- Uncertainties about the thicknesses
- Useful to estimate the absorption efficiency $\eta$ (see backup)

Assumptions/Model
- Mattis-Bardeen theory
- $h\lambda \ll \Delta$, $T < T_C/3$
- $\alpha = \text{kinetic inductance fraction } L_k/L_{tot}$

Keypoints
- $L_k^{20\text{nm}} \approx 3. L_k^{40\text{nm}}$
- $\Delta_{\text{fit}} \approx \Delta_{\text{BCS}}(0.197\text{meV})$
Pulse shape investigation

We expect 3 time constants (ph, qp, ring)

Observations

- Exp. model with 2 characteristics times
  - $\tau_{\text{rise}}$ and $\tau_{\text{decay}}$
- $\tau_{\text{rise}}$ and $\tau_{\text{ring}} = Q_L/\pi f_r$ correlated
- $\tau_{\text{decay}} = \text{Phonons limited?}$ (analysis ongoing)

Values at 200mK

- $\tau_{\text{decay}} = 125 \ \mu s$
- $\tau_{\text{rise}} = 104 \ \mu s$
- $\tau_{\text{ring}} = 83 \ \mu s$
Energy spectrum

Results

- Noise baseline resolution = 1.42keV (ref.=α peak)
- MC smeared simulation → visible 60keV peak
  → BUT no clear 60keV peak in the exp. data
  → Position dependency for 60keV ? (+ lower E. X)
- Estimated energy absorption efficiency (for α) η < 1%
Conclusion
A quick summary

We are here

- Contact-less design is controlled ($f_r$, Q-factors,...)
- Noise energy resolution $= 1.4$keV (RMS)
- Absorption efficiency less than 1%

Future work and goals

- Reduce the low frequency noise $\rightarrow \times 2$ energy resolution
- Increase the phonons energy absorption efficiency to few %
- Refine the design, use lower $T_c$ materials, optimize the absorber, add more resonators, ...

$\leftarrow$ Final goal

Achieve the best energy resolution possible and low energy threshold on massive absorber (DM, $\nu$ physics,...)
L. Cardani et al.

Energy resolution and efficiency of phonon-mediated kinetic inductance detectors for light detection.


M. Martinez et al.

Measurements and simulations of athermal phonon transmission from silicon absorbers to aluminum sensors.


D. Moore et al.

Position and energy-resolved particle detection using phonon-mediated microwave kinetic inductance detectors.


Backup slides - Detuning as a function of absorbed Energy

\[ \delta f/f_0 = \beta E \]

\[ n_{qp} = N_q p / V = 2N_0 \sqrt{2\pi k_B T} \Delta_0 e^{-\Delta_0 / k_B T} \]

\[ \eta_\alpha = \frac{11 e^3}{564 e^6 \times 1.2 e^{-6} \times 5.45 e^3} \approx 0.3\% \]

**Keypoints**

- \( T \to n_{qp} \to E \)
- Detuning \( \propto E \)
- Sensitivity 3.5 greater with 20nm device

**Efficiency estimation**

\[ \eta = \frac{\delta f_{\text{measured}}}{\delta f_{\text{expected}}} = \frac{\Delta f_{\text{measured}}}{f_0 |\beta| E_{\text{expected}}} \]
Backup slides - Noise spectrum (preliminary)