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

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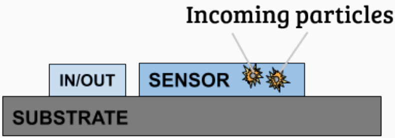
Introduction

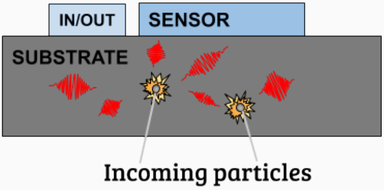
General principle

"Direct"



Particles/Photons break Cooper-Pair

"Phonons-mediated"



Phonons break Cooper-Pair

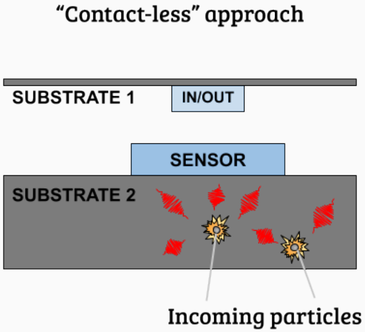
Swenson *et al.* [5] (2010).
CALDER project [2, 1]
Caltech KIDs R&D [3]
Others ...

Why use phonons?

→ **bigger** active **volume**

→ **massive absorber** (>10g)

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

Protocol / Experiment

The materials

- Resonator and Feedline = thin film **Aluminum** (**Lumped Element**)
- Resonator thickness = approx. **40nm** and **20nm** (2 prototypes)

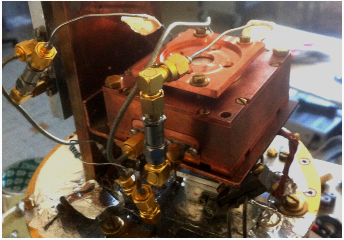
  KIDs fabricated at CNRS Grenoble, e.g. NIKA/NIKA2
- **Massive absorber** = **30g crystalline silicon** (36*36*10 mm)

Cryogenic

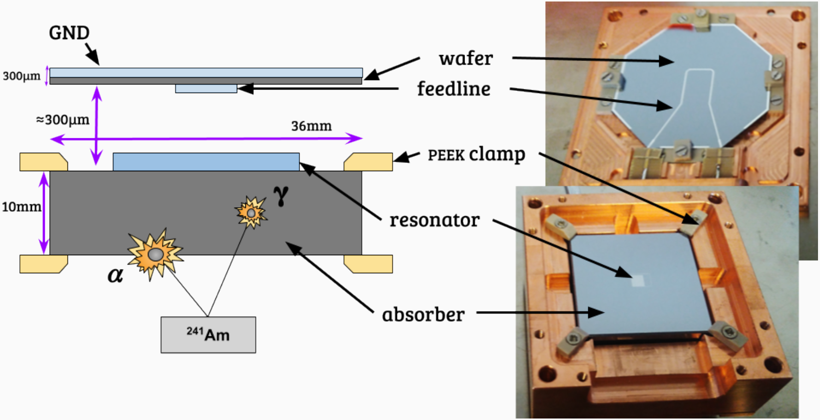
- Dilution refrigerator
- Base temperature = **200mK**

Radioactive source

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



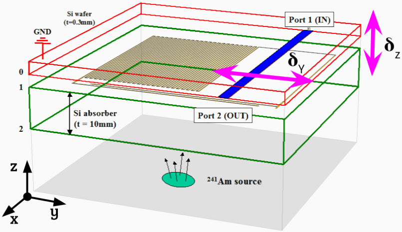
Detector design



Resonator's **filling factor** $\approx 0.2\%$

Absorber held in place by small clamp

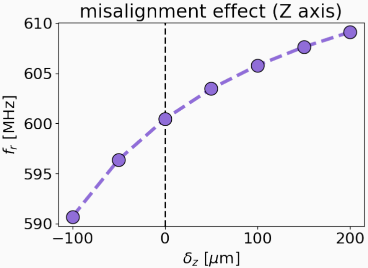
Simulation - Misalignment/Spacing

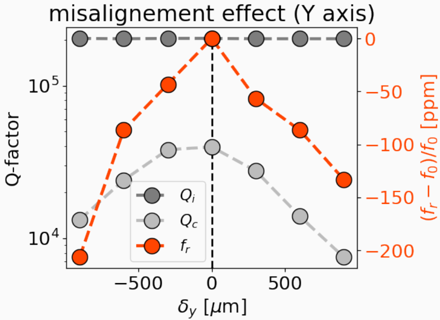


Misalignment

not a big issue on X and Y axis

Z axis may be more problematic ...

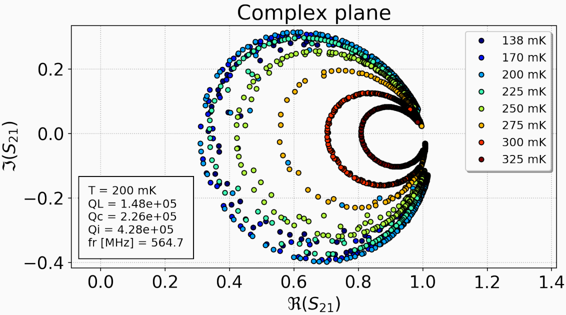


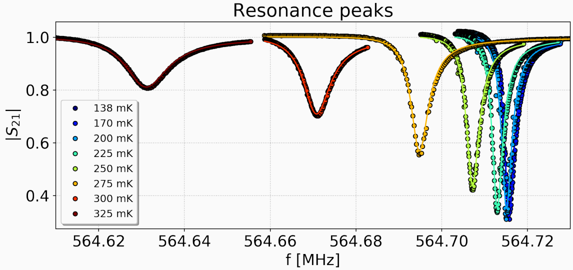


This simulation is done by considering a 40nm thick resonator.

Results

Electrical measurements - IQ circle and resonances





Keypoints

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

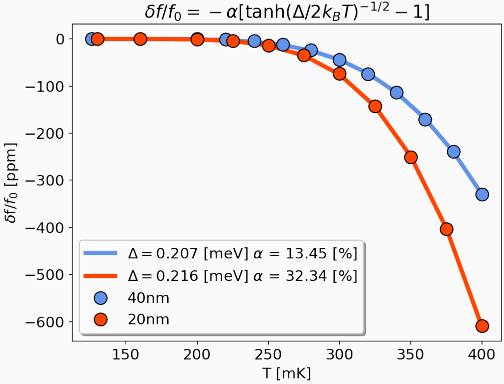
→ $Q_i^{\text{simu}} \approx 2.10^5$
$Q_i^{\text{exp}} \approx 4.10^5$

→ $f_r^{\text{simu}} \approx 560\text{MHz}$
$f_r^{\text{exp}} \approx 564.7\text{MHz}$

↪ **Design is controlled**

These are the data for the 20nm thick resonator.

Detuning as a function of T



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

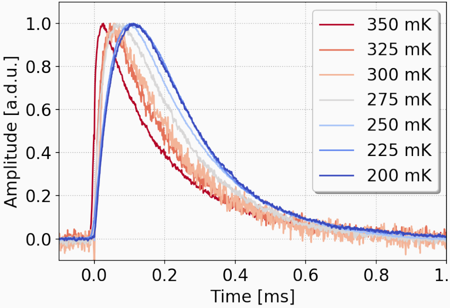
Assumptions/Model

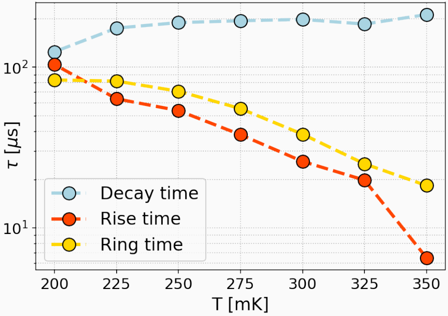
- Mattis-Bardeen theory
- $hf << \Delta$, T $< T_C/3$
- α= kinetic inductance fraction L_k/L_{tot}

Keypoints

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

Pulse shape investigation





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

Observations

- Exp. model with **2 characteristics times**

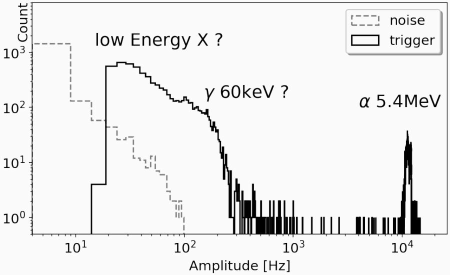
→ τ_{rise} and τ_{decay}

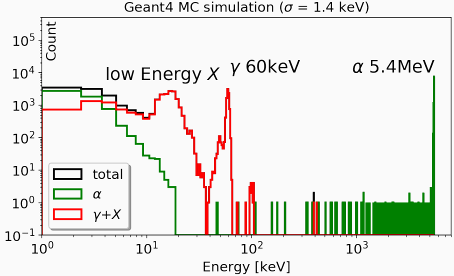
- τ_{rise} and $\tau_{\text{ring}} = Q_L/\pi f_r$ correlated
- $\tau_{\text{decay}} =$ **Phonons** limited? (analysis ongoing)

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.$=\alpha$ peak)
- MC smeared simulation $\rightarrow$ visible 60keV peak

$\hookrightarrow$ **BUT no clear 60keV peak** in the exp. data

$\hookrightarrow$ **Position dependency** for 60keV ? ($+$ lower E. X)

- Estimated energy absorption efficiency (for α) $\eta < 1\%$

Conclusion

A quick summary

We are here

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

Future work and goals

- Reduce the low frequency noise → ×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, ...

↪ **Final goal**
Achieve the best energy resolution possible and low energy threshold on massive absorber
(DM, ν physics,...)

L. Cardani et al.
Energy resolution and efficiency of phonon-mediated kinetic inductance detectors for light detection.
Applied Physics Letters, 107(9), 8 2015.

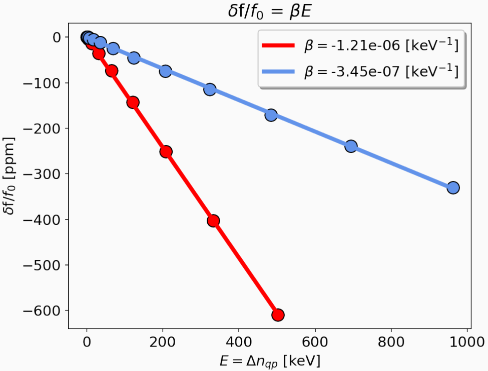
M. Martinez et al.
Measurements and simulations of athermal phonon transmission from silicon absorbers to aluminum sensors.
Phys. Rev. Applied, 11:064025, Jun 2019.

D. Moore et al.
Position and energy-resolved particle detection using phonon-mediated microwave kinetic inductance detectors.
Applied Physics Letters, 100, 03 2012.

S. Probst, F. B. Song, P. A. Bushev, A. V. Ustinov, and M. Weides.
Efficient and robust analysis of complex scattering data under noise in microwave resonators.
Review of Scientific Instruments, 86(2):024706, 2015.

L. J. Swenson et al.
High-speed phonon imaging using frequency-multiplexed kinetic inductance detectors.
Applied Physics Letters, 96(26):263511, 2010.

Backup slides - Detuning as a function of absorbed Energy



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

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

Keypoints

- $T \rightarrow n_{\text{qp}} \rightarrow E$
- 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)