Investigation of Single Crystal Niobium for Microwave Kinetic Inductance Detectors

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Microwave Kinetic Inductance Detectors

***Aim:* Study of Single Crystal Niobium with high RRR for sub-mm radiation detection**

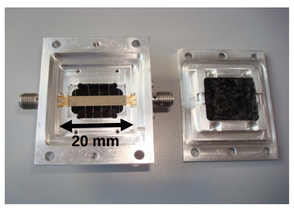
MKID [1]:
1. **Superconducting film into a resonant microwave circuit**
2. **Creation of quasi particles by incident photon (breaking of Cooper pair)**
3. **Change in Kinetic Inductance and Resonance: measure of (Δf) & (ΔA)**

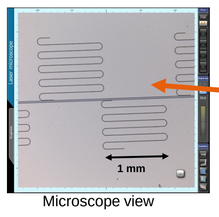
- ✓ **simplicity of the device**
- ✓ **intrinsic frequency multiplexing capability**
- ✓ **good sensitivity from X-ray to sub-mm electromagnetic spectrum**
- ✓ **possibility of a large array of pixels**
- ✓ **readout with only one pair of microwaves coaxial cables**

Fabrication

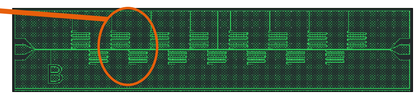
Fabrication parameters

- R-Plane Sapphire wafer: 500 µm thick
- DC magnetron sputtering: high rate ≈ 1,7 nm/sec
- Substrate heated at 800 °C during the deposition
- Vacuum = 10^{-6} Pa
- Low level of residual gas: Hydrogen, Nitrogen & H_2O
- MKID pattern with photolithography
- MKID definition with Reactive Ion Etching



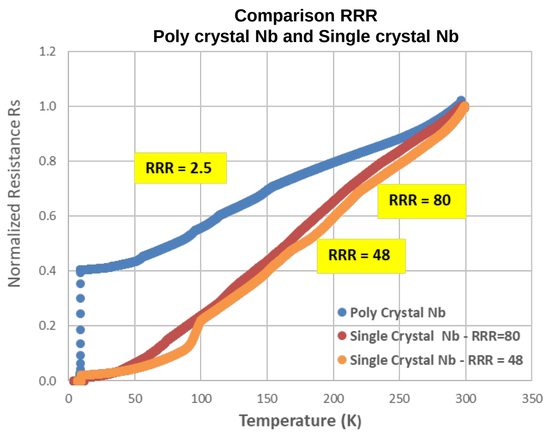


Microscope view

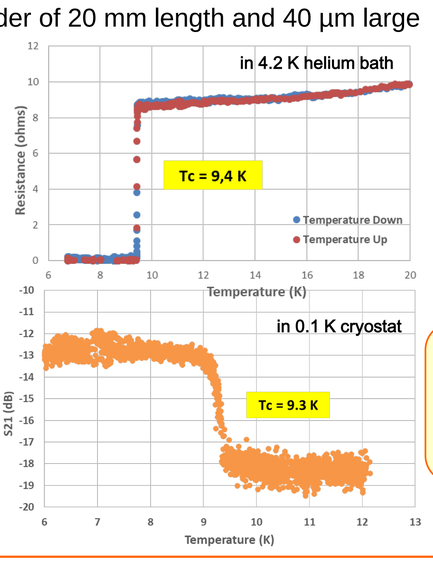


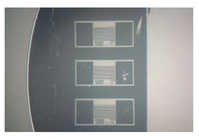
DC properties of the Nb layer

Experimental setup: DC test device = meander of 20 mm length and 40 µm large



Residual Resistivity Ratio (RRR) up to 80 for Single Crystal Nb





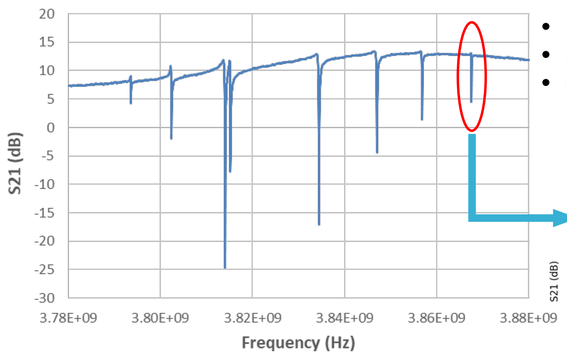
Tc = 9.4 K ≈ Tc bulk

Resistivity @ T 300K:
ρ = 15.8 µΩ.cm ≈ ρ bulk

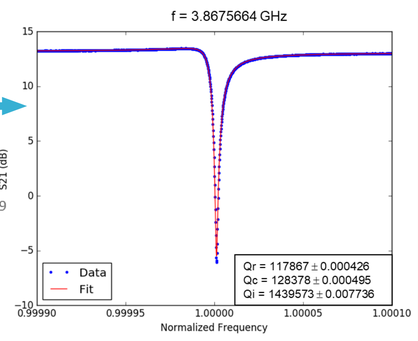
Resistivity @ Tc :
ρ = 0.27 µΩ.cm

Characterization of MKID made of Single Crystal Nb

Resonance Quality factors



- 14 resonances over 15 designed
- 2 groups around 3.8 GHz & 5 GHz
- resonance dips up to 30 dB



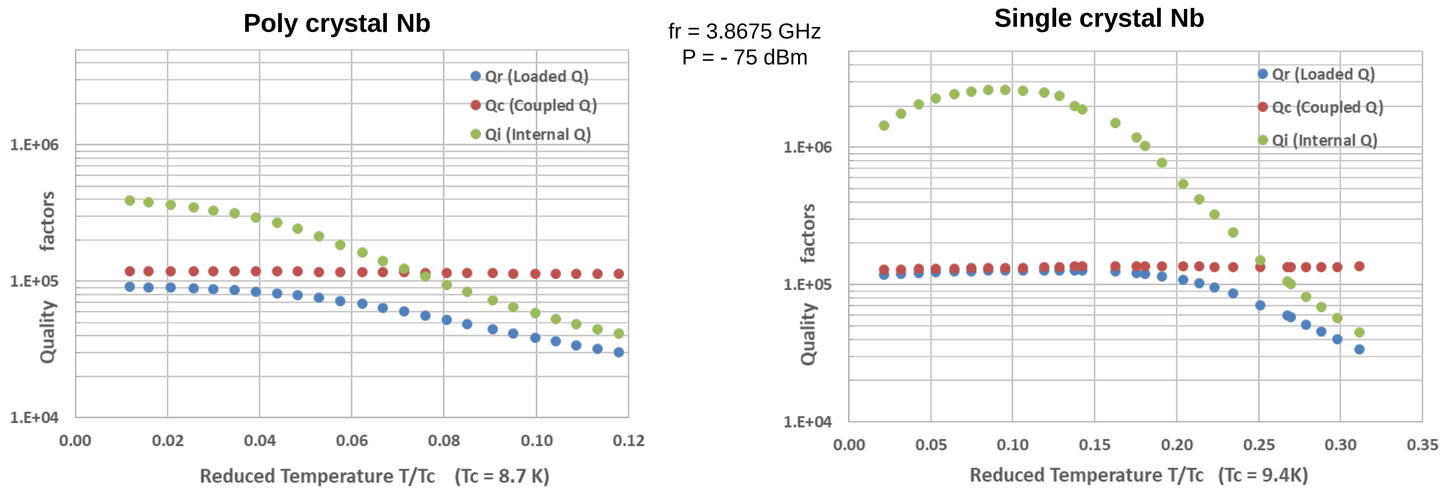
Quality factors

$Q_r = 1.2\ 10^5 \pm 0.04\ \%$

$Q_c = 1.3\ 10^5 \pm 0.05\ \%$

$Q_i = 1.5\ 10^6 \pm 0.77\ \%$

Temperature dependence of Quality factors

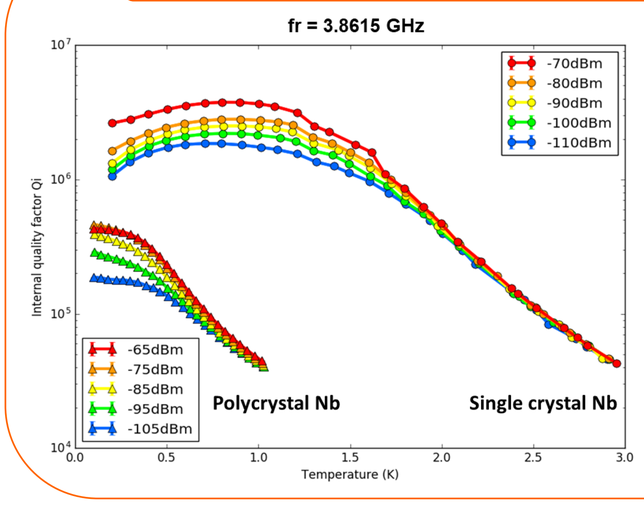


Q_i up to 4.10^5

Qc constant = 1.1 ~ 1.3 10^5

Q_i up to 3.10^6

Power dependence of Quality factor Qi



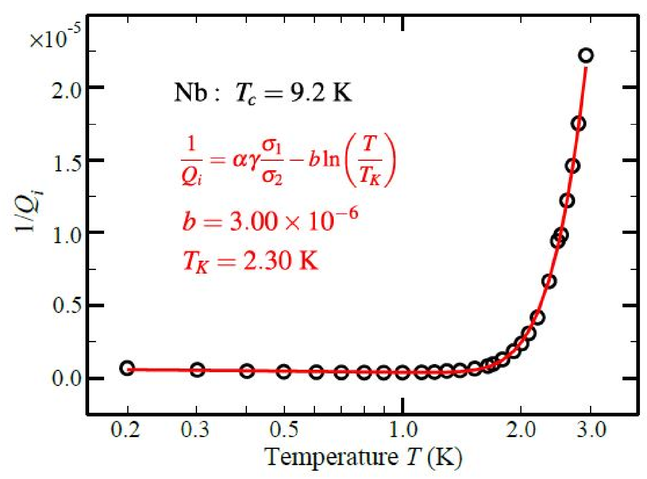
- **increase of Qi when increase of Input Power**
- **not saturated @ T << Tc not following Mattis-Bardeen theory anymore**
- **need to add corrections to MB theory @ T << Tc to explain the temperature-dependence of Qi and δfr/fr of Nb thin-film resonator**

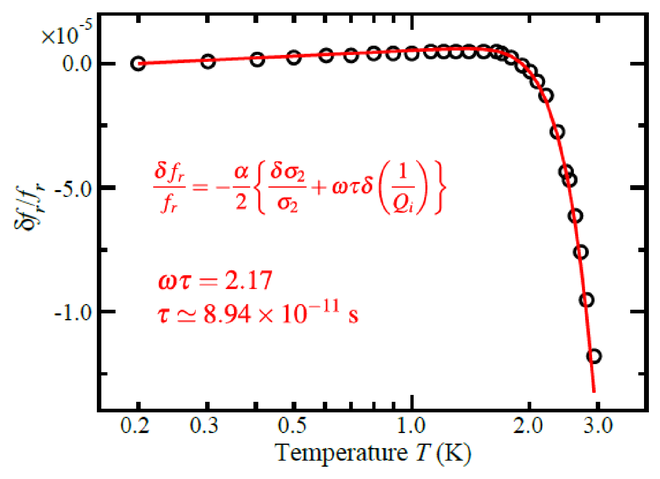
Added correction to MB theory @ T << Tc

@ T > 0.2 K: T-dependence of Qi and δfr/fr follows the prediction of the extended Mattis-Bardeen theory [2]
@ T < 0.15 K: need to add other contributions to predict the behaviour of Qi and δfr/fr respect to the temperature [3]

Q_i { Complex conductance given by the extended MB theory ⊕ Normal resistance with the Kondo effect-like behaviour

$\delta f_r/f_r$ { $\delta X_s/Xs$ predicted by Mattis-Bardeen theory ⊕ Small fraction of Q_i δ $(1/Q_i)$

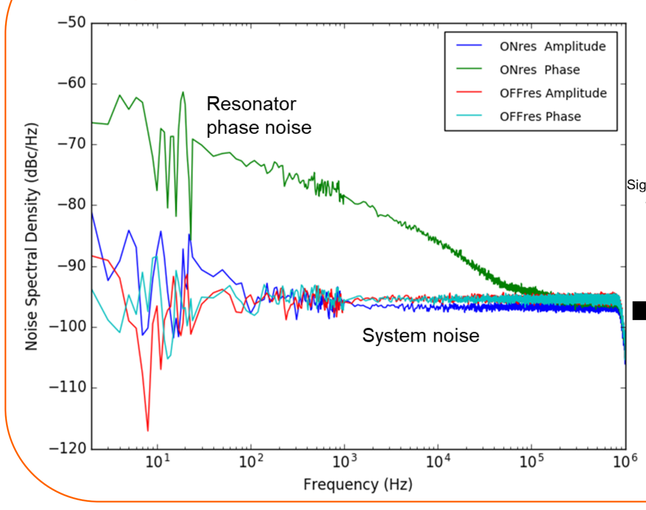




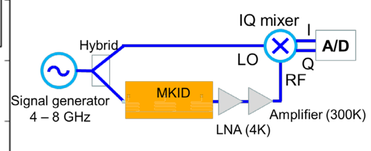
Good agreement between measurement (circle) and predicted model (red line)

➡ **See Poster PA4 (Noguchi-san)** for more explanation on added correction model

Noise Spectrum Density Measurement



Homodyne detection



- 95 dBc/Hz

T = 100 mK
fr = 3.8615 GHz
P_{input} = - 90 dBm

Conclusion and Perspectives

Conclusion: Good results on Single Crystal Nb: - high RRR (up to 80)
- $Q_i > 10^6$
- low noise level

Added correction model checked on Single crystal Nb measurement

Perspectives:
- To improve Single Crystal Nb performance (film quality, etc..)
- To investigate other materials to confirm the added correction model

Refs: [1] J. Zmuidzinas et al., Annu. Rev. Cond. Mat. Phys. 3 (2012)
[2] T. Noguchi et al, IEEE Trans. Appl. Supercond. 26 (2016)
[3] T. Noguchi et al, LTD17, Poster PA25 (2017)
[4] J. Gao, PhD. Thesis, Caltech, Pasadena, CA (2008)