Development of large array of Kinetic Inductance Detectors using commercial-level foundry

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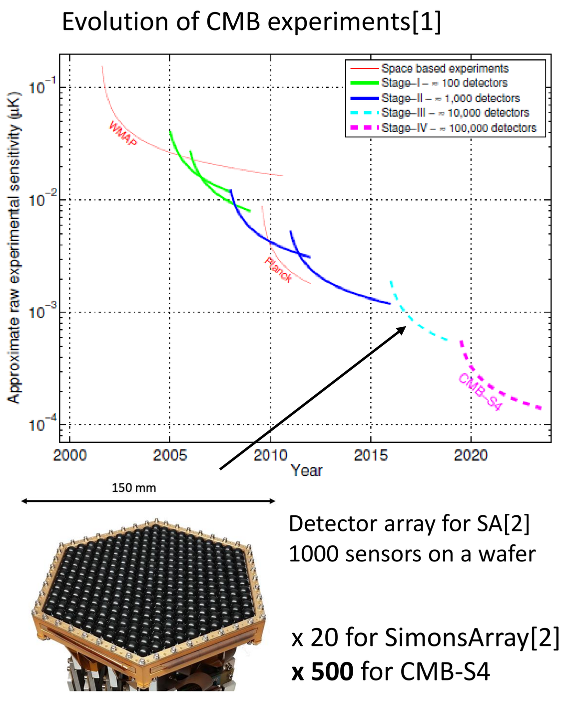
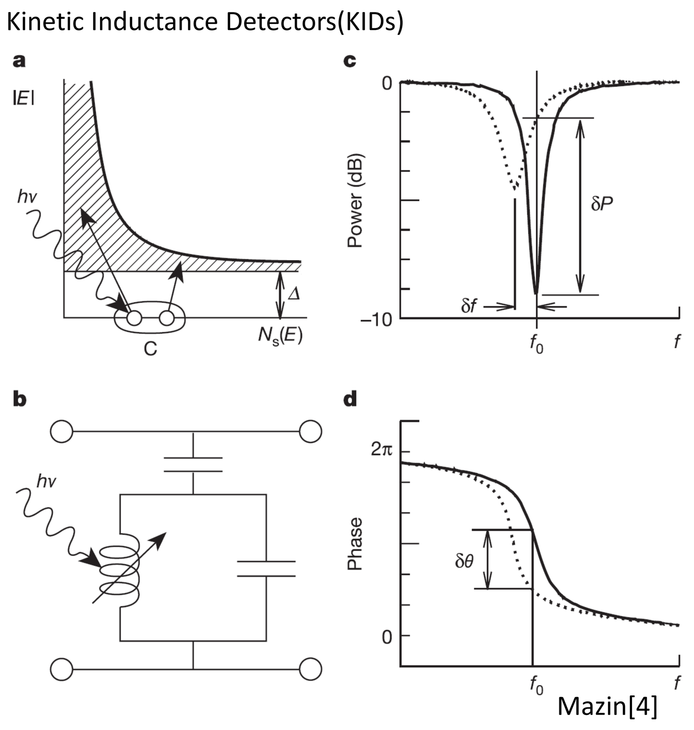
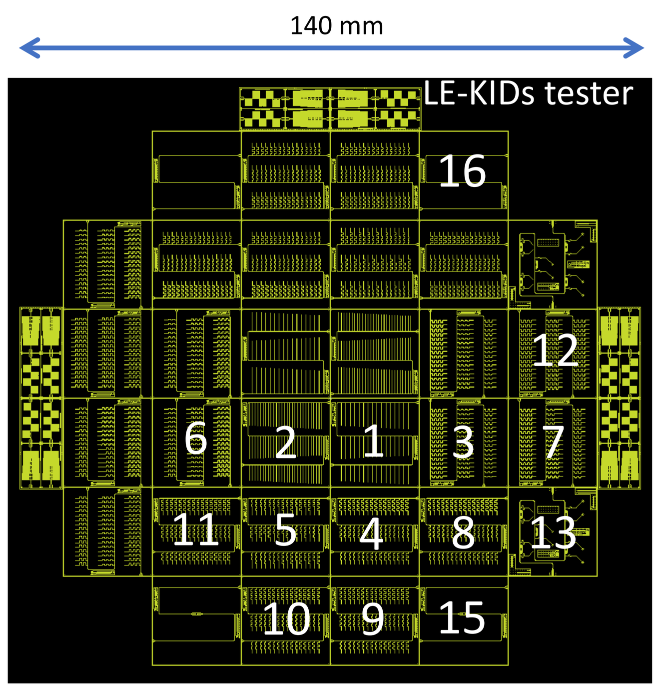
Introduction

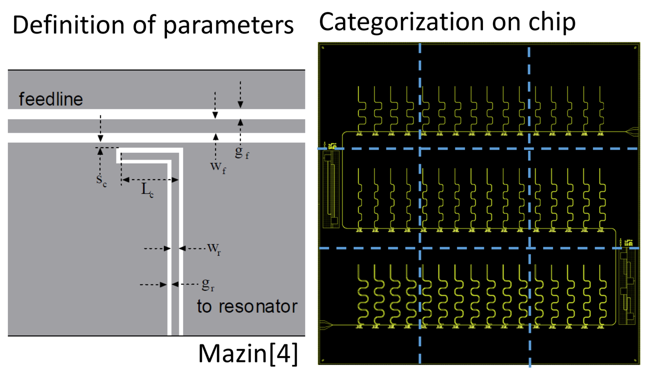




Next generation experiments, especially CMB experiments, require a large array of superconducting detector.
A Kinetic Inductance Detectors(KIDs, [3]) is promising detector to develop a large array of detector.
(a) Electrons in a superconductor create cooper-pairs and there is an energy gap between energy state of cooper-pairs and normal states.
Cooper-pairs create an inductance due to their inertia.
Once the energy above energy gap is deposited, cooper-pairs excited into normal states.
(b) KIDs consists of superconducting resonators and inductance shift is measured as a frequency shift(c) and/or phase shift(c) of resonators.
More than 1000 resonators, each resonator has unique frequency, can readout by single a pair of wire thanks to frequency multiplexed readout scheme.

Design of KIDs



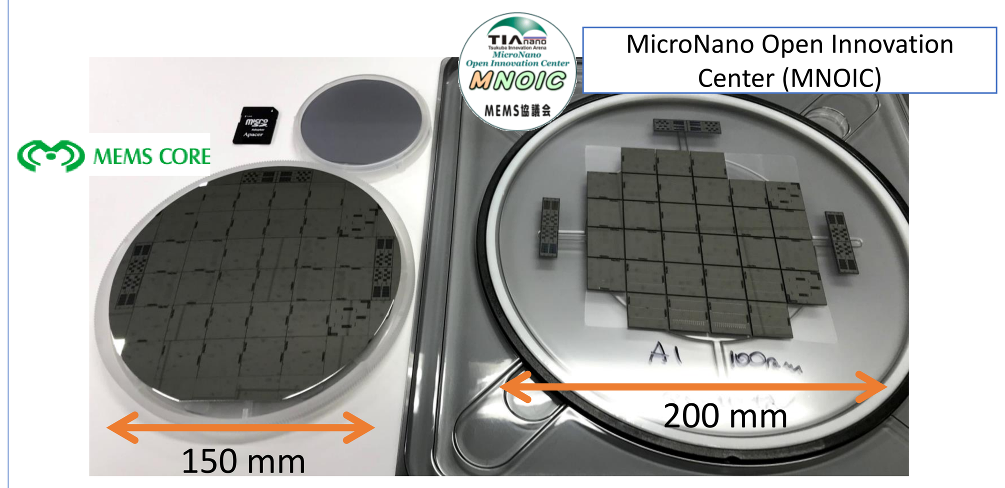


List of test chips

1. Straight line 84 resonators
2. Straight line 48 resonators
3. Gap width dependency
   w_r = 5.0 μm, g_r = 2.1 μm ~ 30 μm
4. Signal line width dependency
   g_r = 3.0 μm, w_r = 3.5 μm ~ 50 μm
5. Frequency – position dependency
6. Impedance of resonator is fixed to 50Ohm
   Full width ($w_r + 2g_r$) 7.7 μm to 110 μm
7. 24 narrow resonators and 24 wide resonators
8. Gap width dependency (w_r is fixed to 10 μm)
   w_r = 10.0 μm, g_r = 2.1 μm ~ 30 μm
9. Coupling length (L_c) dependency
10. baseline (w_r : g_r = 5.0 μm :3.0 μm)
11. x1.2 dense frequency spacing
12. x10 dense frequency spacing
13. Antenna coupled KIDs
14. Feed line check, half length
15. Feed line check

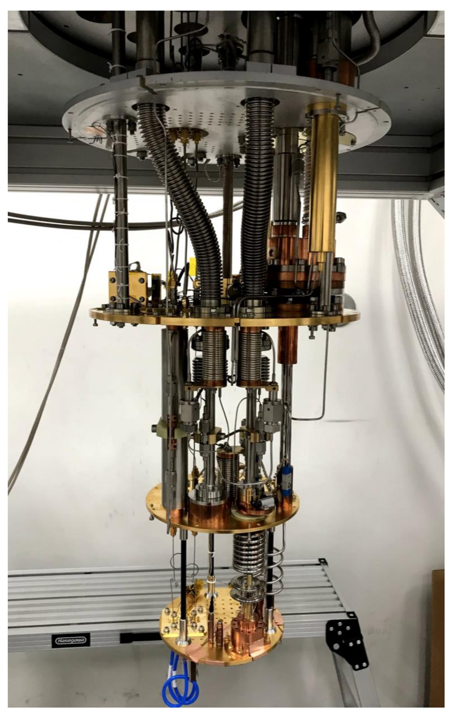
Photomask is designed to check the performance of new process and basic performance of kids fabricated on MEMS processes.
15 types of 20 mm^2 chips are designed.
The KIDs consists of coplanar waveguide (CPW) feed line and $\lambda/4$ CPW resonators.
The dimension of the feed line is designed to be g_f = 3 μm, w_f = 5 μm
So its impedance is set to be 50 Ω in all chips.
Resonators are categorized into 9 section and there are frequency gap between each section.
Parameter is set to each section.

Fabricated 6in and 8in KIDs

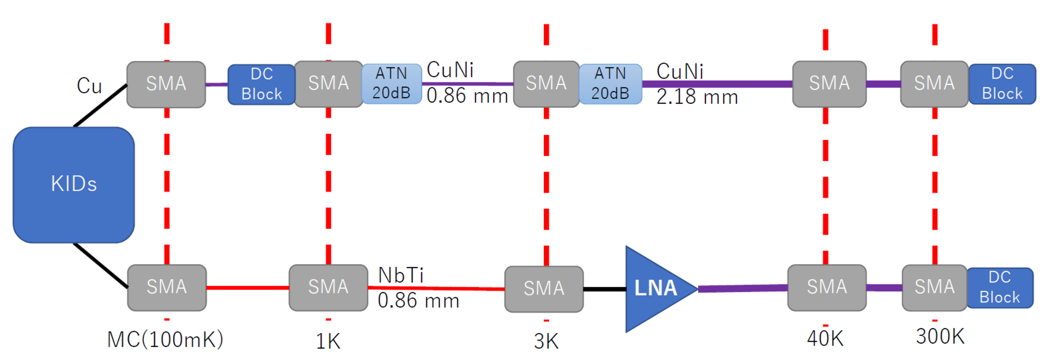


Designed KIDs are fabricated by commercial-level MEMS foundry to fabricate KIDs on large diameter wafers.
Simplest single layer Aluminum KIDs are fabricated as a first test.
MEMSCORE fabricated on a 6-inch FZ wafer and MNOIC fabricated on an 8-inch MCZ wafer.
Oxidation(SiOx) layer is removed by HF solution.
Aluminum is sputtered 50 nm and 100 nm to study the thickness dependency.
KIDs patterns are exposed using aligner.
Aluminum layer is processed by wet etching process.
The advantage of MEMS process is availability of Niobium which has a $T_c = 9K$ (Δ~330GHz) is very useful for several application including CMB observation. We will fabricate Nb-KIDs in next fabrication.

Measurement setup



RF circuit inside the cryostat



Dilution refrigerator, an Oxford Io, is used to produce operational temperature of KIDs.
The temperature of KIDs is measured and controlled using an AC resistance bridge (LakeShore 372) with RuOx sensor.
CuNi coaxial wires are employed for thermal isolation.
Two 20dB fixed attenuators are installed in 1K and 3K stages to minimize the noise.
NbTi coaxial wires are employed for output line from MC stage to 3K stage to minimize the attenuation of signal and thermal loading to MC stage.
Output signal is amplified by cryogenic low noise amplifier (LNF-LNC4_8C).
Frequency response is measured using Vector Network Analyzer (Anritsu MS46522B).

Conclusion

- We demonstrated the KIDs fabricated on a 6-inch wafer and an 8-inch wafer using commercial-level MEMS process.
- Measurement setup using dilution refrigerator is prepared to develop the KIDs for next generation experiments.
- Measured results look comparable to the KIDs fabricated on a dedicated cleanroom and is very promising to realize the large array of KIDs.

Reference

[1] A. Suzuki, et al., JLTP 184, 3, 805-810 (2016)
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[3] P. Day, H. Leduc, B. Mazin, A. Vayonakis, and J. Zmuidzinas, Nature 425, 817–821 (2003).
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Acknowledgement

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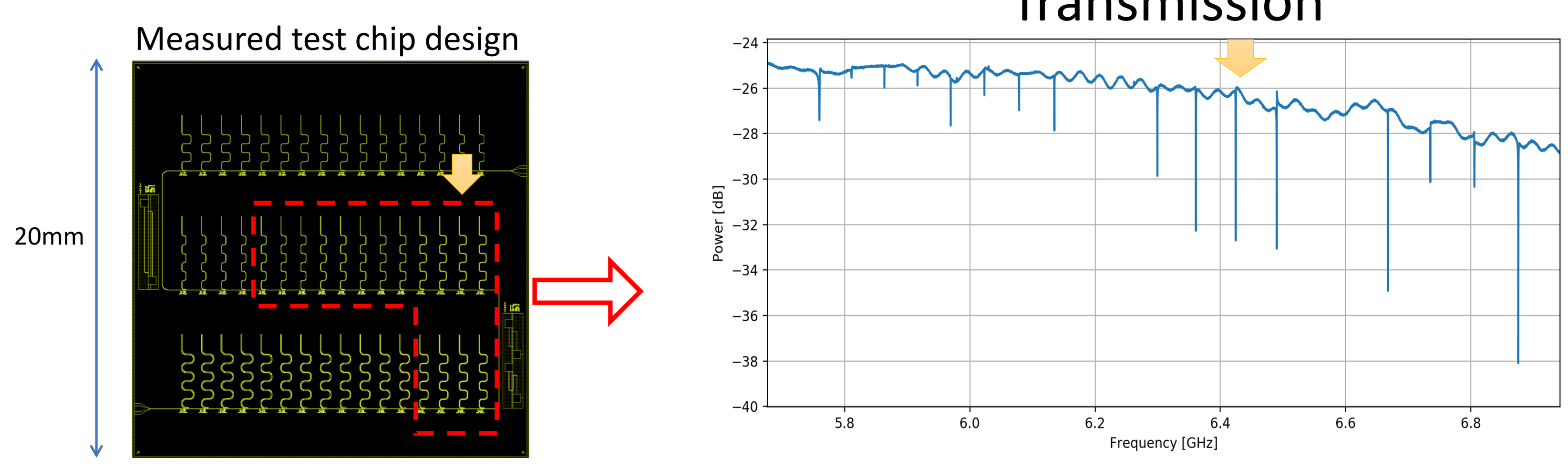
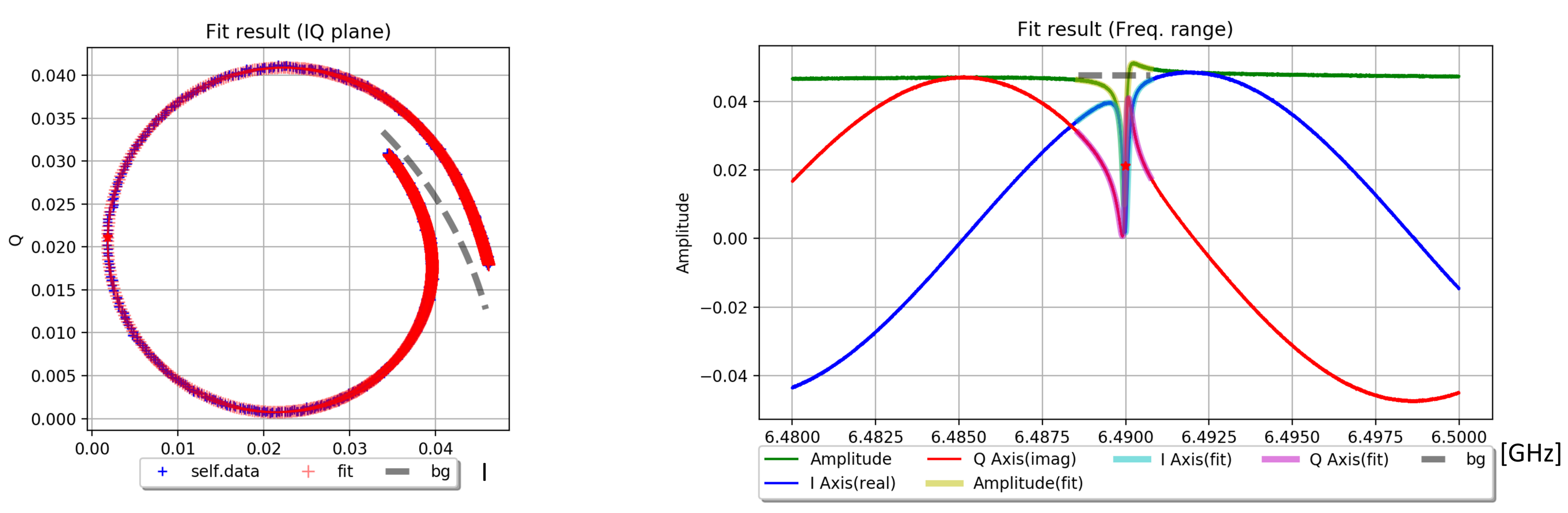
Results



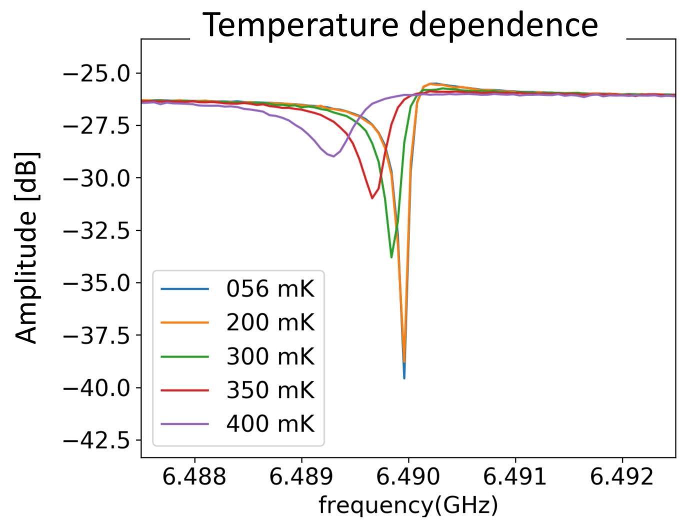
A test chip fabricated in an 8-inch process is measured. The thickness of Al was 130 nm
Sharp resonances are observed in a designed frequency range of 4 GHz – 8 GHz.
And the resonances are disappeared above Tc of aluminum (T = 1.2 K).
We can identify the resonator on chip which create a peak on a transmission curve thanks to the frequency gap between the categories and wide frequency distribution.



Quality of the resonator is expressed by quality factor (Q) of resonator.
Quality factor is defined by stored energy over power loss and can breakdown to internal quality factor (Qi) and coupling quality factor(Qc). Qc is controlled by design.

$$Q = (\omega E_{stored})/P_{loss}, \qquad 1/Q = 1/Q_c + 1/Q_i$$

Observed resonances are fitted using Gao's function[5] to extract parameters.
Fit result of resonances at 6.49 GHz is shown.
Fitting is well performed, and the result well reproduced the data. ($\chi^2/ndf = 1.2$)
Extracted Qi was 150,000 and coupling quality Qc was 40,000.



Temperature response is measured by controlling the temperature of mixing chamber.
The resonance frequency is shifted toward lower frequency side as we expected.
Quality factors and temperature response are comparable to the KIDs fabricated in a dedicated cleanroom for superconducting device.