

Fundamental Evaluation of Hafnium LEKIDs Fabricated by Sputtering with Substrate Heating for Future Dark Matter Searches

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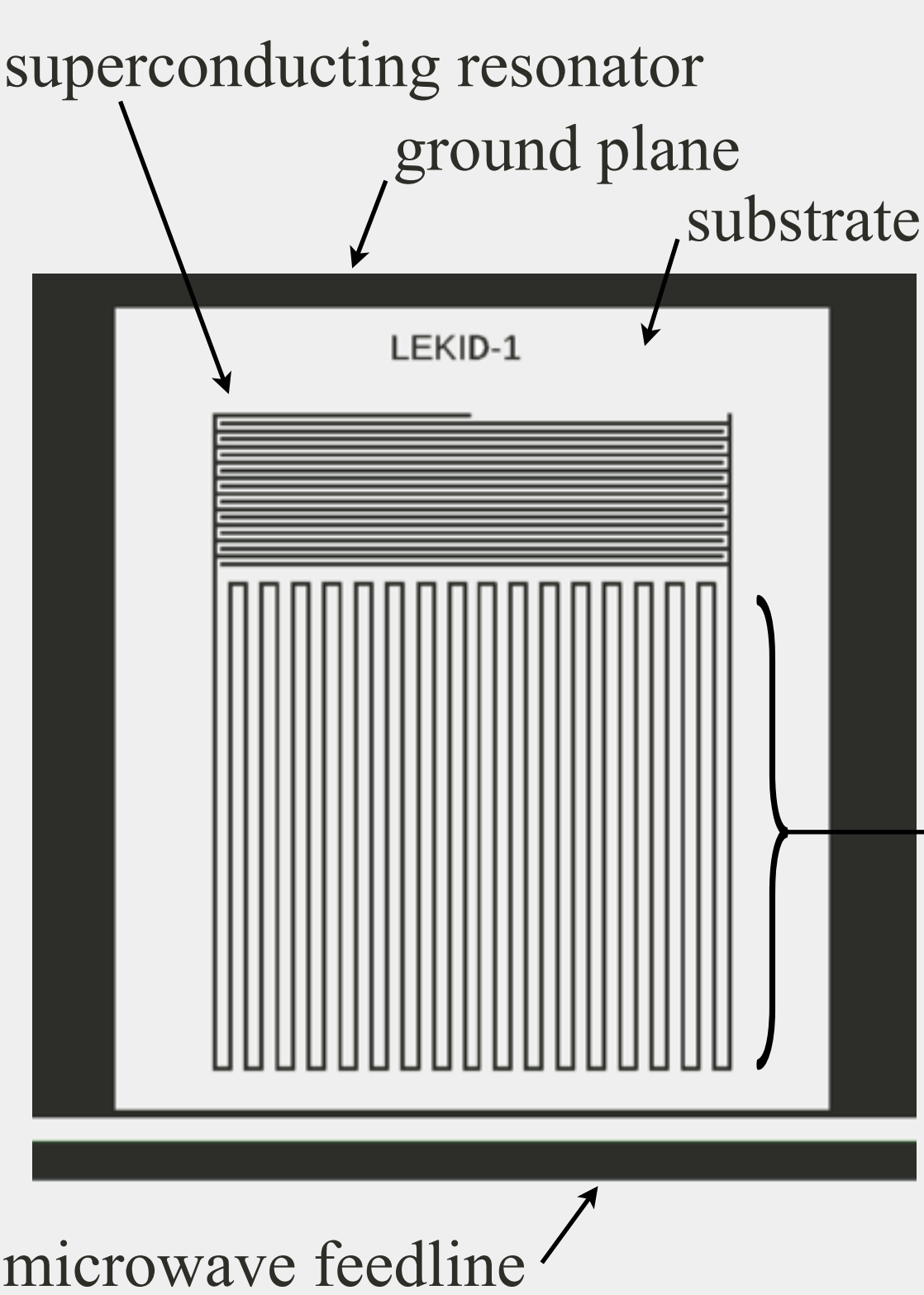
1. LEKID [1]

- A type of cryogenic energy sensor
- Superconducting resonator with larger sensitive area
- Readable signal of multiple KIDs with single feedline
- Low energy threshold, high energy resolution

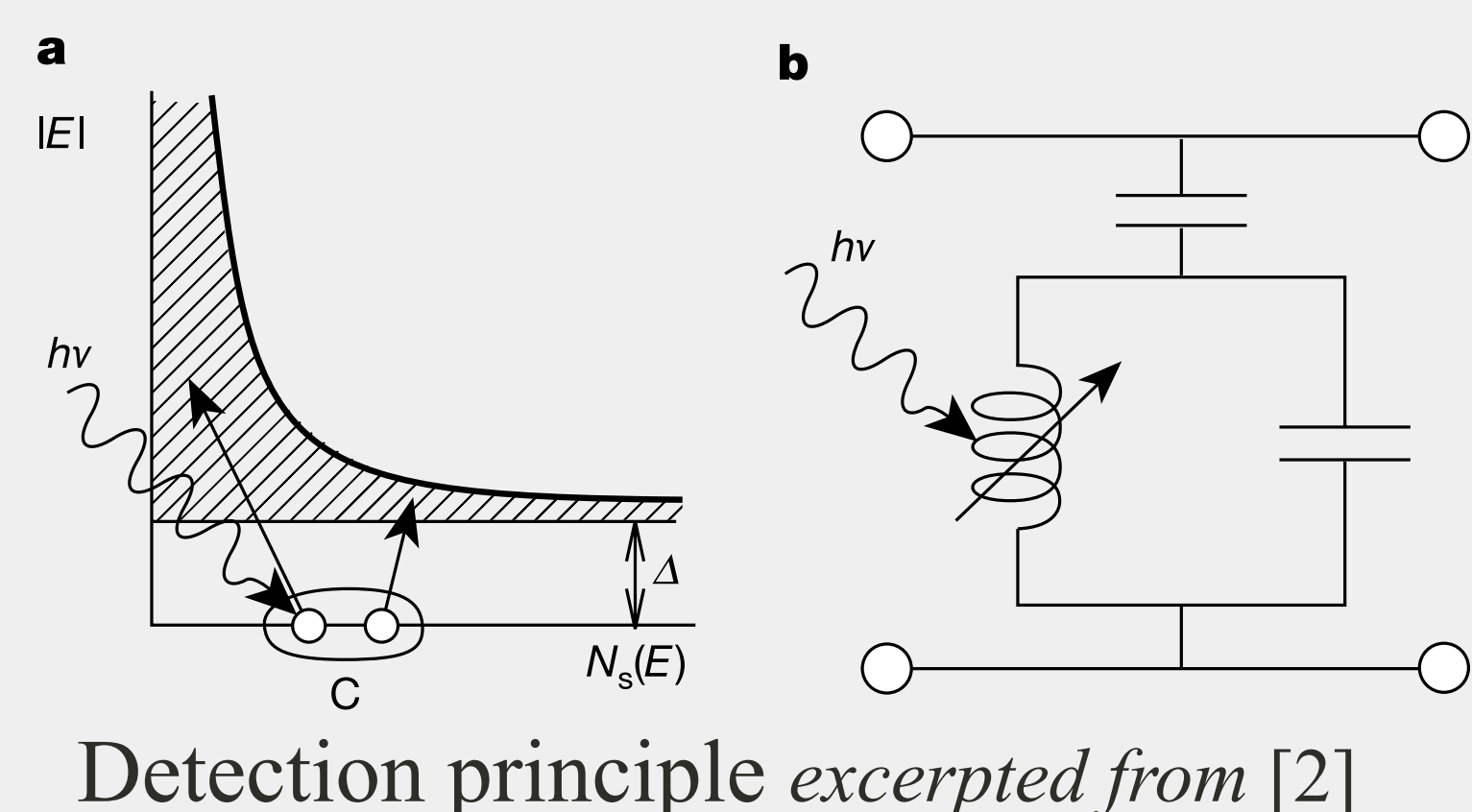
[Detection principle]

Energy deposition ^a → Breaking Cooper pair ^a
→ Changing kinetic inductance ^b → Changing resonant frequency

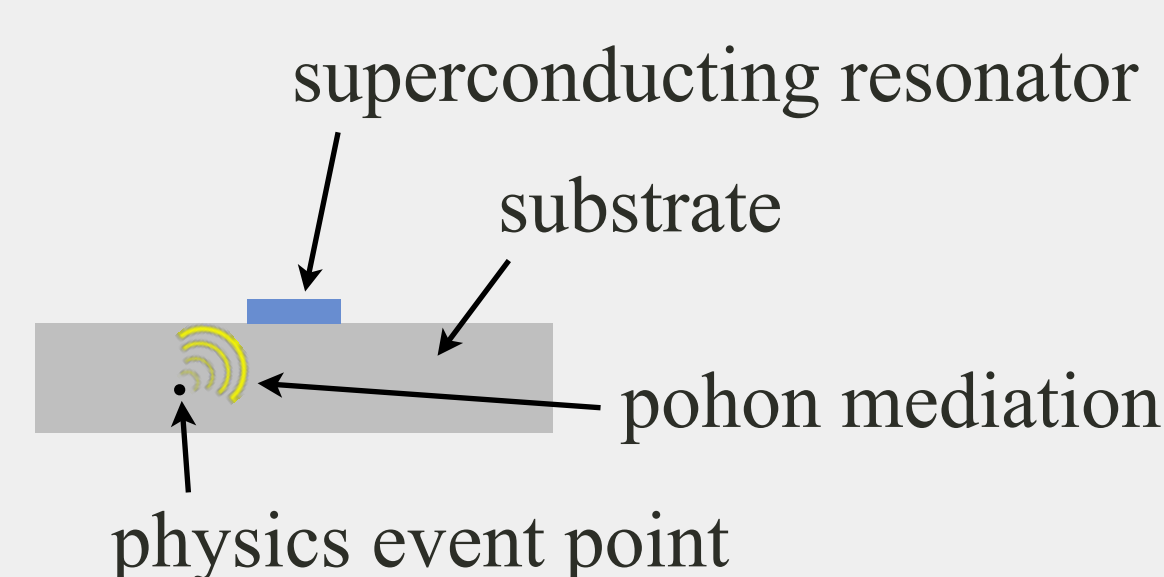
Detect!



Design of LEKID



Detection principle excerpted from [2]



Concept for physics events detection

3. Fabrication and Measurement

○ Why Hafnium?

Superconducting transition temperature $T_c = 128$ mK

$$\Rightarrow 2\Delta_0 = 38 \mu\text{eV}$$

Usual KID operating temperature is $T_c/10$.

In case of Hf, $O(10)$ mK is required.

$\Rightarrow$ Limitations of modern cryogenic technology

○ Previous studies and motivation of this work

- Hf-KIDs have been developed[4][5].
 $T_c = 200 - 400$ mK, Quality factor Q of resonant: $O(10^5)$
- T_c of Hf changes by condition of deposition[6].
- For achieving a high Q , heating sputtering deposition or annealing is effective[7].
- In our test, the resonant of Hf-KID was not found.
Deposition was normal sputtering. $T_c = \sim 250 - 500$ mK
→ We tried heating deposition and fabricated Hf-KID.

○ Fabrication method

Hf sputtering with *substrate heating* (~ 350 °C) (~ 50 nm)

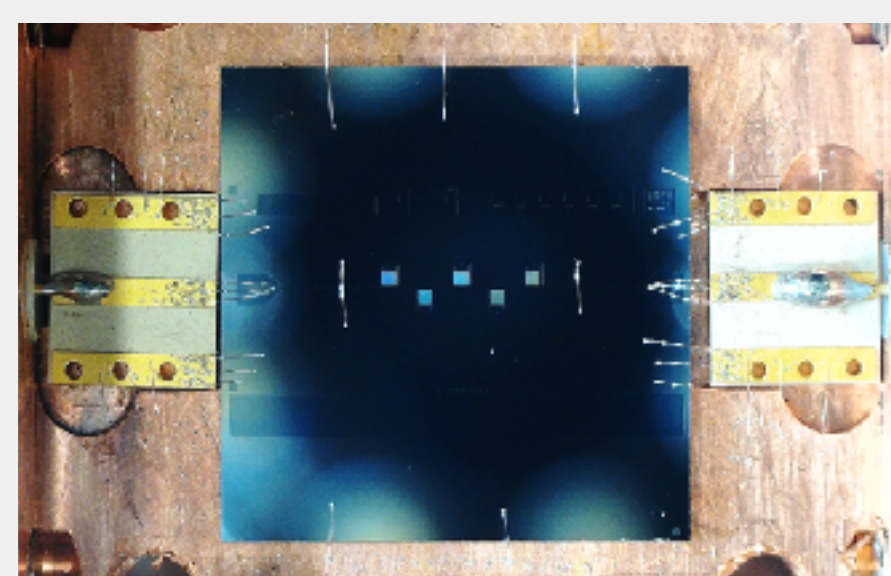
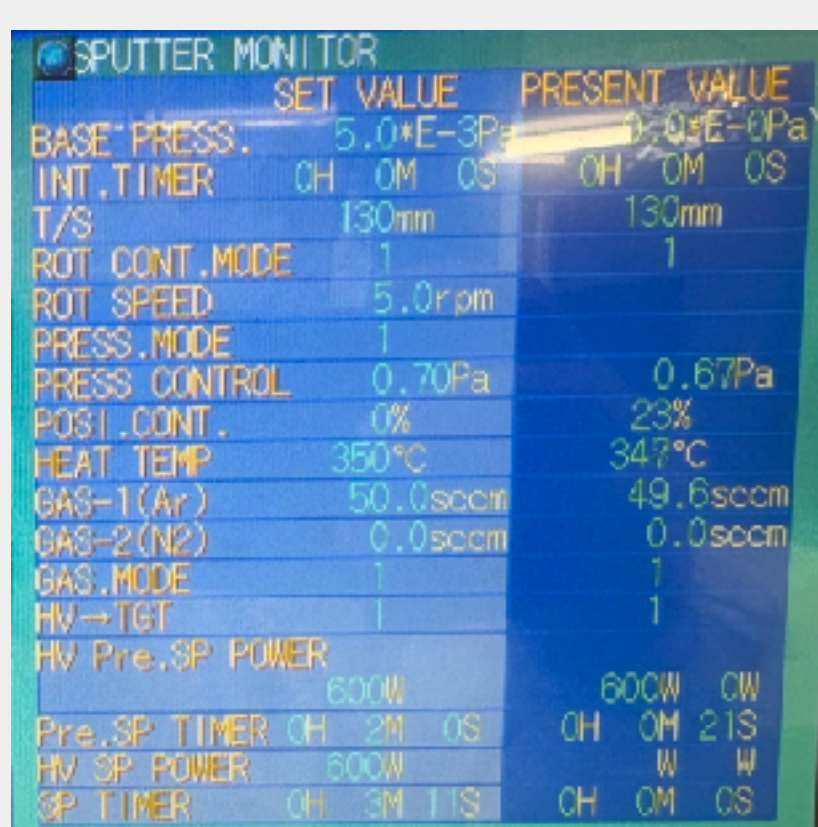
→ Photolithography → Dry etching for removing extra Hf

• Sputtering Condition

RF magnetron sputtering (Ar 0.7 Pa, 600 W)

○ Cryogenic test

- Using $^3\text{He}/^4\text{He}$ dilution refrigerator
Reachable temperature ~ 0.12 K
- RF measurement with vector network analyzer (VNA)
→ Measure the forward RF transmission coefficient (S_{21}) via KIDs
- Measurement at different temperature
0.12 - 0.6 K every 0.1 K



5 LEKIDs fabricated with Hf on Si



Dilution Refrigerator

2. Light Dark Matter(LDM) and KIDs

As you know, the search for LDM with a mass on the sub-GeV scale is attracting significant attention.

Detectors with low energy threshold ($O(\text{eV})$) is required to detect recoil energy of LDM event.

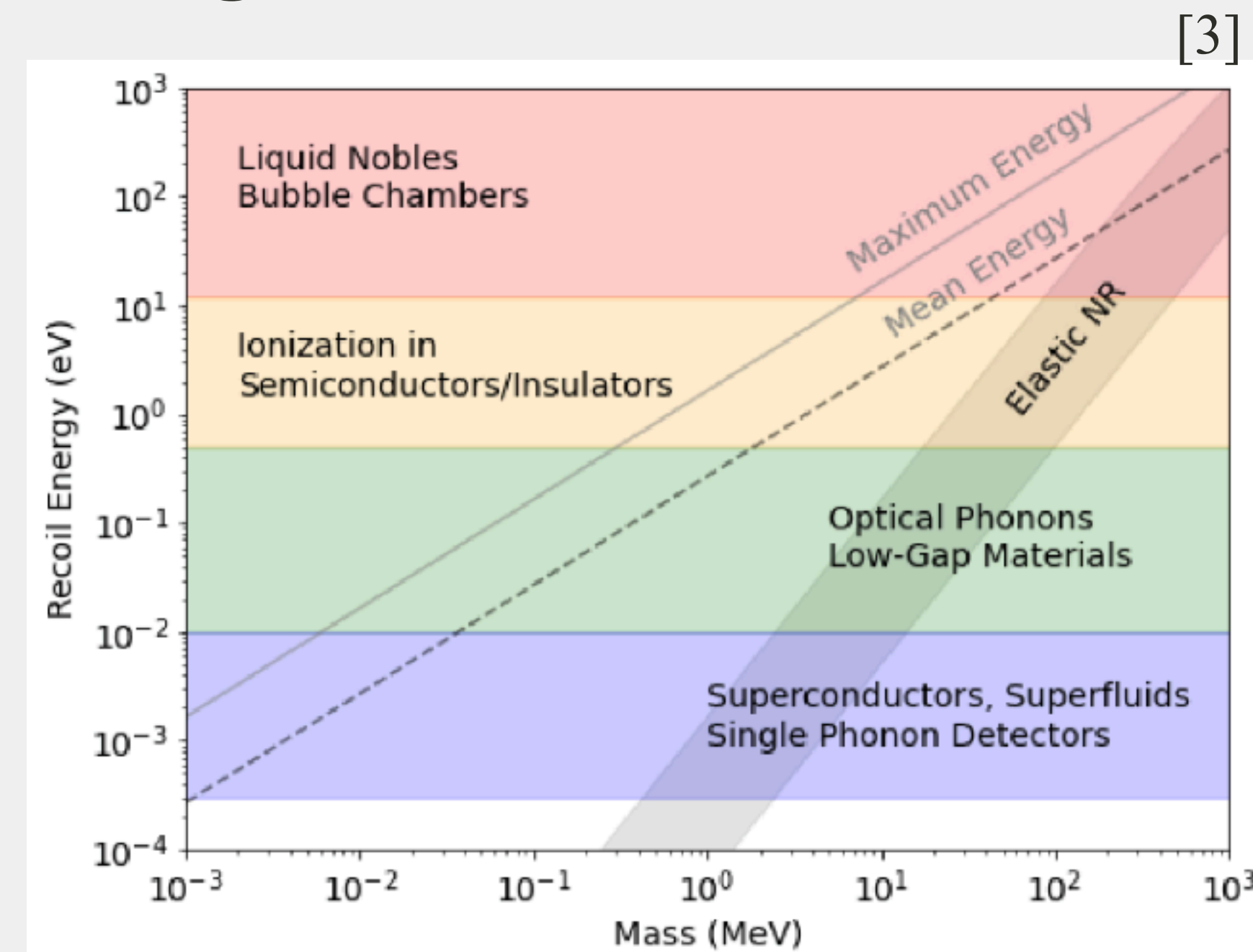
○ How to detect $O(\text{eV})$ energies?

Energy carrier: phonon

→ Cryogenic sensor is sensitive to phonons!

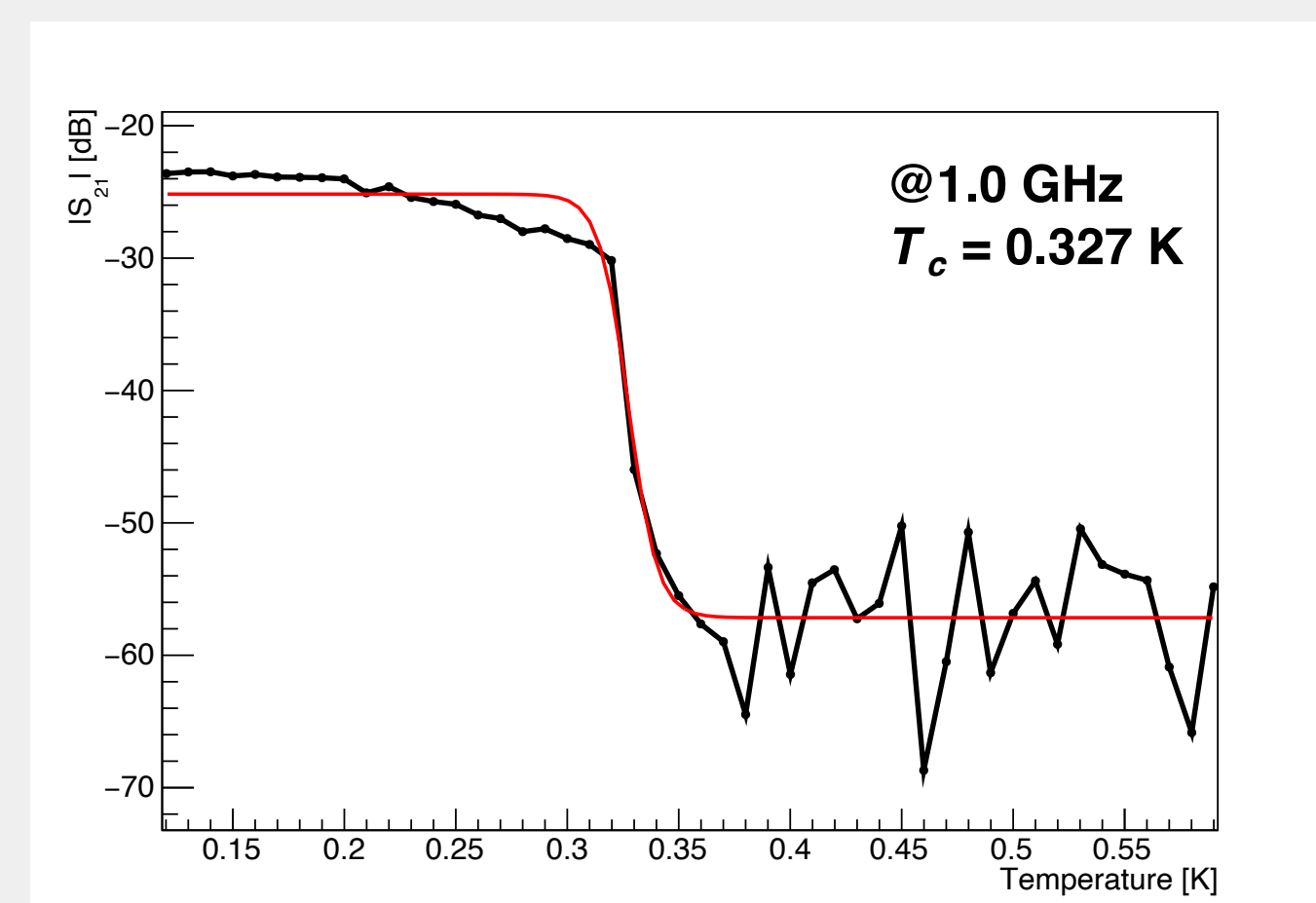
○ Why use KIDs?

- A kind of phonon sensor
- Low threshold
→ sub-eV in principle
- High scalability
→ $O(1000)$ KIDs
→ g - kg-scale target

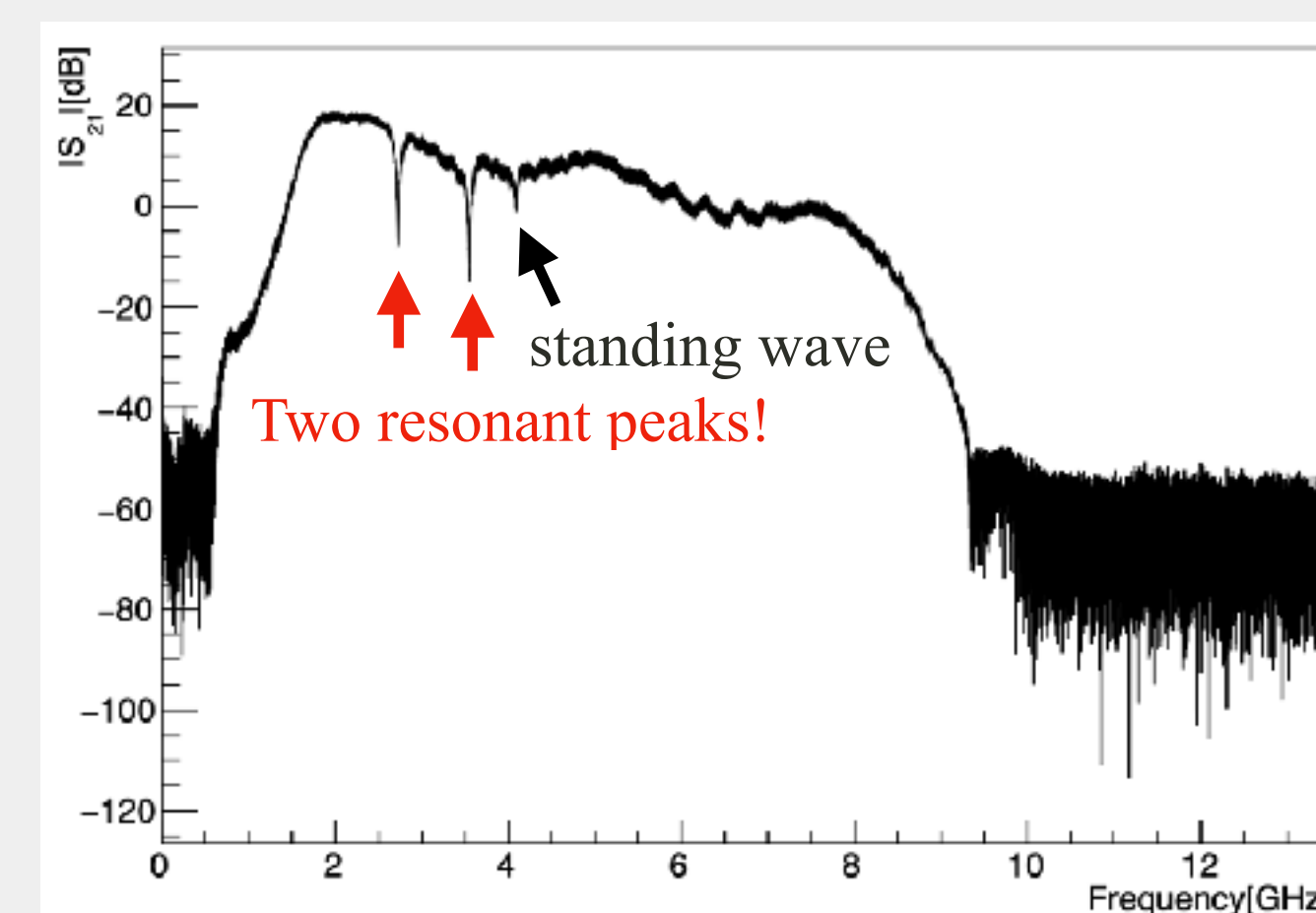


4. Result

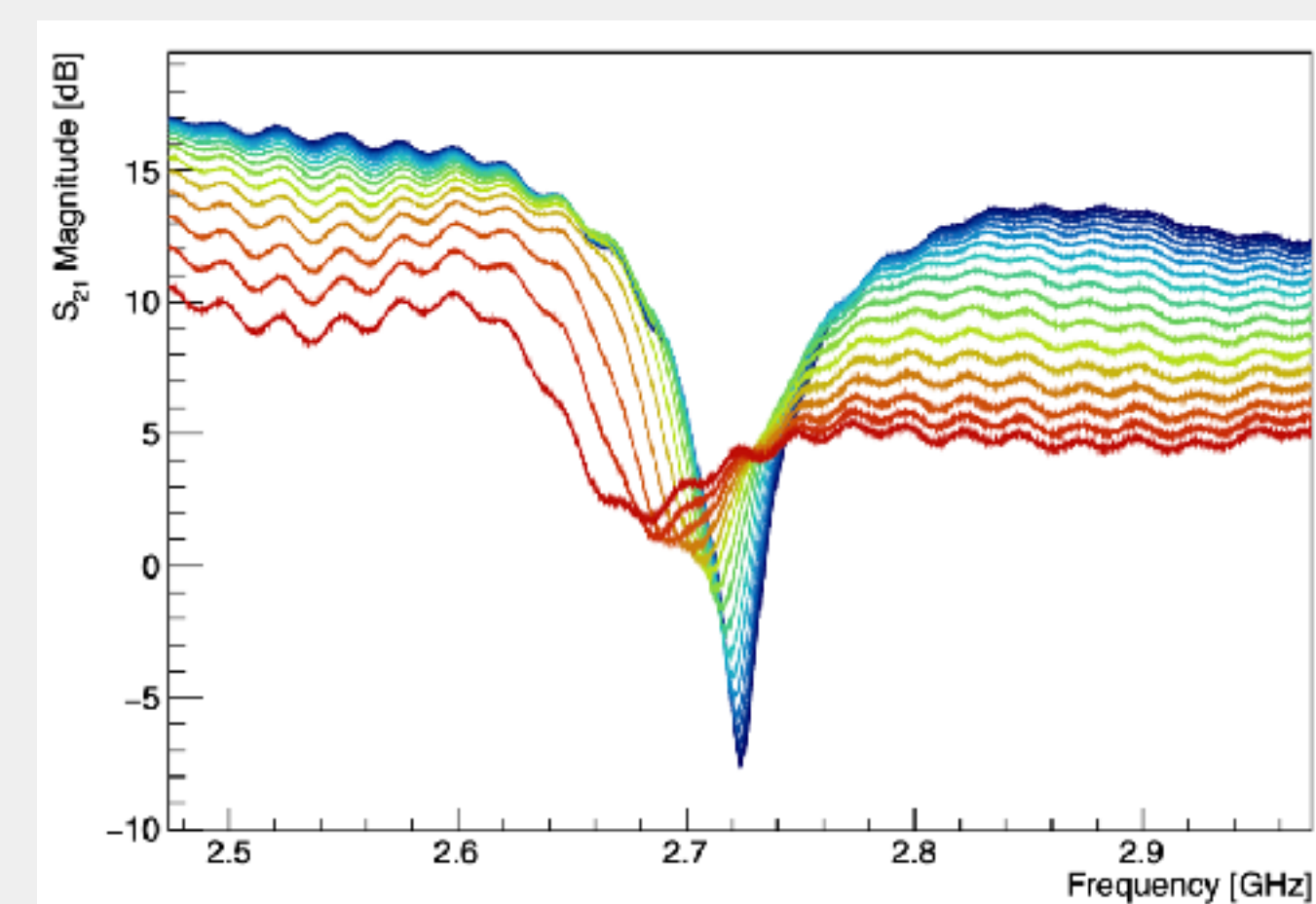
- Superconducting transition was confirmed. $T_c = \sim 330$ mK
- Two resonant peaks were found. Yield: 2/5



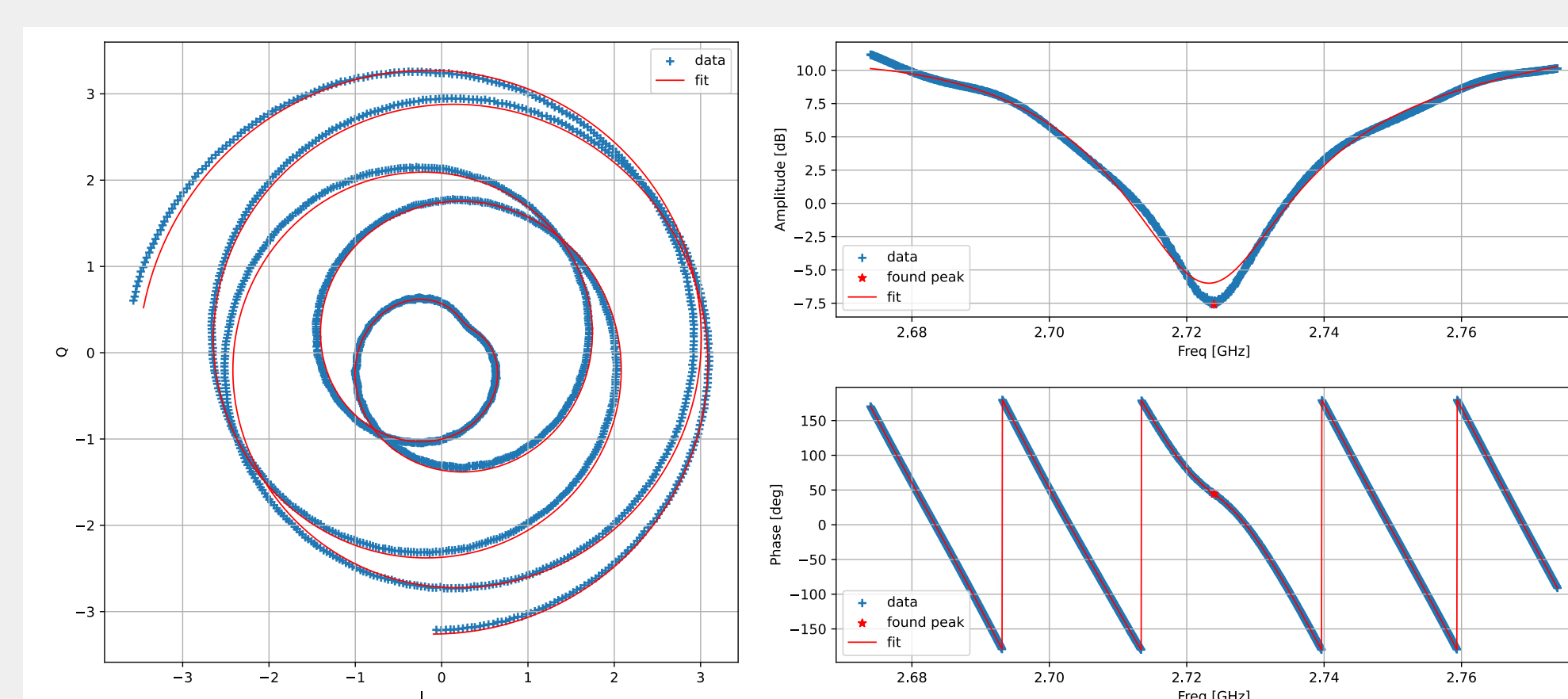
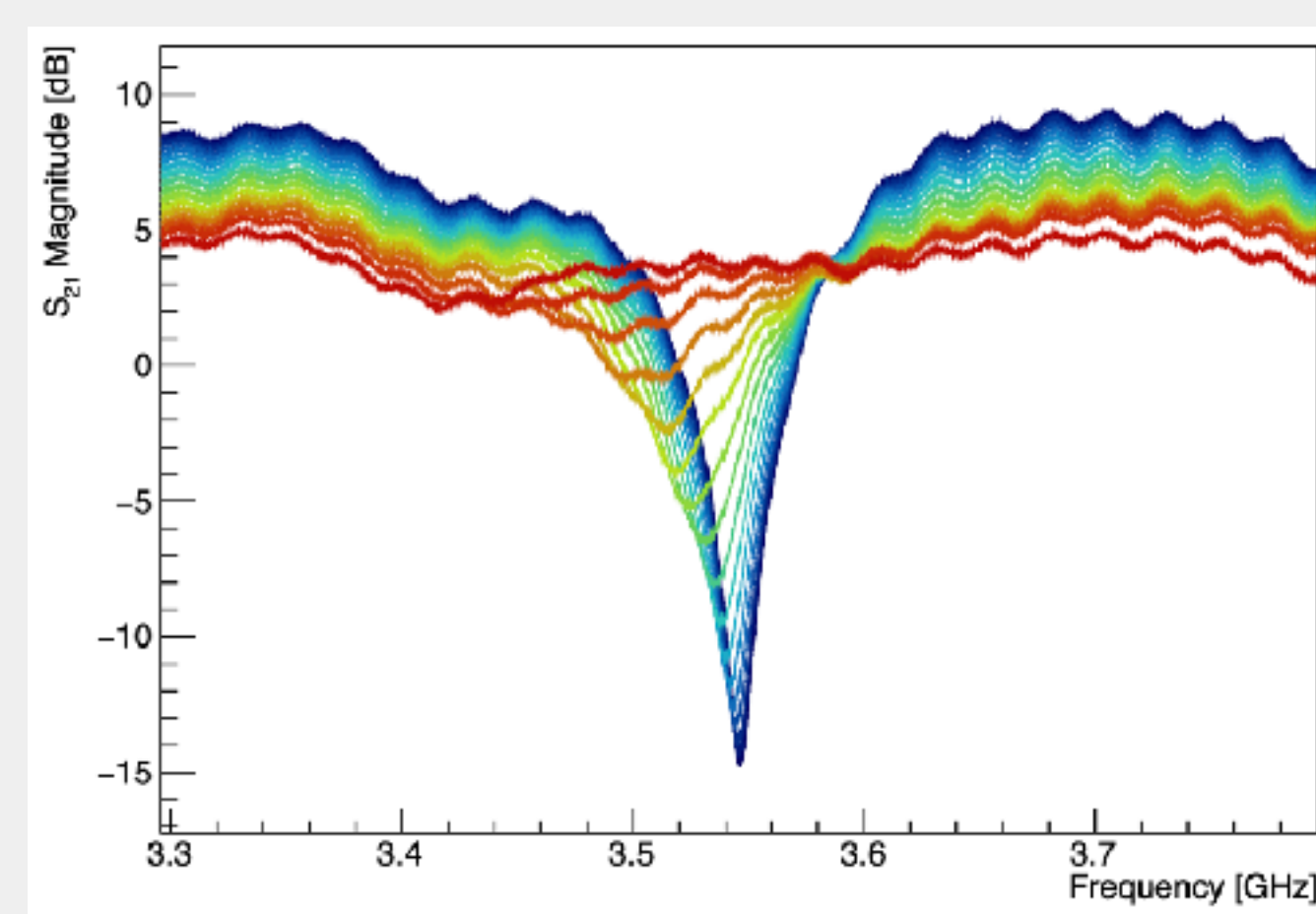
$|S_{21}|$ jumped at 0.33 K



$|S_{21}|$ at 0.12 K



Peak shifts with temperature sweep (0.12 - 0.28 K)



○ Fitting for 1st peak

$$f_r = 2.73 \text{ GHz}$$

$$Q_i = 333$$

$$Q_c = 22.6$$

$$Q_r = 21.4$$

○ Likewise for the 2nd.

Resonant peaks were confirmed, likely due to the improvement in Hf-film quality achieved through substrate heating sputtering based on previous research.

We will try to measure resonant peaks of Hf-KID at $T_c/10$.

5. Acknowledge and References

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