

Development of Superconducting Transition-Edge Sensor for Light Dark Matter Search

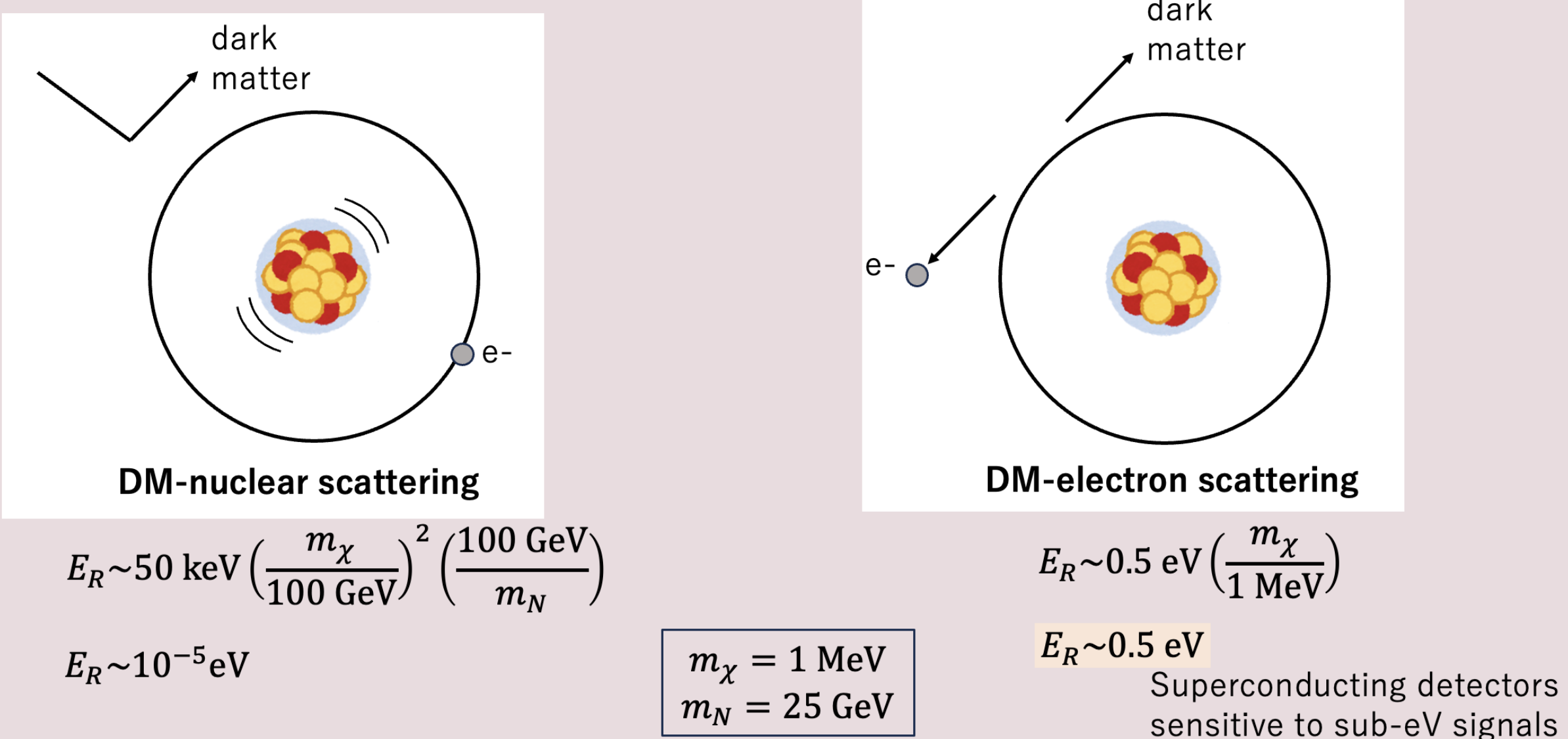
Kaori Hattori¹, Jiao Ding¹, Yu Zhou^{1,2}, Maurice Garcia-Sciveres^{1,4}, Tommaso Ghigna^{1,3}, Ryota Hayakawa¹, Aritoki Suzuki⁴

¹KEK, ²QUP ³NAOC ⁴Kavli IPMU ⁵LBNL

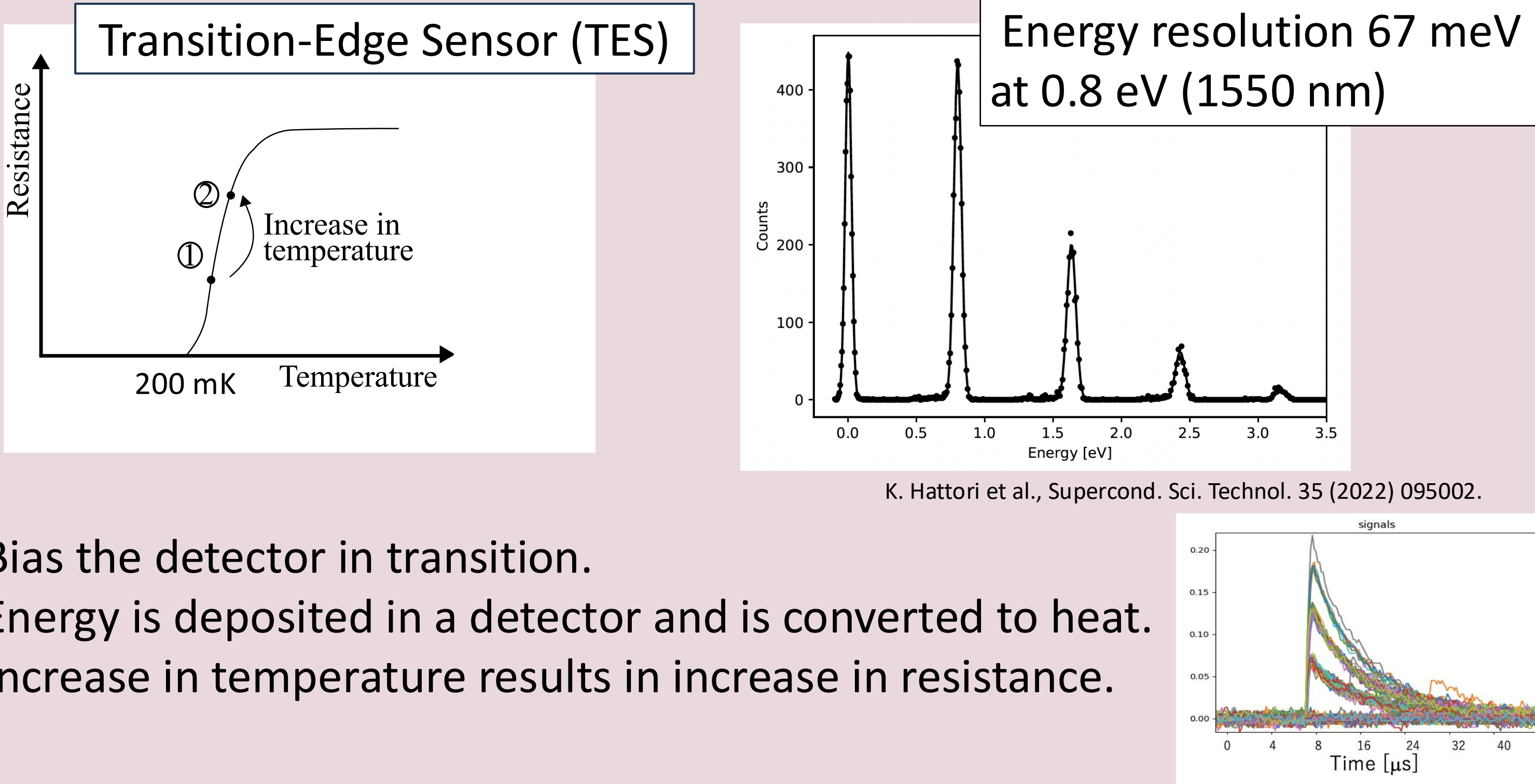
Our group is developing superconducting transition-edge sensors (TESs) sensitive to sub-eV signals for direct detection of light dark matter in the mass range of approximately 0.01 MeV to 100 MeV. The experiment is being prepared for deployment at the Kamioka underground lab. Using cryogenically cooled aluminum as the target, we aim to detect sub-eV signals generated by dark matter-electron scattering through TESs.

We are developing AlMn TESs that can be efficiently coupled to the aluminum target and operated with a low energy threshold. We have successfully observed a superconducting transition in fabricated AlMn TESs. In parallel, we are developing a microwave SQUID multiplexer (μMUX) readout system for simultaneous readout of a large-format TES array.

MeV Dark Matter Direct Detection

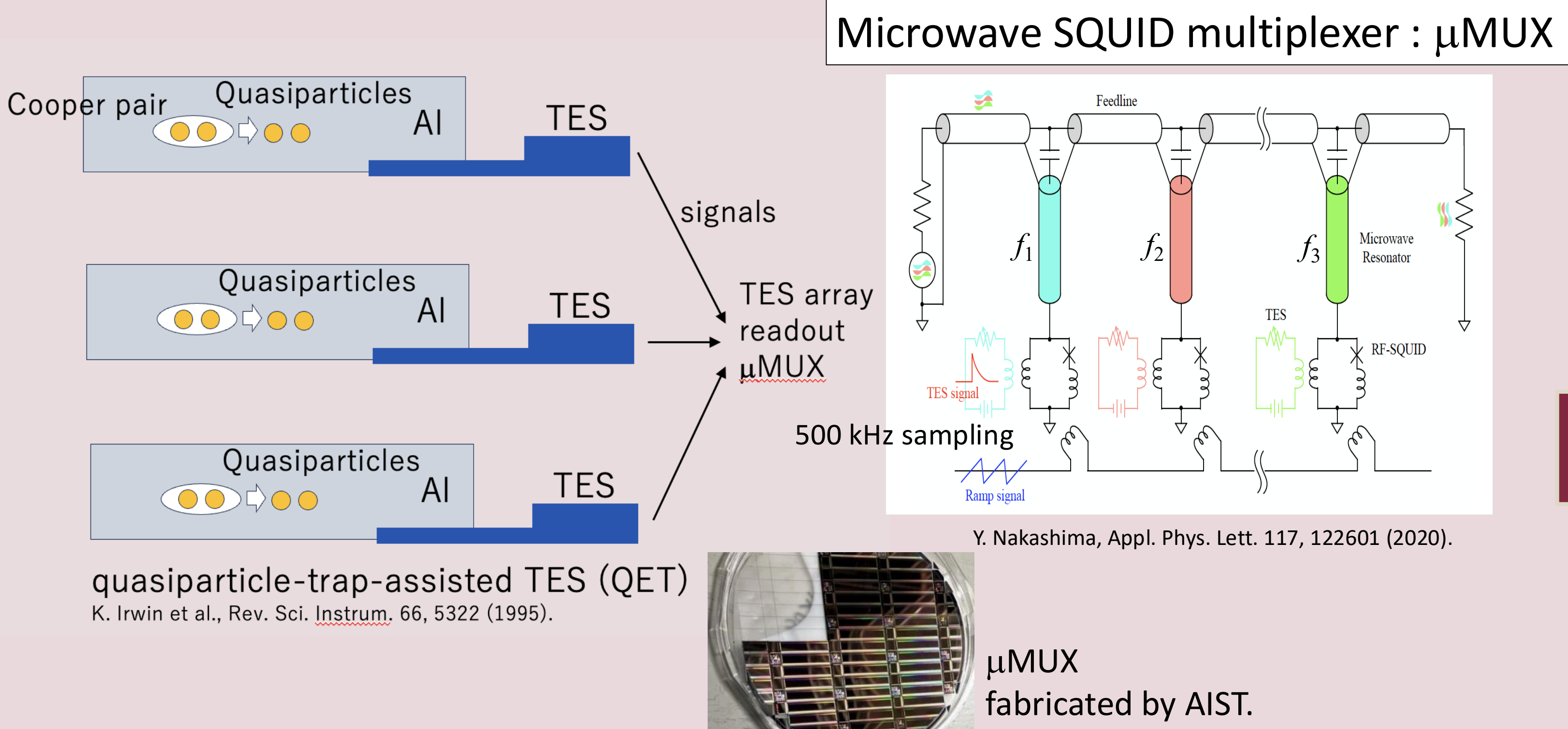


Superconducting Detector Sensitive to Sub-eV Signals



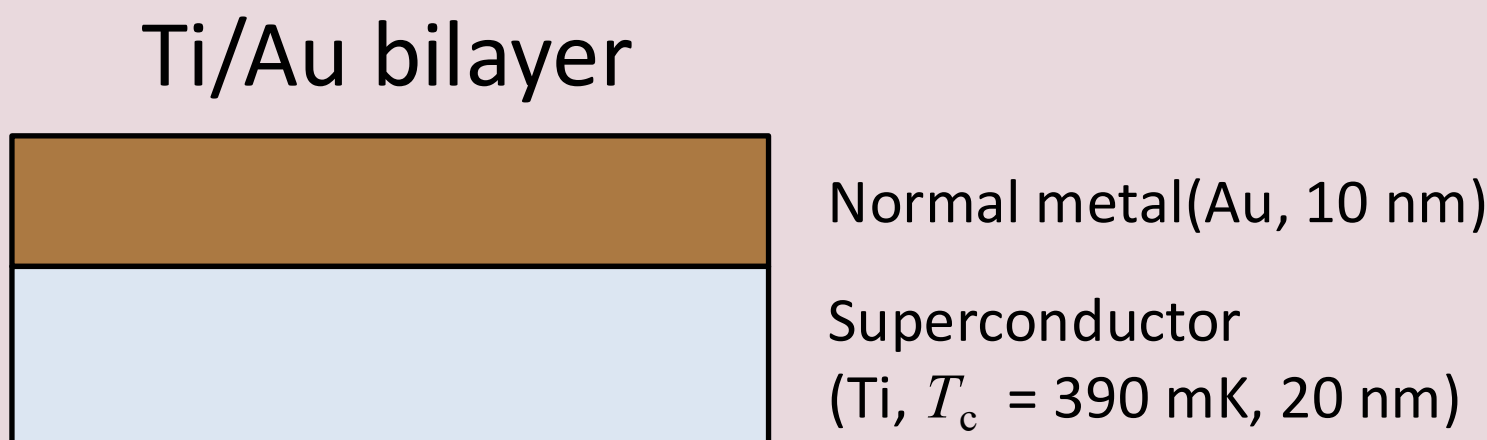
1. Bias the detector in transition.
2. Energy is deposited in a detector and is converted to heat.
3. Increase in temperature results in increase in resistance.

TESs Coupled with Aluminum Targets



- Cooled down below 50 mK by a dilution refrigerator
- Low energy threshold is crucial to search sub-MeV dark matter. → Lower T_c .
- Quasiparticle collection
High collection efficiency for quasiparticles generated in the Al target.
Diffusion coefficient of quasiparticles in Al : $D \sim 100 \text{ cm}^2/\text{s}$
→ Time constant of TES should be 10 to 20 μs or longer to efficiently detect quasiparticle signals.
- μMUX with 500 kHz sampling is suitable for the required detector response.

TESs Material Candidates

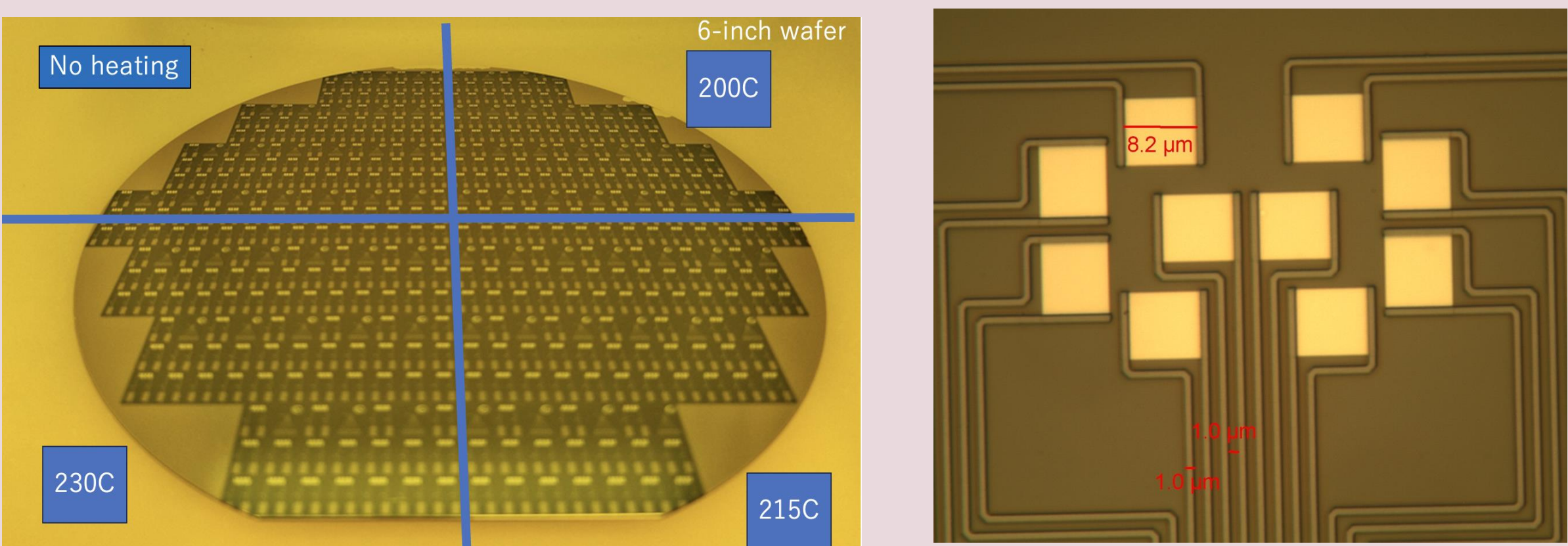


T_c is tunable by changing thickness.
Theoretical limit of T_c is around 50 mK.
Ti thin layer is needed to couple with an aluminum target.



T_c is tunable by baking.
Low $T_c < 50 \text{ mK}$ has been achieved.
Easy to couple with an aluminum target.
AlMn TES bolometers used for CMB experiments.

AlMn TESs

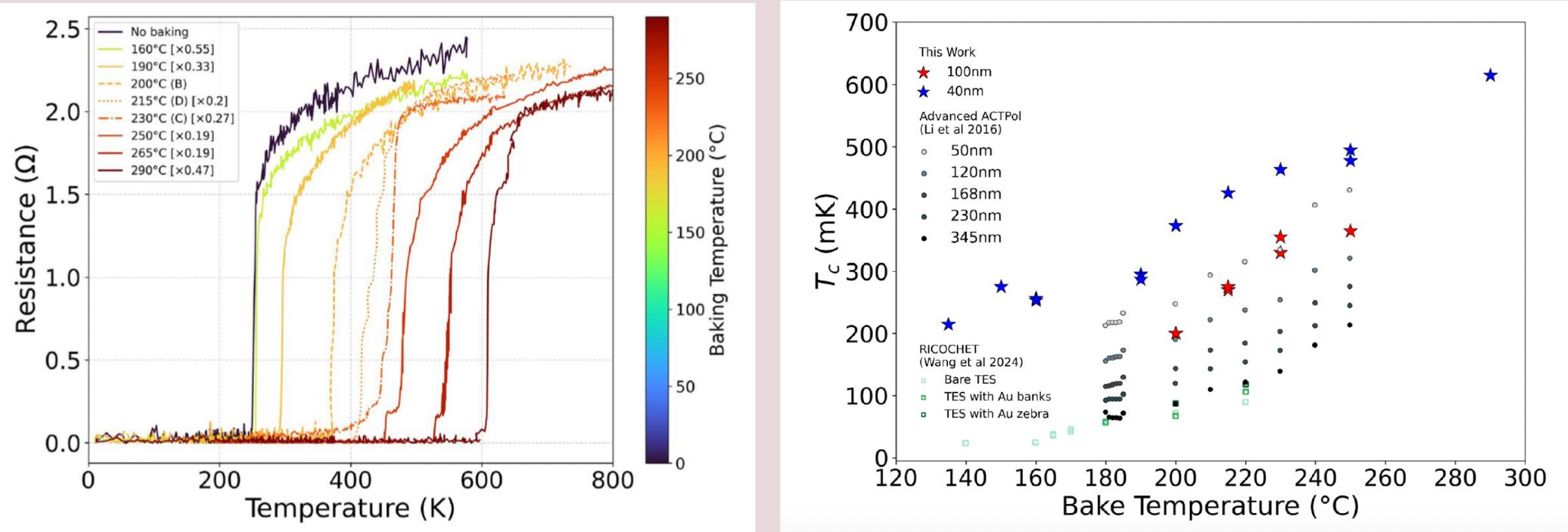


Fabricated by Seeqc (US).
Thickness : 40 nm and 100 nm
Mn doping concentration : 2,500 ppm
Sub-eV TESs are ~1/10 the size of TES bolometers in side length.

T_c Measurements

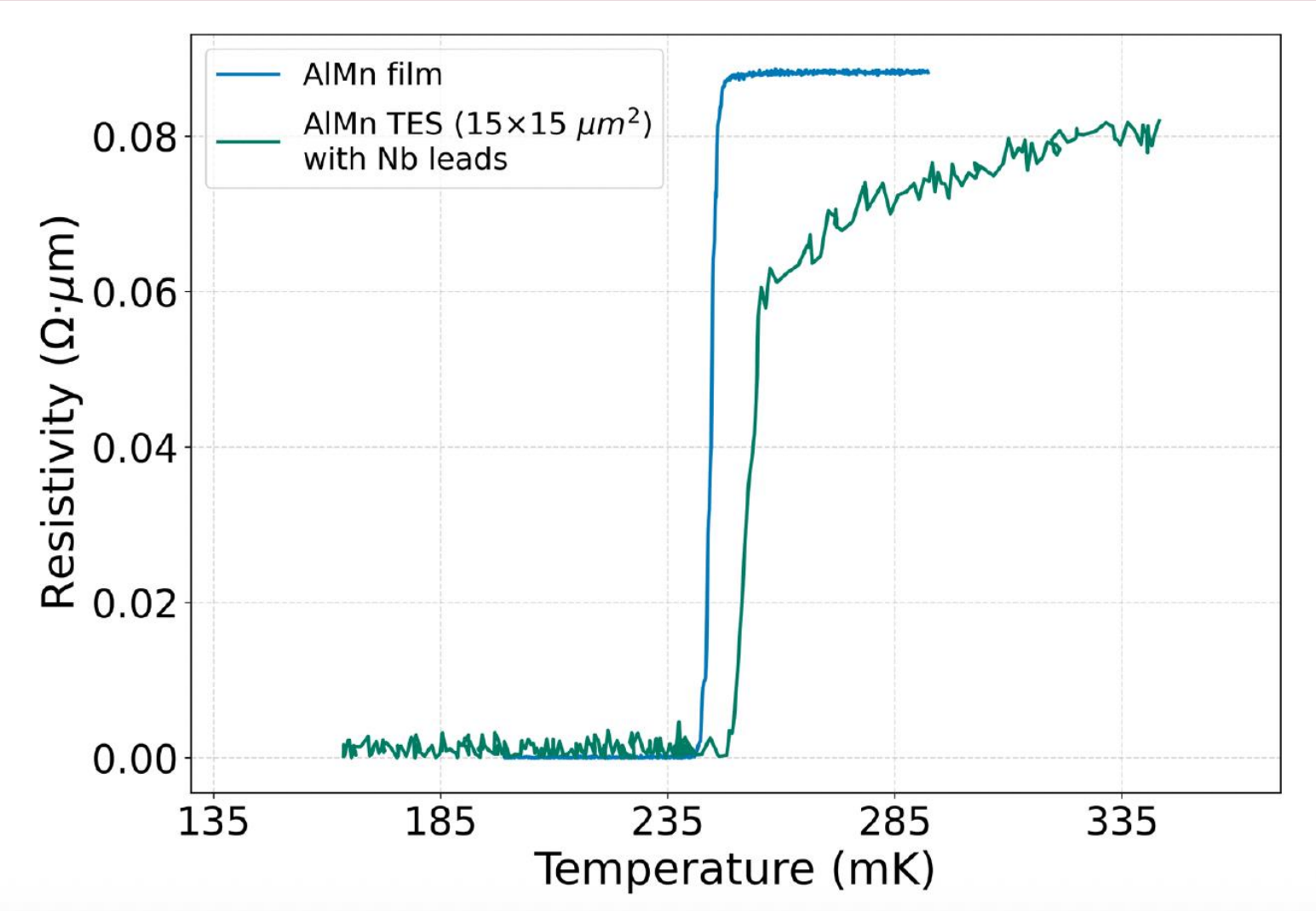


T_c vs Bake Temperature



TESs baked at room temperature in the air.
The R-T curves measured by Lakeshore 372 at bias current 100 nA.

Proximity Effect



Small TESs are more strongly affected by Nb leads with higher T_c .
This may broaden the superconducting transition.
Transition sharpness affects energy resolution and threshold.

Conclusion

TESs for MeV Dark Matter Direct Detection

- A low energy threshold is crucial for sub-MeV dark matter search.
- Developing AlMn TESs for efficient coupling to aluminum targets.
- A key challenge for sub-eV-sensitive TESs is their small size.
- Successfully achieved a superconducting transition in AlMn TESs.
- Demonstrated that the T_c of AlMn TESs can be tuned by baking.

TES array readout

- The required detector response time of 10–20 ms allows us to leverage existing μMUX technology developed for X-ray TESs, accelerating readout development.