Material properties to understand superconducting metals

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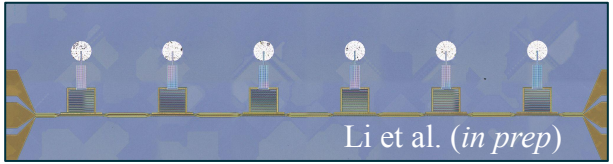
BERKELEY LAB MOLECULAR FOUNDRY STAR CRYOELECTRONICS

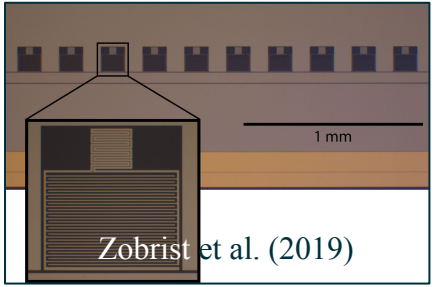
Hafnium in Superconducting Sensors

TES bolometers LBNL
Rotermund et al. (2024) arXiv:2410.06227

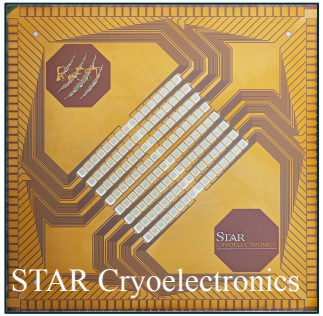
Phonon-sensitive MKIDs LBNL
Li et al. (*in prep*) → RDC08 Nov 20, 9 am



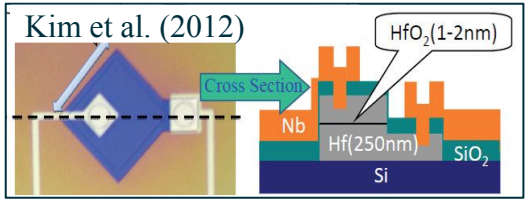
Optical and near-IR MKIDs
Nicholas Zobrist et al. (2019) & Gregoire Coiffard et al. (2020)



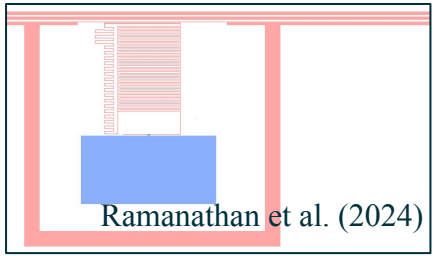
TES calorimeters
Adriana Lita et al. (2009), Safonova et al. (2024)



Superconducting Tunnel Junctions
Kraft et al. (1998), Kim et al. (2012), STAR Cryoelectronics SBIR (2021)



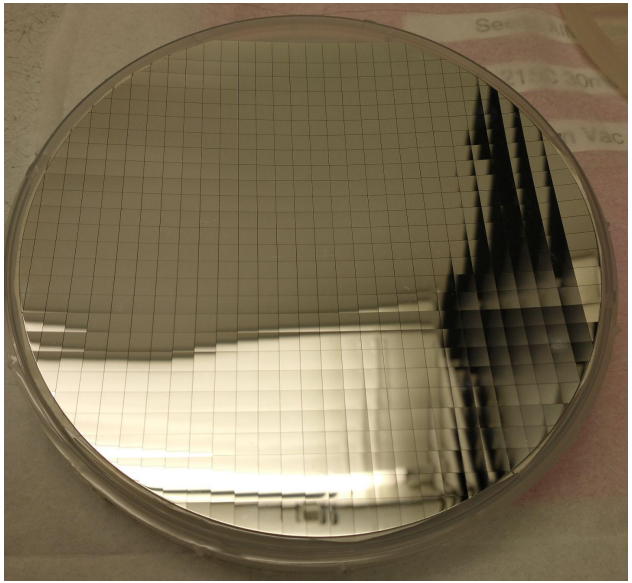
Quantum Parity Detectors
Ramanathan et al. (2024)



Hafnium – an attractive superconductor

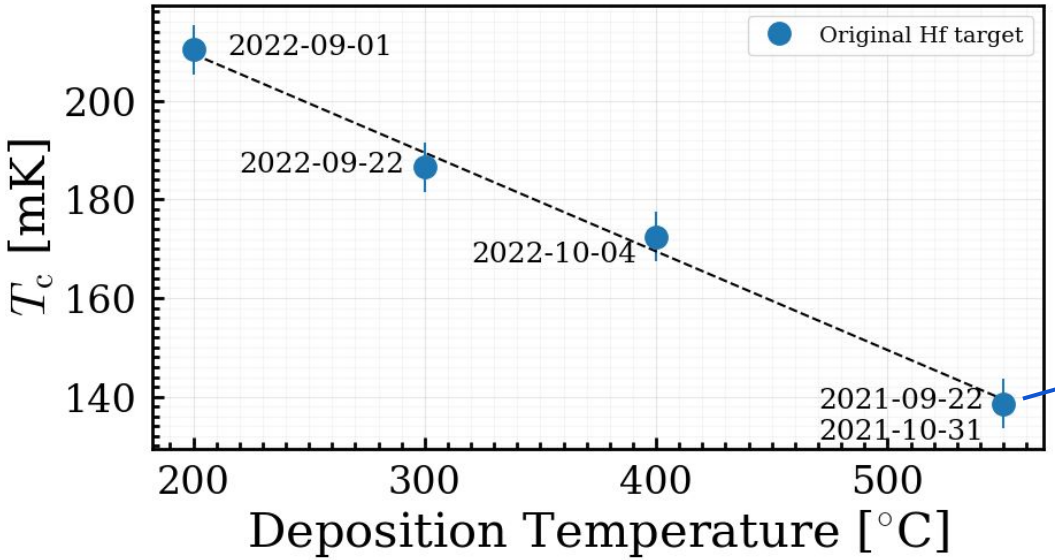
- Single element
- ~800 mΩ/□ sheet resistance (250 nm film, measured at 1 K)
- Tunable Tc ~ 130 - 300 mK
  - Heated sputter deposition
- High kinetic inductance
  - 4.7 pH/□ for 250 nm film (Li et al. *in prep*)
- Hf-based Josephson Junction have been fabricated
  - Hf-STJ

^{72}Hf

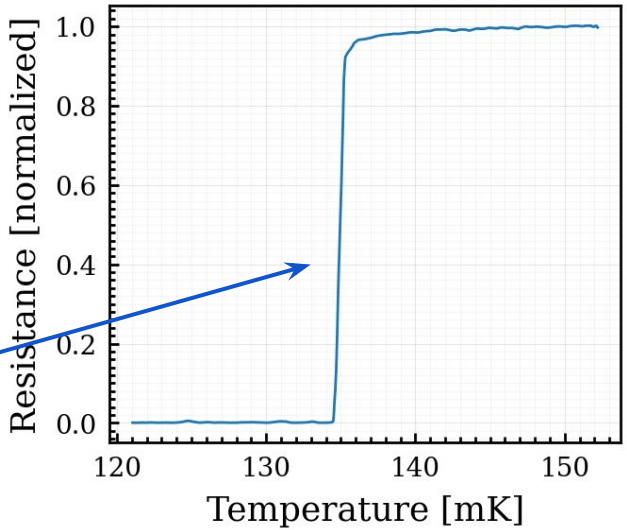


Tunable critical temperature

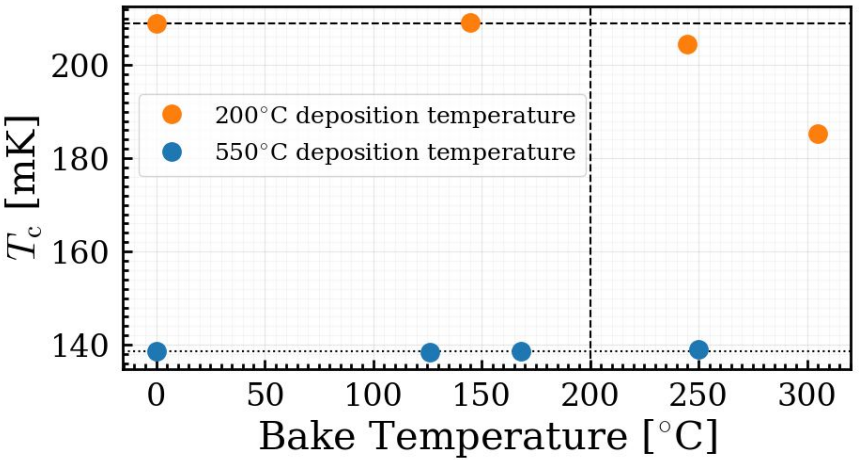
Reproducible → scatter ~ 5 mK
averaged over several samples



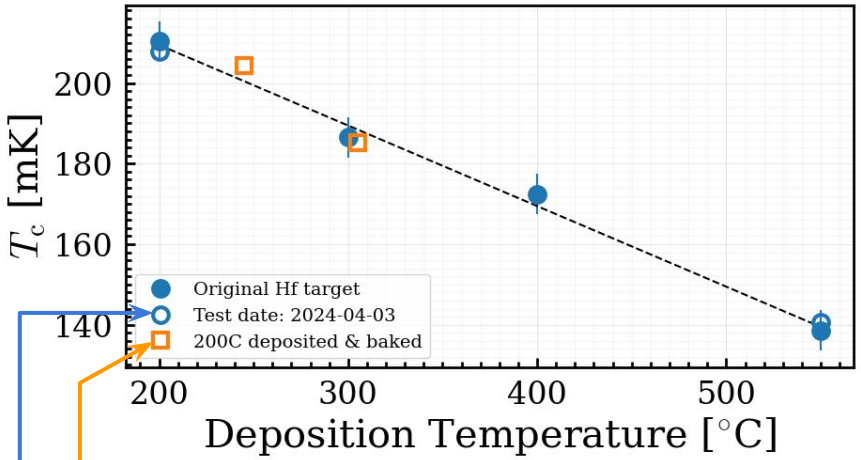
Steep transition → Δ ~ 3 mK



Robust against heating



*If original deposition temperature is not exceeded
Bake time ~ 30 min



T_c tunable by additional baking

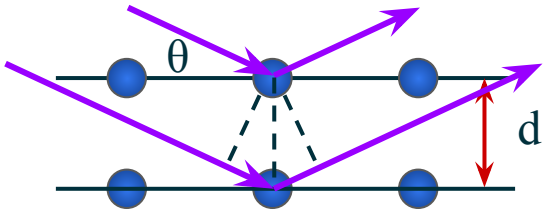
Stable in time
Stored in ambient conditions → unchanged T_c

Phases of Hafnium

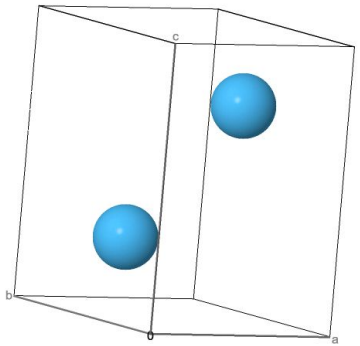
X-ray diffraction (XRD) → scattering of x-rays off of atomic crystal lattice planes (d)

Bragg's Law: $n\lambda = 2d \sin(\theta)$ → constructive interference

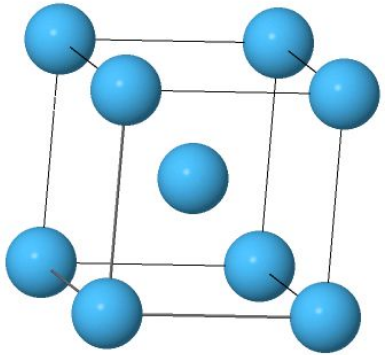
Elements/phases/grain orientation of material have a unique XRD pattern



α-phase



β-phase



ICSD (Inorganic Crystal Structure Database)

Grain orientation in films

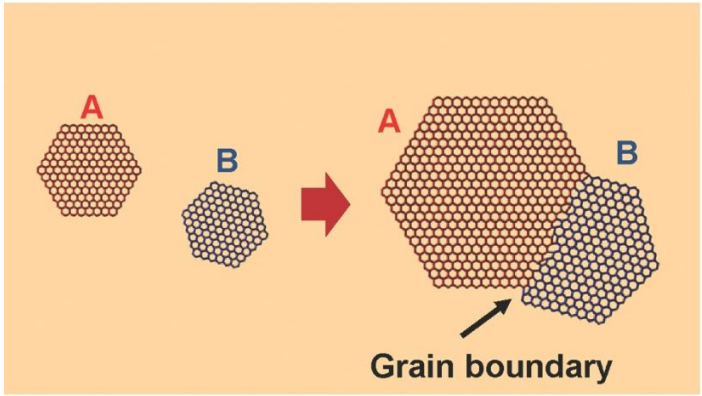
Polycrystalline: random orientation

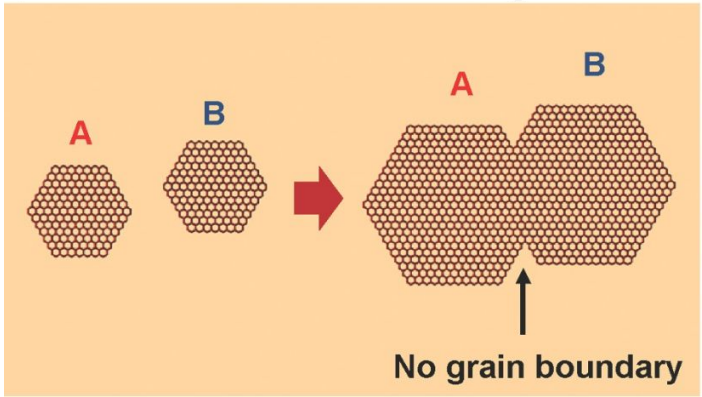
↓

Textured: preferred orientation

↓

Crystalline: single orientation



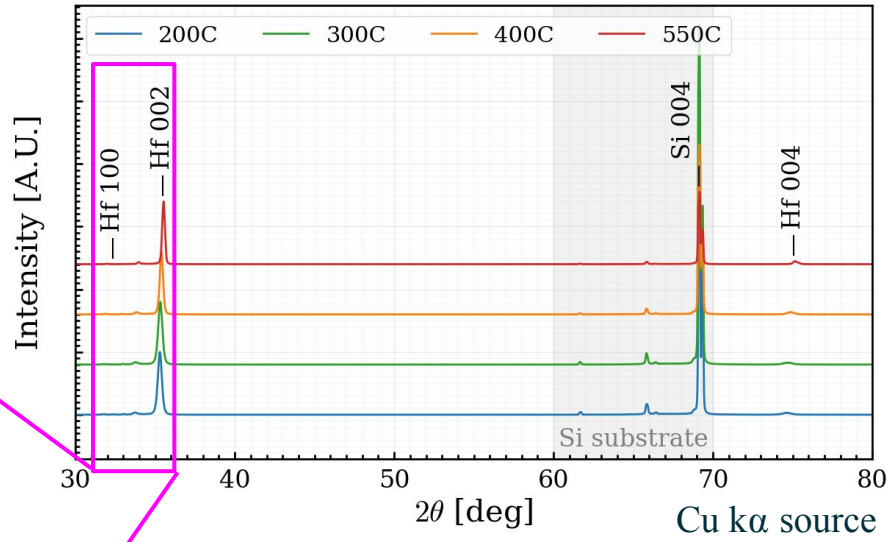


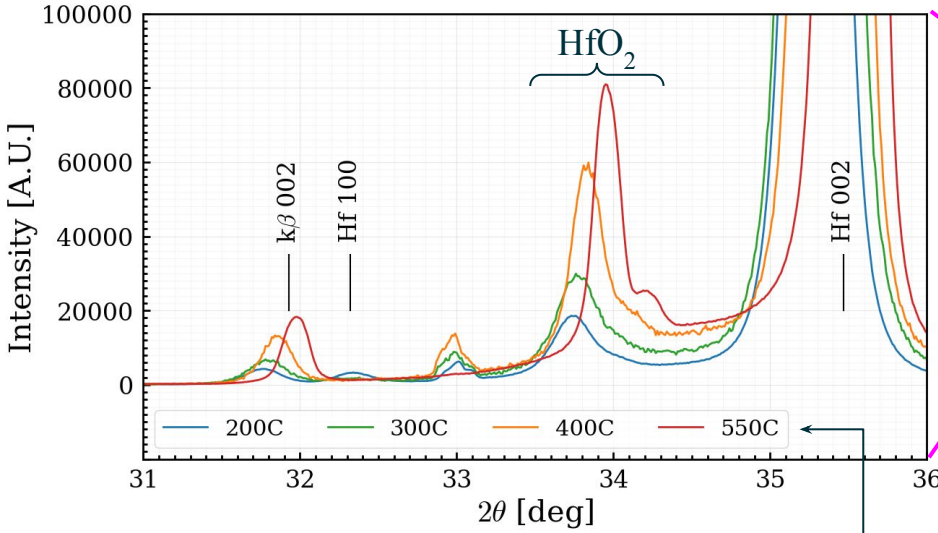
Nguyen et al. (2015)

XRD of Hafnium films

Detected:

- Hf α-phase (002/004 & 100)
- HfO_2
- Si substrate





No Hf β-phase measured

Varying deposition temperatures

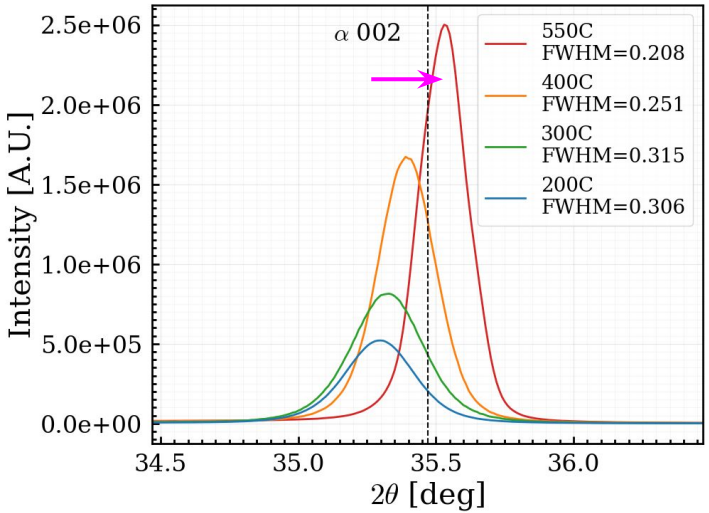
Hf α 002

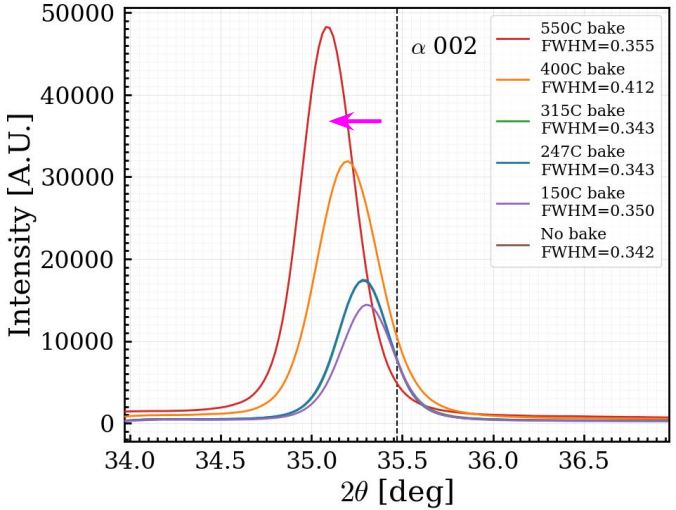
- Increasing deposition temperature (200C → 300C → 400C → 550C)
  - Lattice parameter d approaches that of bulk
  - Wider FWHM (smaller grain) → narrower FWHM (larger grain)

- Increasing bake temperature (No Bake/150C/247C/315C → 400C → 550C)
  - Lattice parameter d grows due to defects
    - ➢ Possibly oxidization

Opposite shift to deposition temperature

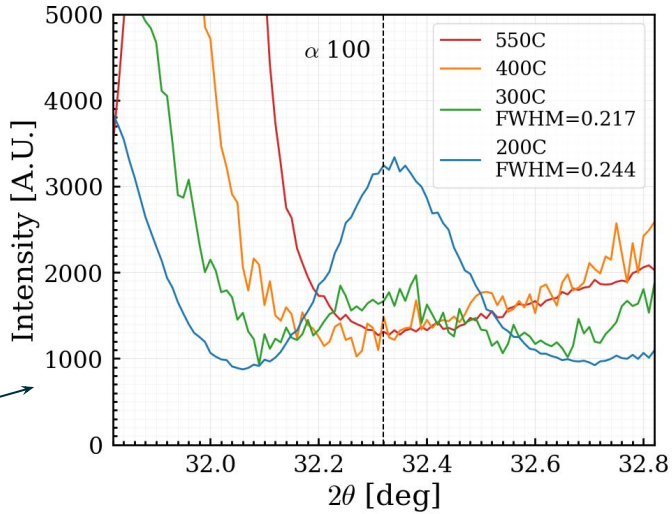
Commonality: amplitude increases with temperature → larger volume of sample is α 002

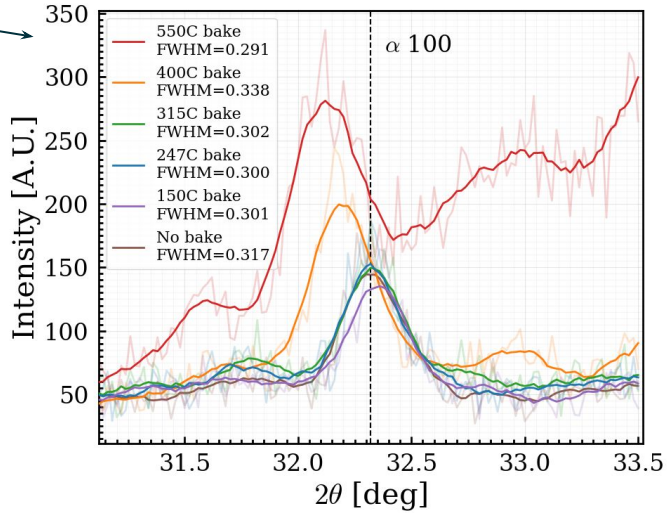




Hf α 100

- Low-deposition temperature orientation
  - Smaller abundance with increasing deposition temperature
  - Baking to elevated temperatures does not suppress the peak



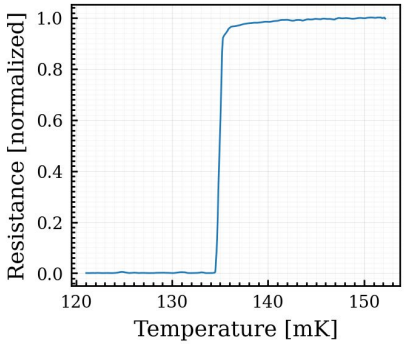


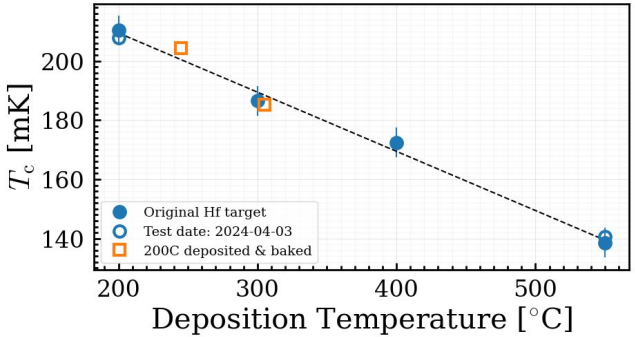
Summary

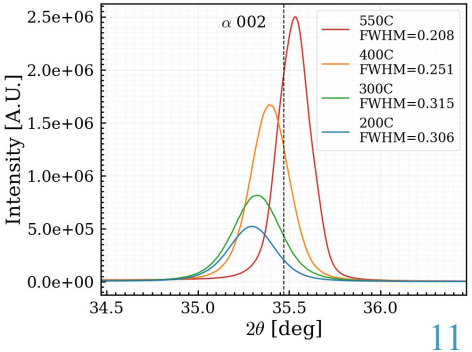
Hafnium

- Reliable, steep transitions
- Tunable T_c with heated sputter deposition
- Robust against heating below deposition temperature
- Highest temperature film is exposed to sets T_c

- Hf α 002 and α 100 detected in films
- Heated sputter deposition and baking have different effects on grain size/orientation
  - Higher temperatures → preferred grain orientation







Thank You.