Hafnium for optical and near-infrared microwave kinetic inductance detectors

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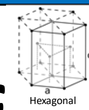
G. Coiffard[1], M. Daal[1], N. Zobrist[1], S. Steiger[1], B. Bumble[2] and B. A. Mazin[1]
[1] *University of California, Santa Barbara*
[2] *NASA JPL*

72
Hf



~\$120 per gram
Common Application:
- High temp super alloy constituent
- Neutron moderator material in control rods

Much recent interest in ferroelectric HfO_2 for SSD memory apps. And, $\varepsilon_r \sim$ 20 for HfO_2 !

WHY HAFNIUM?

Low transition temperature Tc → increase **detector response** $\frac{\delta f_r}{f_r} \propto \frac{1}{V T_C{}^2}$ and **energy resolution** $\frac{E}{\Delta E} \propto \sqrt{\frac{1}{T_C}}$

V = volume of the resonator

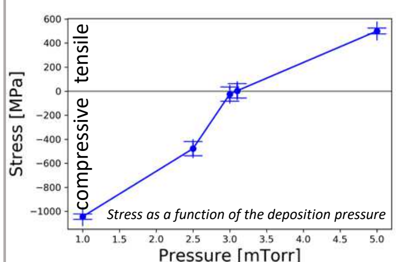
$\Delta = 1.72 k_B T_C$ Superconducting gap

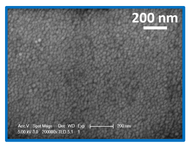
T_C drops → **more quasi-particle** produced by a photon of fixed energy

- Elemental material → easy to deposit from bulk target → **Better uniformity** and process reproducibility than reactively sputtered materials (TiN, PtSi)
- High normal state resistivity → **high surface inductance**

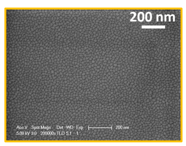
HAFNIUM DEPOSITION

- sputter deposition in UHV chamber from a 3 inch hafnium target (P_{base} 1e-9 Torr, 100W DC, gun angel: 19˚ off ⊥)
- Hafnium deposited on rotating sapphire substrate (rotation) at 20C.
- By adjusting sputtering parameters, we can control the film morphology, stress, crystal structure, resistivity, purity



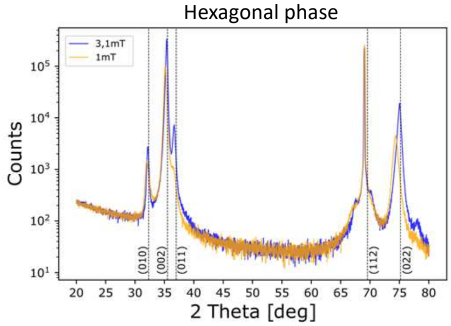


3,1 mT
near zero stress



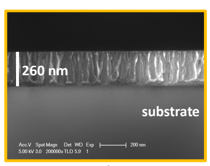
1 mT
High **compressive stress**

Hexagonal phase



X-ray diffraction pattern of hafnium

Hafnium is strongly **oriented along the c-axis** (002) and (004)
→ columnar growth



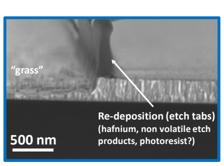
Cross section of a 260 nm thick film (1 mT recipe)

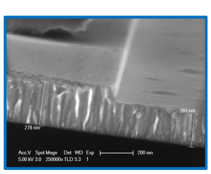
HAFNIUM ETCH

7 parameters to tune for ICP etch: plasma power, substrate bias power, reactive gas flow (Ar, Cl_2 and BCl_2), pressure, temperature
GOAL: get clean etch profile (sidewalls, etch tabs and bottom)

Low pressure process → need to get volatile chlorine compounds and $HfCl_4$ vapor pressure is ~ 0.01 Pa at 45C

Temperature and substrate bias are the key!



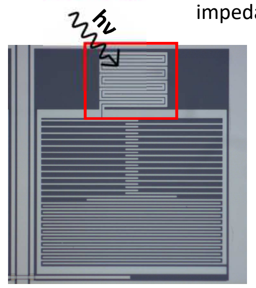


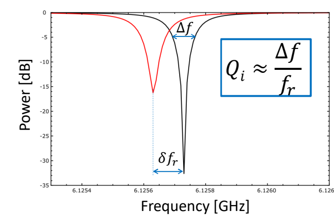
700 W DC
150 W bias
0.07 Pa
Cl2 3.2 / Ar 1.7 sccm
45 °C

By increasing the bias voltage and the substrate temperature, etch tabs and "grass" were eliminated

MKIDs RESULTS

Kinetic inductance effect causes incident photons to change the surface impedance of a superconductor

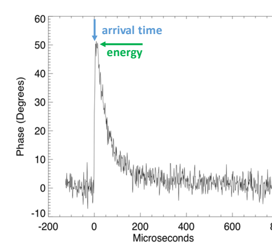




$Q_i \approx \frac{\Delta f}{f_r}$

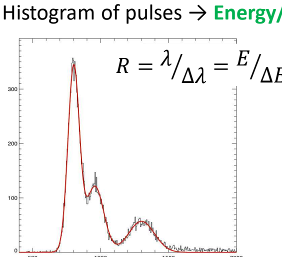
$f_r \propto \frac{1}{\sqrt{(L_g + L_k)C}}$ → Change in L_k → Change in f_r

Film properties	
Substrate	A-plane sapphire
Thickness	125 nm
Sheet resistance	6.5 Ω/□
Resistivity	77.5 μΩ.cm
Surface impedance	13.5 pH/□
T_C	360 mK
Stress	-1095 MPa



Single photon detection = pulse

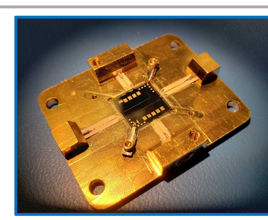
Histogram of pulses → **Energy/Spectral resolution**



	TiN	PtSi	Hf
τ_{qp} [μsec]	25	35	80
Q_i	1,000,000	400,000	200,000
$R = E/\Delta E$ @800 nm	8	8	10

CONCLUSION

- **Low base temperature** cryostat : work on thermalization $T_C/8$ ≈ 45 mK
- Why are we only getting resonators when using **a-plane sapphire and high stress** (~-1 GPa) hafnium?
- Using hafnium in x-ray sensor project



Hafnium test devices in its box. Gold bond pads have been added to improve thermalization of the device