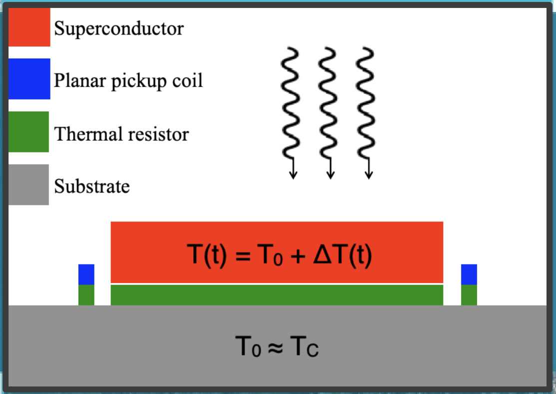
SAND2023-08081C

Nanostructured thin films for Meissner-Effect Transition-Edge-Sensor Devices



Presented by

Patrick Finnegan

Christian L. Arrington, Chris St John, and Steve M. Carr

Sandia National Laboratories, Albuquerque, New Mexico

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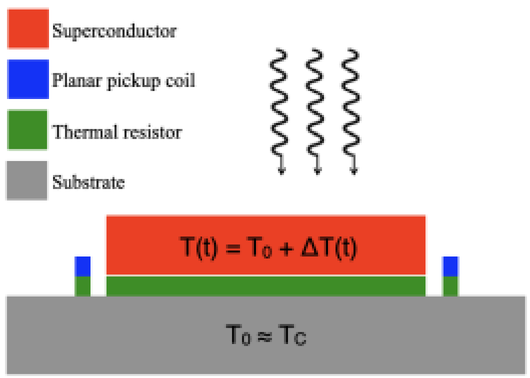
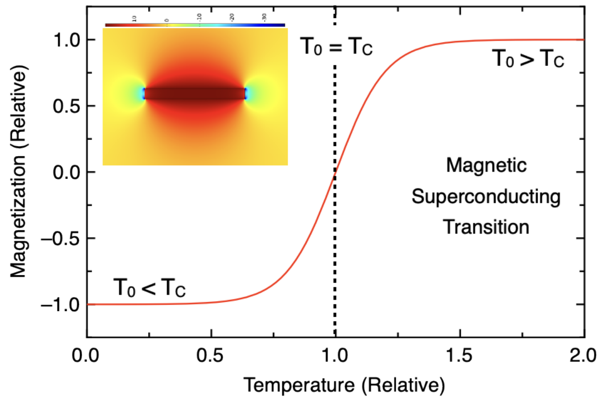
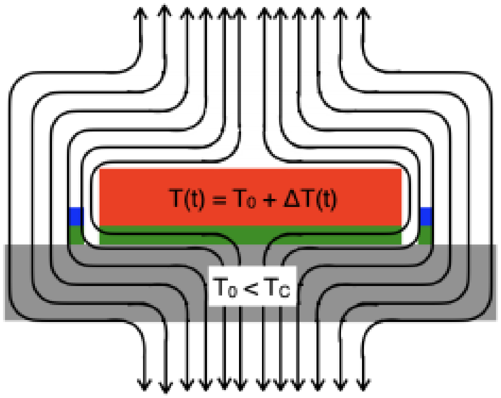
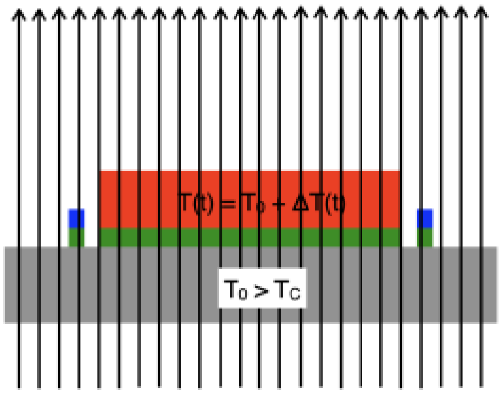
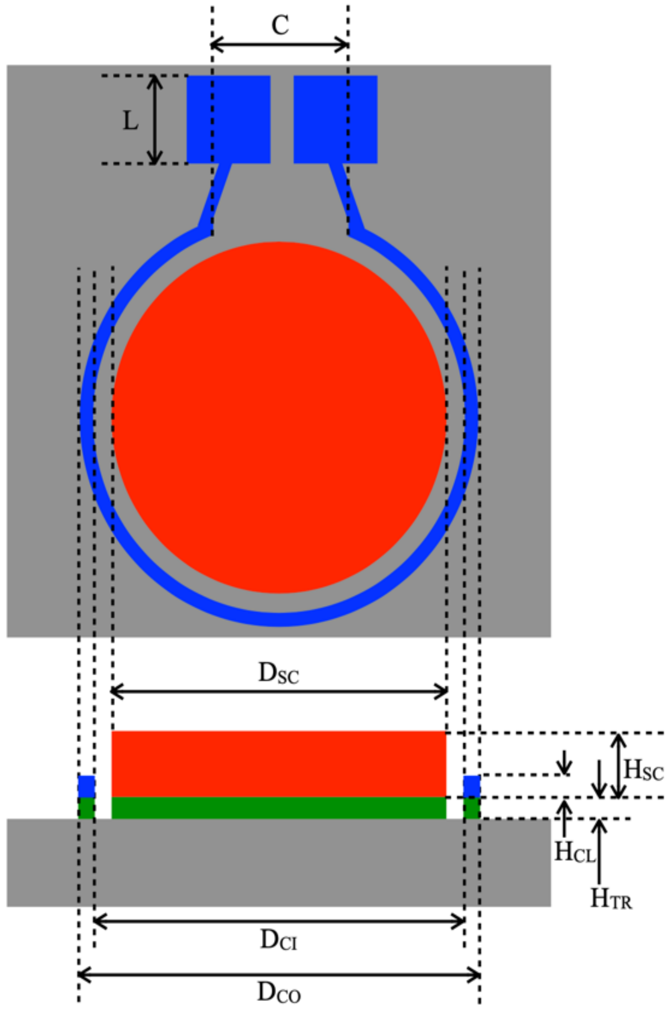
Meissner-Effect Transition-Edge-Sensor (ME-TES): Introduction









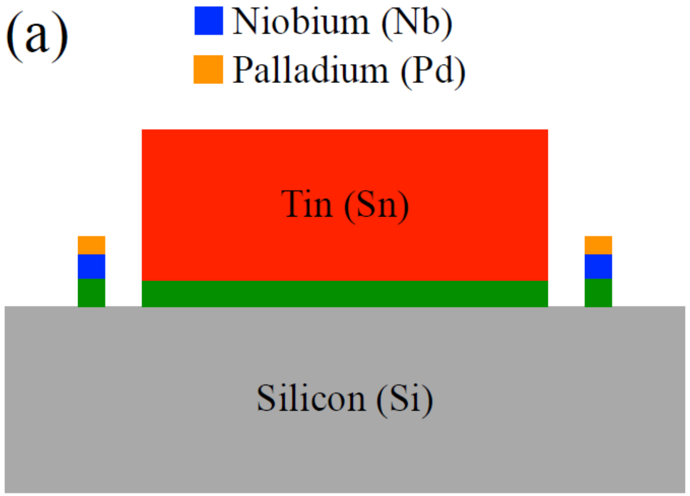


- An ME-TES microcalorimeter employs thermal detection of radiation, as shown schematically above with incident radiation as wavy lines, in particular gamma-ray radiation.

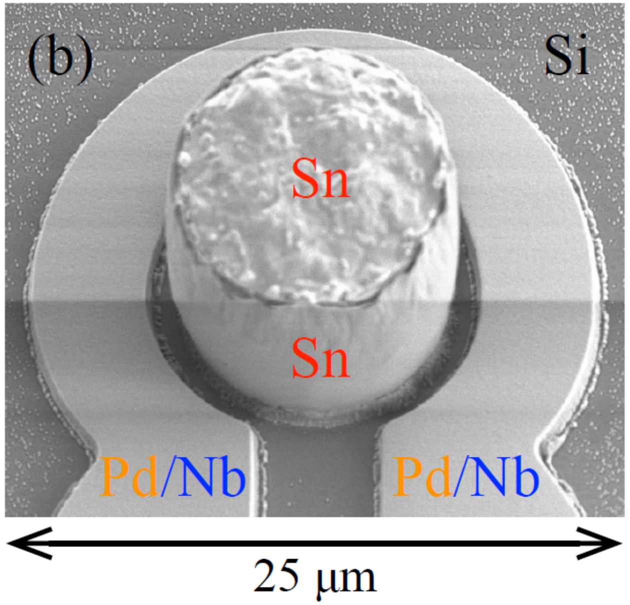
$S = (D_{CI} - D_{SC}) / 2 =$ Separation or gap between outer diameter of tin and inner diameter of niobium coil.

$W = (D_{CO} - D_{CI}) / 2 =$ Width of niobium coil.

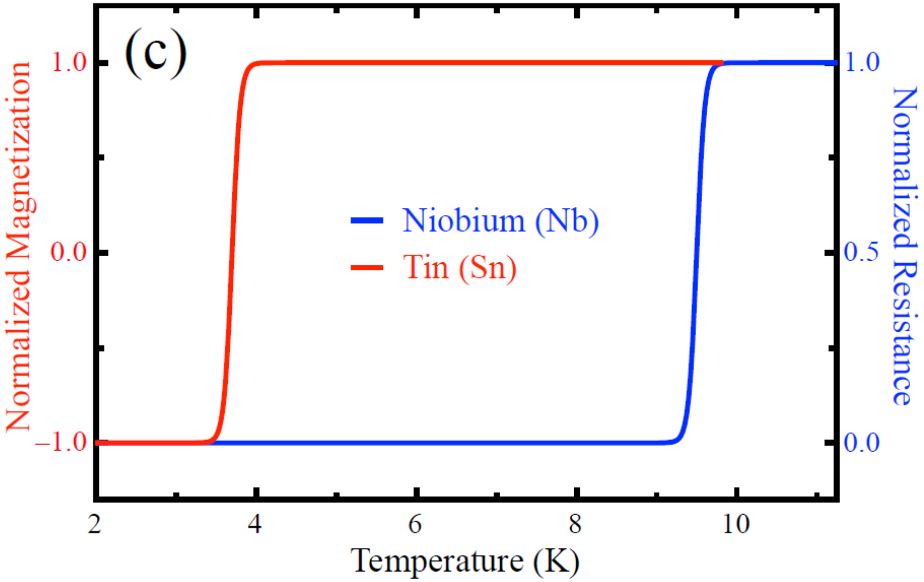
Meissner-effect transition edge sensor (ME-TES)



ME-TES device schematic cross-sectional image.

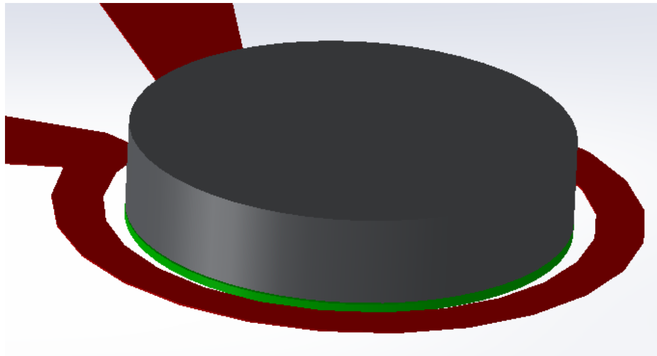


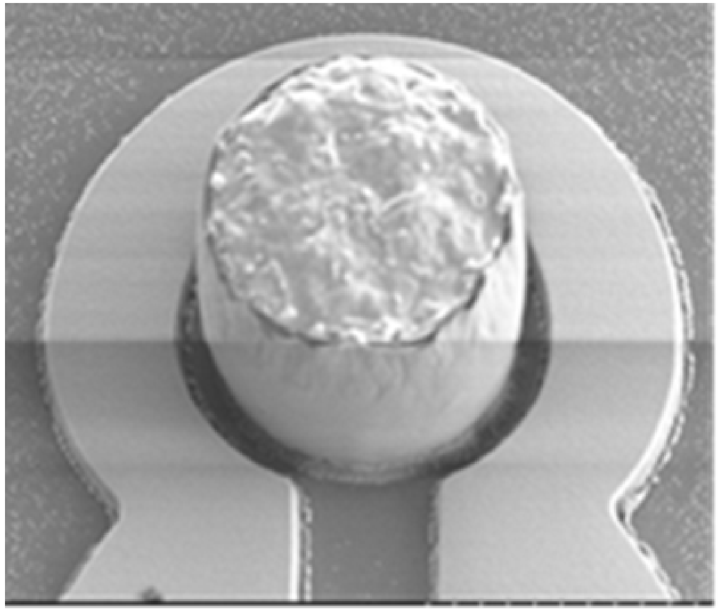
Scanning Electron Microscope (SEM) micrograph of a completed ME-TES device

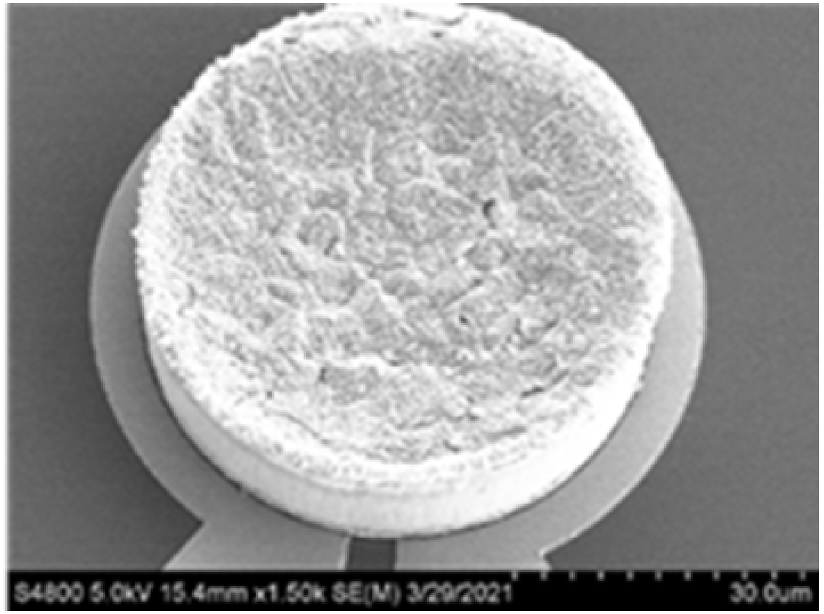


Operation intended to be at the Sn magnetic superconducting range while the Nb is fully superconducting

Device size and geometries







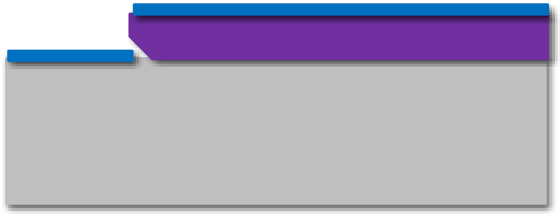
Scanning Electron Micrograph (SEM) images of completed devices (a) Dsc = 10 µm and Hsc = 10 µm and (b) Dsc = 50 µm and Hsc = 10 µm.

Pick up coils: “Lift off” and “etch” microfabrication

Niobium metal deposition to pattern coils

Photoresist with re-entrant profile

silicon substrate

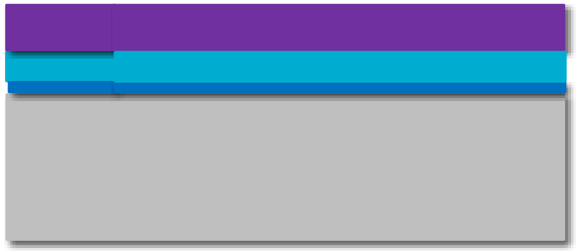


Photoresist

Silicon oxide

Niobium metal deposition

silicon substrate

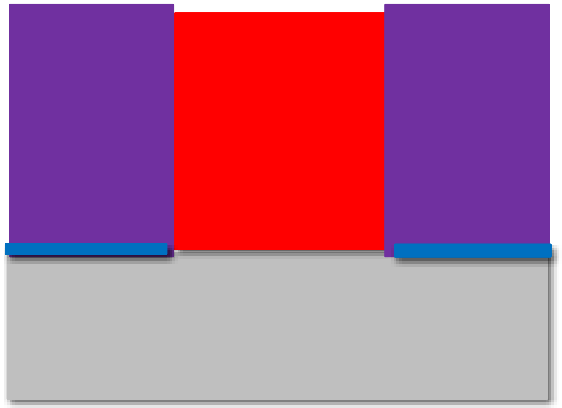


Tin metal deposition

Photoresist with straight sidewall

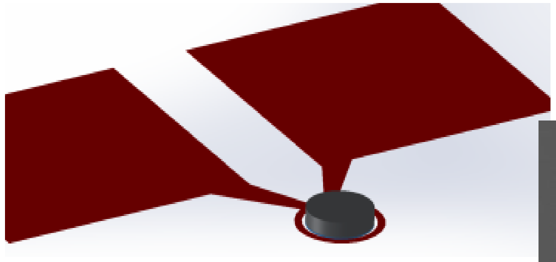
Niobium metal

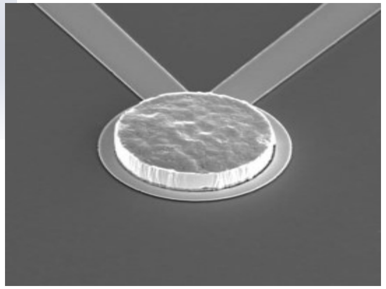
Silicon substrate



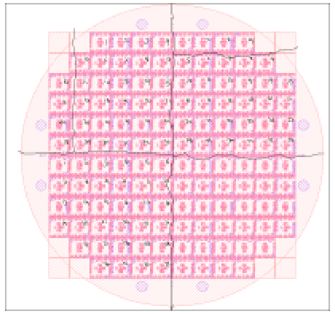
ME-TES Fabrication layout

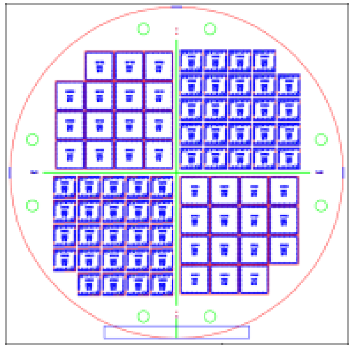
- 150 mm silicon nitride wafers
- Layer 1 defines Al/Nb/Pd superconductor
- Layer 2 defines electroplated tin disc
- Electroplating tin one quarter wafer at a time after
- Microscopy, SEM, XRF, and EDS for analysis



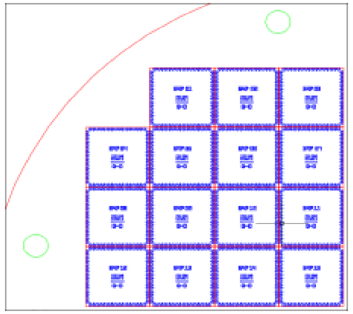


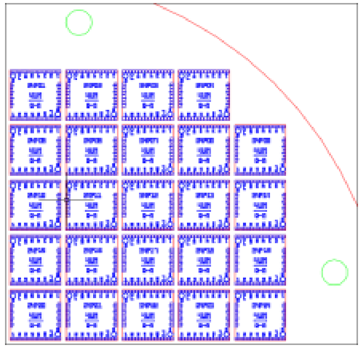
Wafer



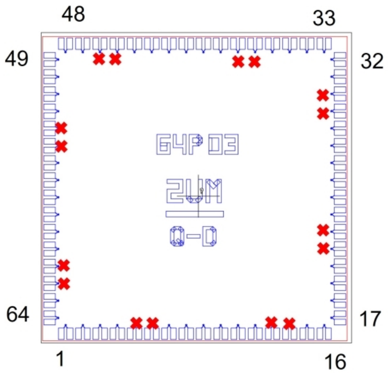


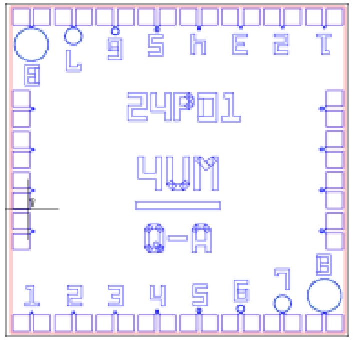
¼ wafer



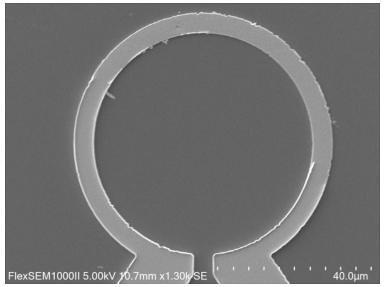


Die

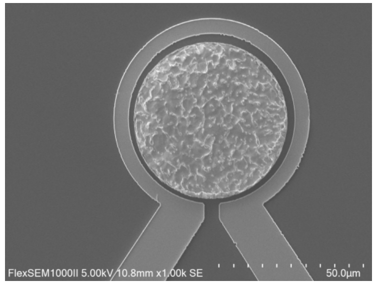


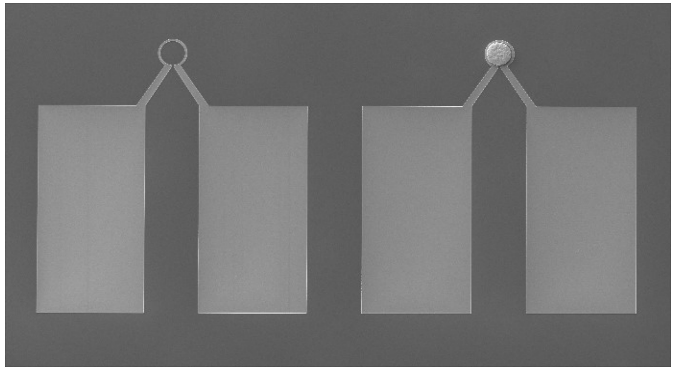


Device without tin (pickup coil)



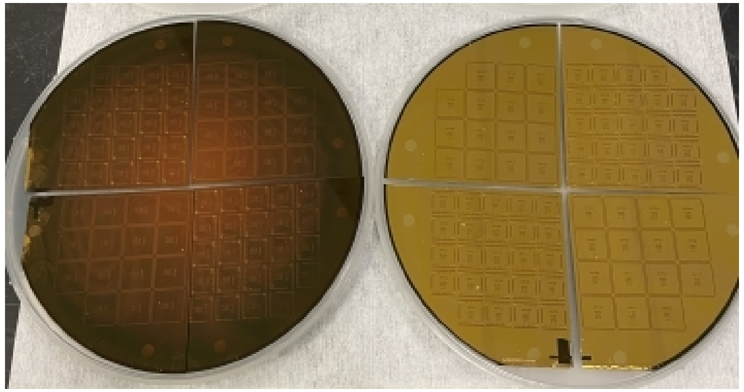
Device with tin

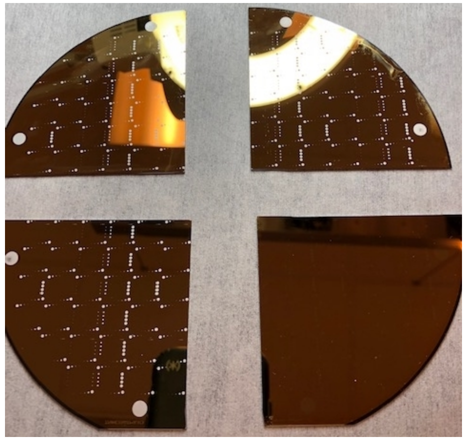


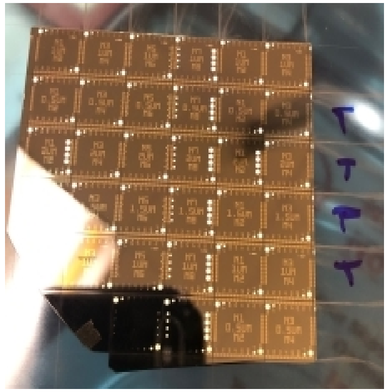


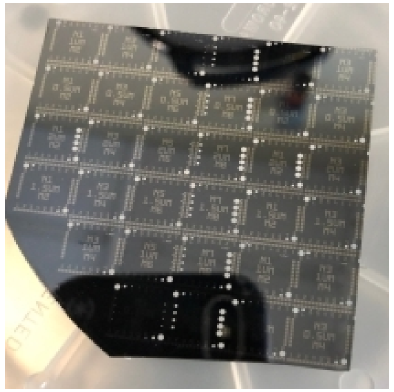
Process flow

Wafer → Quarter wafer → Die/device level

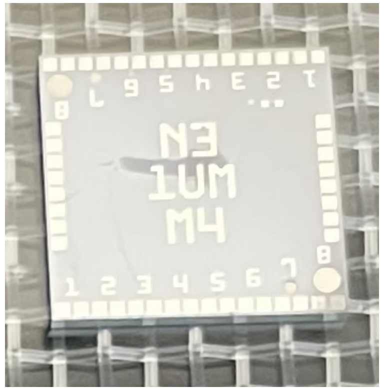


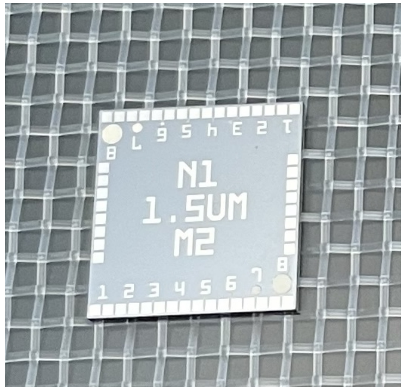


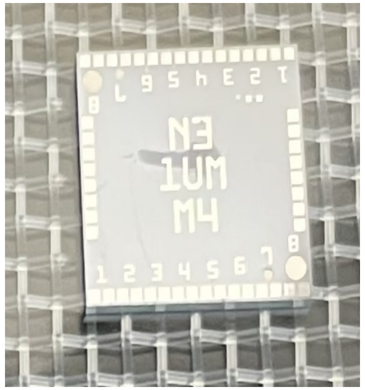




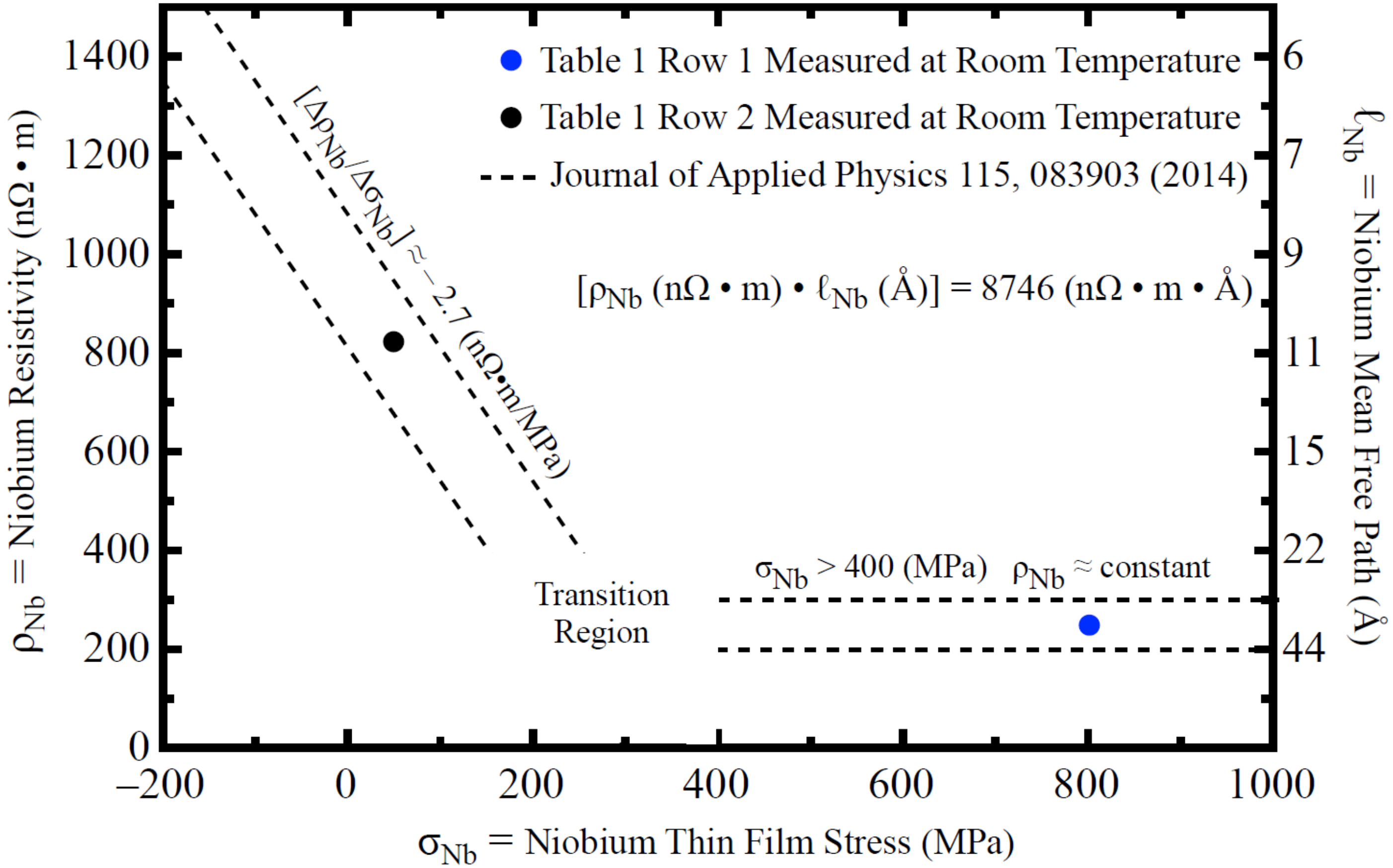
Diced quarter wafer







Nb Film stress vs. resistivity at room temperture



Henry et al, Stress dependent oxidation of sputtered niobium and effects on superconductivity JAP 115,083903 (2014)

Deposition parameters and resulting film resistivity

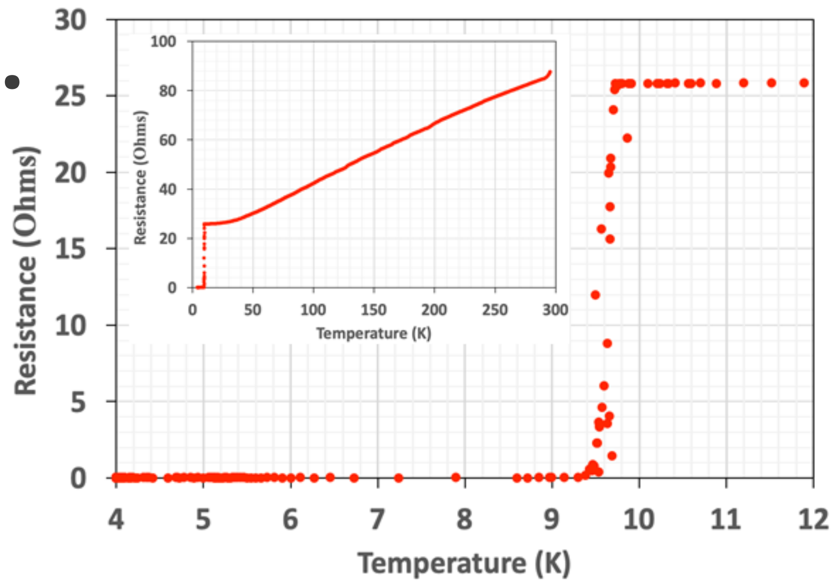
Thickness nm	Stress MPa	Rs Ω/sq	Ar sccm	Power W	mT	BulkR nΩ-m
341.3	50.7	2.38	43	150	8	812.3
335.3	46.1	2.40	43	150	8	804.7
274.0	822.6	0.89	22.5	225	4.5	243.9
294.4	797.2	0.83	22.5	225	4.5	244.4
267.5	802.6	0.86	22.5	225	4.5	230.1
262.5	642.5	1.05	22.5	225	4.5	275.6

Sputter deposition parameters and resulting stress and room-temperature resistivity measurements.

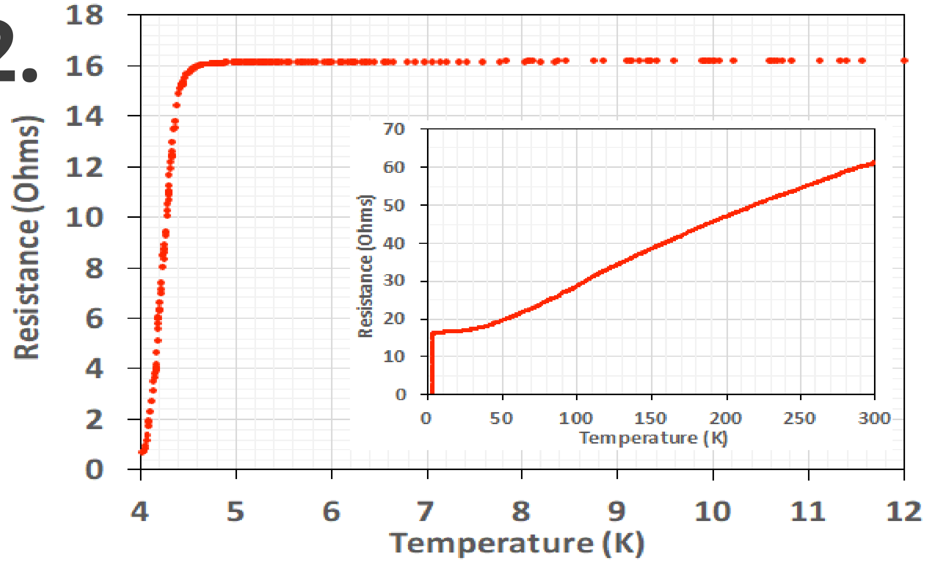
As the power increases from 160 W to 240 W and chamber pressure decreases from 8 mTorr to 4.5 mTorr and argon (Ar) gas flows decrease from 43.3 sccm to 22.9 sccm, transition temperature of the Nb is higher, closer to 10 K, which provides a greater contrast to that of the Sn. The transition temperature od Sn is 3.7 K. We attribute the difference to film stress, which is correlated with room-temperature resistivity

Optimization superconductivity of nanostructured Nb films

1.



2.



Row Number	DC Power (W)	Argon Flow Rate (sccm)	Pressure (mTorr)	d_{Nb} (nm)	σ_{Nb} (MPa)	$\Re_{Nb}$ ($\Omega/\square$)	ρ_{Nb} ($n\Omega \cdot m$)	ℓ_{Nb} (Å)	T_c (K)
1	225	22.5	4.5	274	823	0.89	244	36	9.6
2	150	43.0	8.0	341	51	2.38	812	11	4.2

Experimental data showing the resistance as a function of temperature for sputtered niobium For (a) the transition temperature near 4 Kelvin is so low that it could interfere with the transition for tin (approximately 3.7 Kelvin in bulk). For (b) the transition temperature is near the expected bulk value and well separated from the transition for tin.

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Questions?