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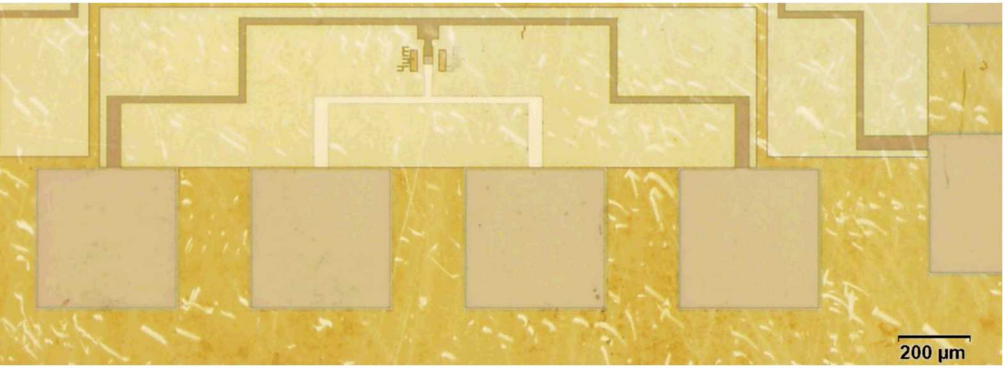

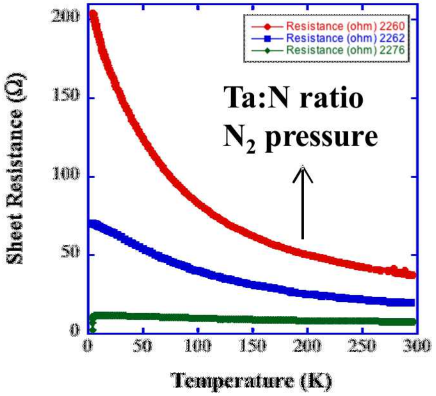

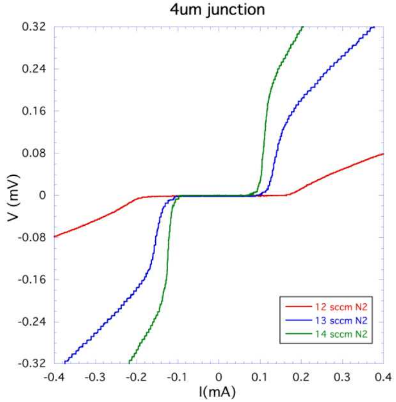

Tunable Ta_xN Josephson Junctions for Scalable, High Performance, Low Power Computing

M. A. Wolak, M. D. Henry, R. Lewis, S. Howell, S. Wolfley, L. Brunke and N. A. Missert

Sandia National Laboratories, Albuquerque, NM 87185

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Outline

- Motivation for Ta_XN based Josephson Junctions
  - Advantages of using Ta_XN as a barrier material
  - Quality of sputtered Ta_XN and implications for use in a microfabrication process
- Fabrication of Ta_XN Josephson Junctions
  - Device fabrication and process flow
- Characterization of Ta_XN based Josephson Junctions
  - Scaling with junction size
  - Changes in characteristics as a function of stoichiometry and barrier thickness
- Summary and Outlook

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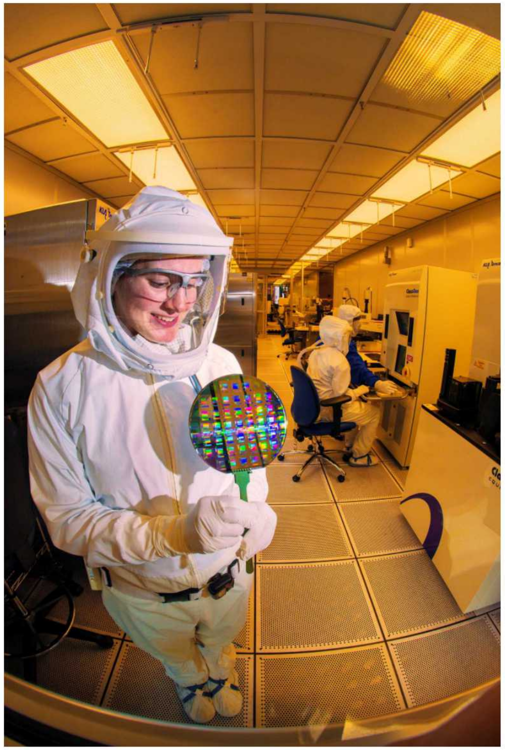
Motivation

- Go beyond current superconducting electronics (SCE) technology in order to enable devices for scalable, low power, high-performance computing
- Demonstrate avenue for ambient temperature, tunable technology to address a variety of applications
- Understand and optimize thin film growth for wafer scale fabrication of junctions
- Develop next-generation technology (beyond Moore) based on nitrides for alternative technologies



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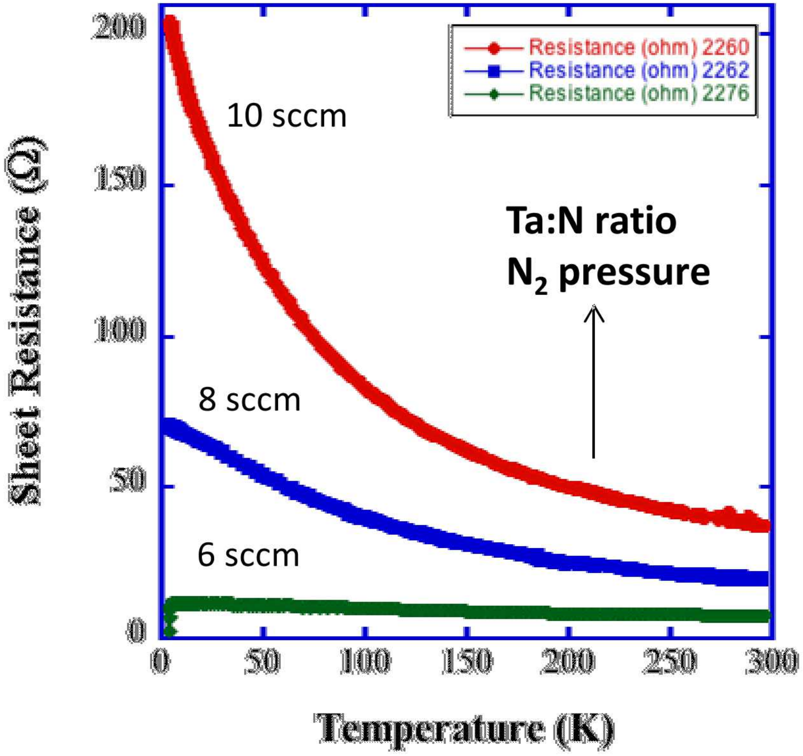
Motivation

- <u>Can Ta_XN offer advantages over AlO_X barriers?</u>
- Thermal stability – can use optimized dielectric, potential for 3D scaling
- Barrier properties can be tuned – self shunting, may be less susceptible to electronic defects

➢ Explore Nb/Ta_xN/Nb SNS JJs grown at ambient temperature on SiO_2/Si substrates (for future scaling)

Tunable Resistance



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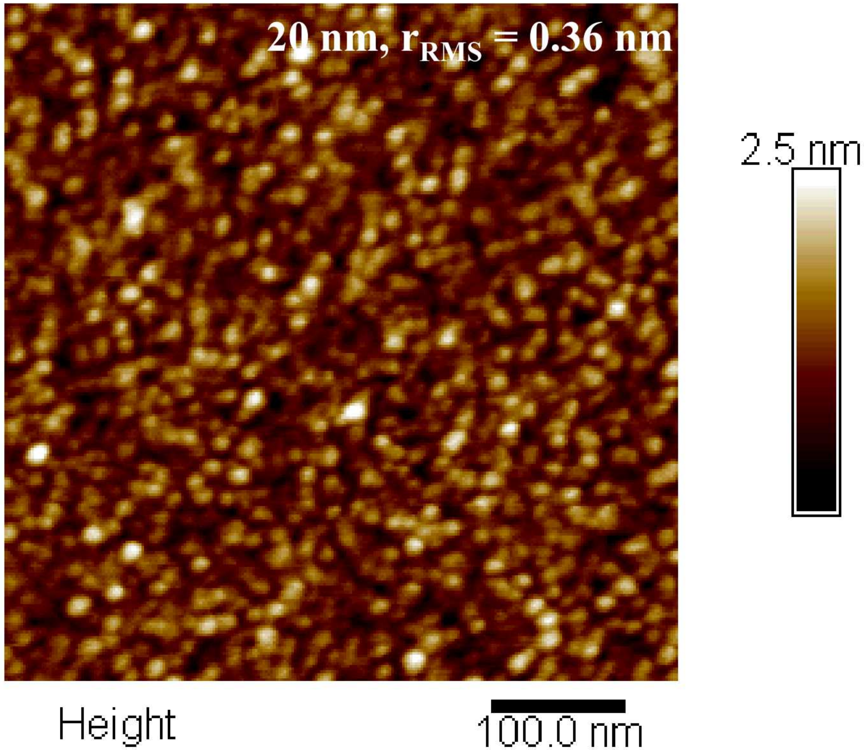
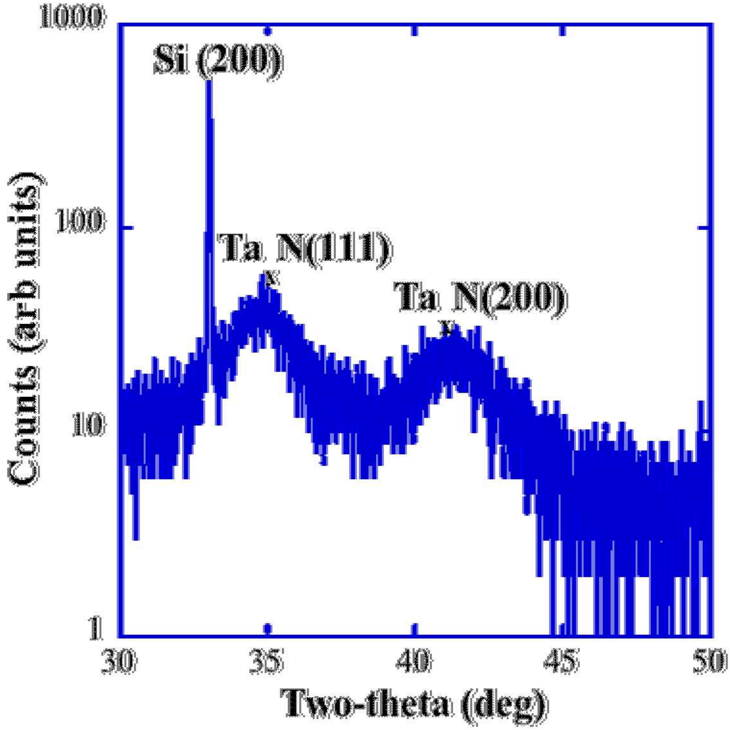
Motivation

AFM: smooth



XRD: disordered



- High quality films and JJs previously demonstrated on crystalline substrates and/or with high temperature growth
- Single Ta_XN films on SiO_2/Si substrates are smooth, single phase and have tunable electronic properties

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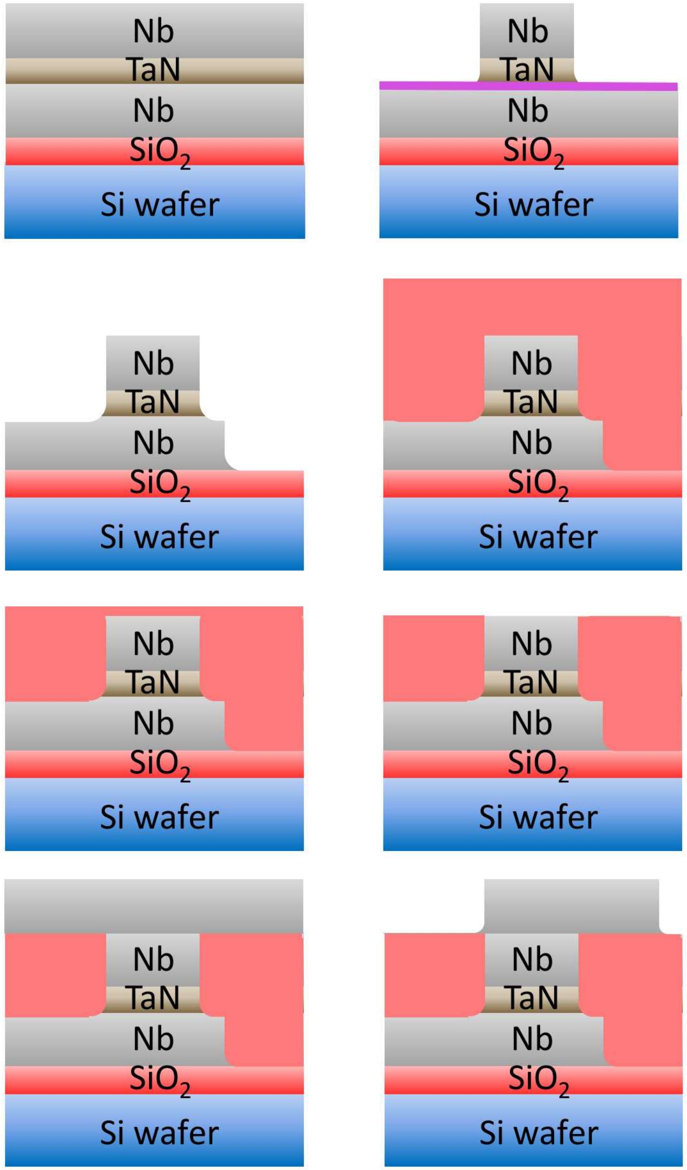
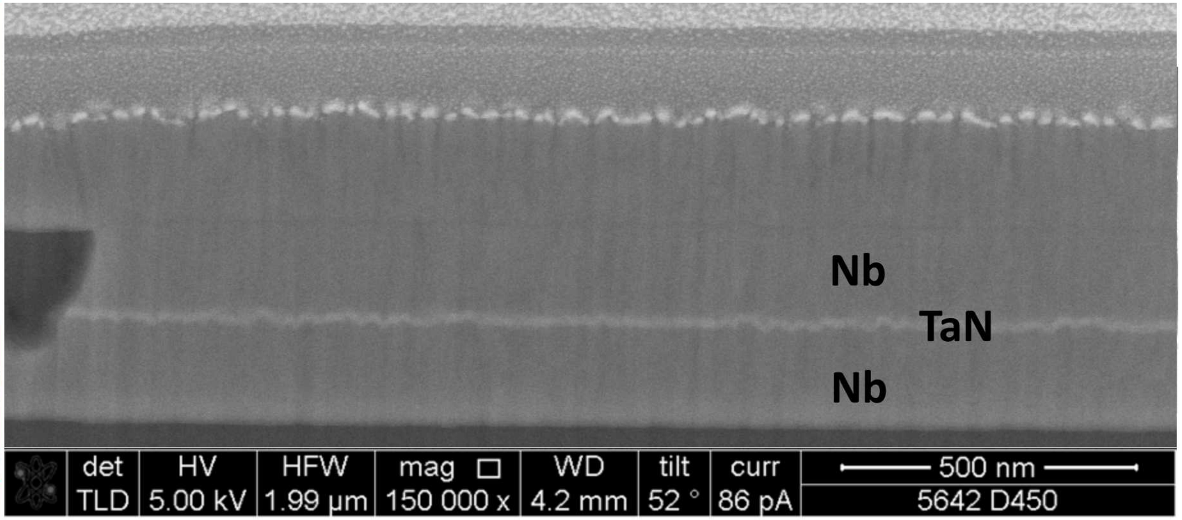
N. A. Missert *et al.*, IEEE Trans. Appl. Supercond, Vol 27, 4, 1100904, (2017).

Fabrication of Ta_xN Josephson Junctions



a) **Trilayer** of Nb (200 nm) / Ta_xN ~ (15 nm) / Nb (200 nm) is DC sputter deposited. The Nb has T_c of ~ 8.5K.
b) **Mesa etch** to the bottom Nb electrode (**with Al etch stop**), defining device area.
c) **Metal 1 etched** down to the bottom oxide, defining pad locations.
d) **SiO_2** deposited over the metal stack.
e) **CMP** flattening of the oxide.
f) **Oxide etch** to expose mesa top.
g) **Metal 2** (Nb) is deposited.
h) **Metal 2** is patterned.



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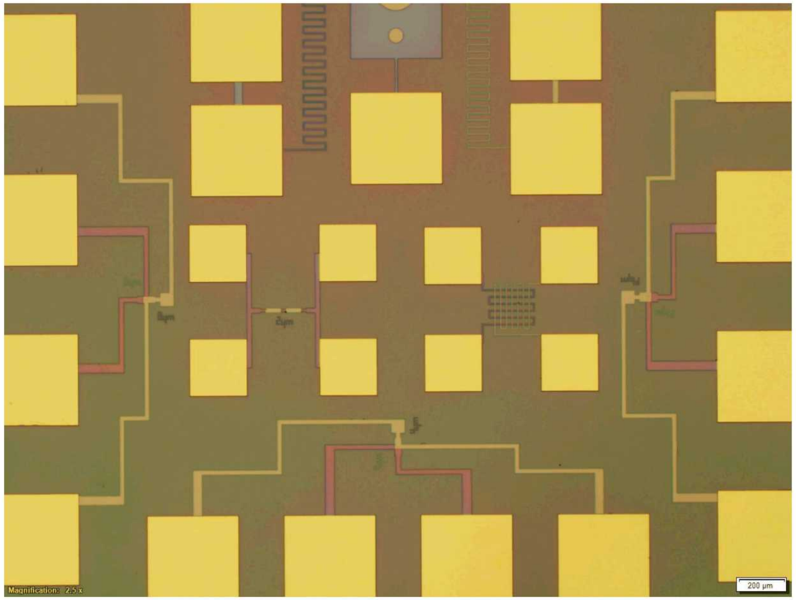
Fabrication of Ta_XN Josephson Junctions

- The process has been developed for 150mm sized wafers, leading to uniform thin film and junction properties across the wafer

- The junctions characterized in this study range from 4 µm to 10 µm in diameter (circular junction area)



- Barrier thicknesses of 10 nm, 15 nm, and 20 nm chosen to study effects on Ta_XN junction properties

- Ta_XN stoichiometry has been varied through the use of different N flow rates (10 sccm – 14 sccm) in 15 sccm of Ar during the Ta_XN growth

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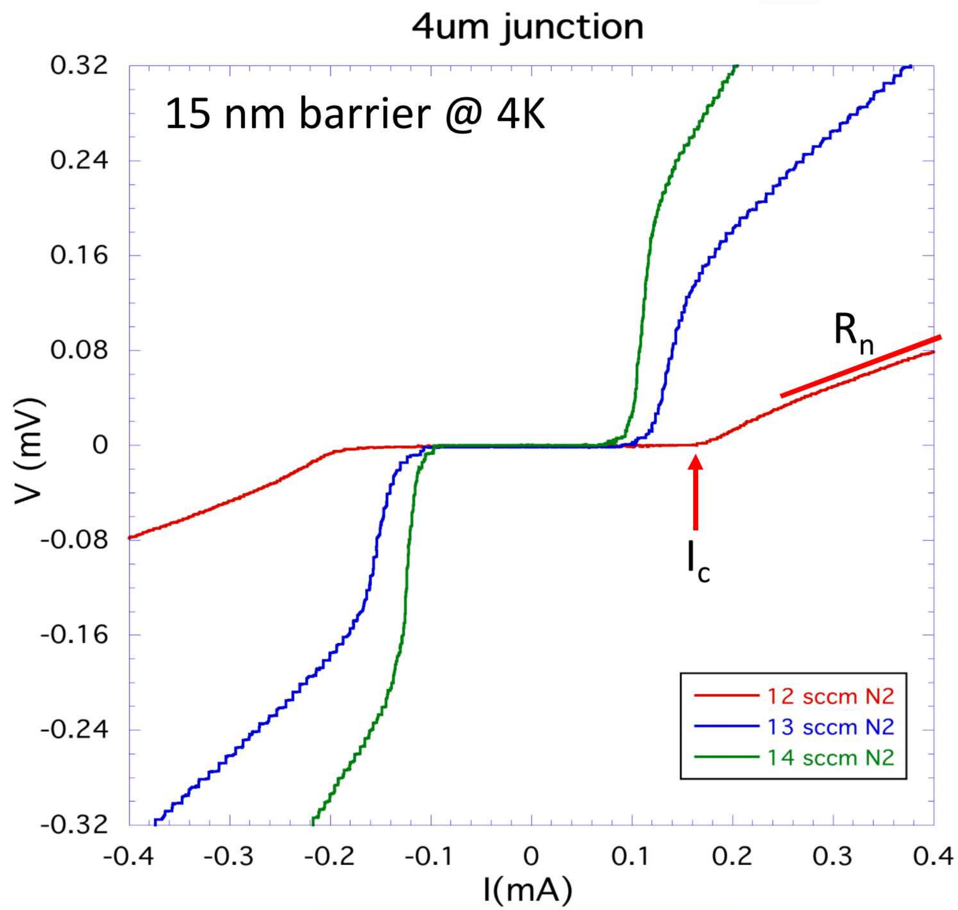
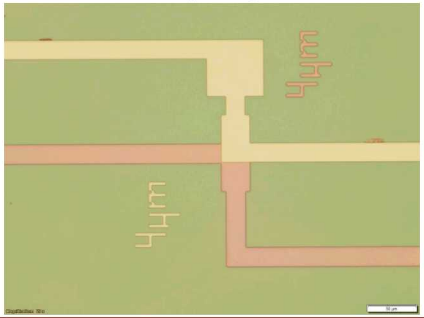
Characterization of Ta_XN based Josephson Junctions

- Barriers of the same thickness clearly indicate a dependence of I_c and R_n of the JJ
- I_c decreases with higher N concentration in Ta_XN (less metallic, more insulating)
- R_n increases with higher N concentration
- A clear display of tunability of Ta_XN barriers based on stoichiometry





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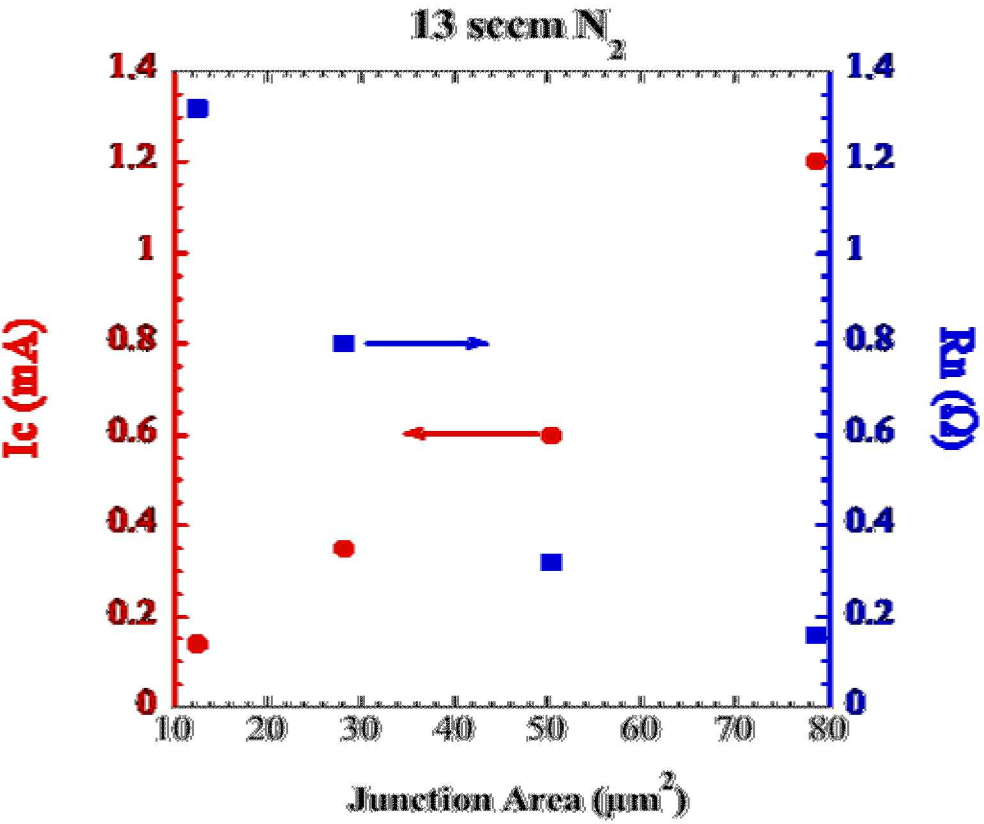
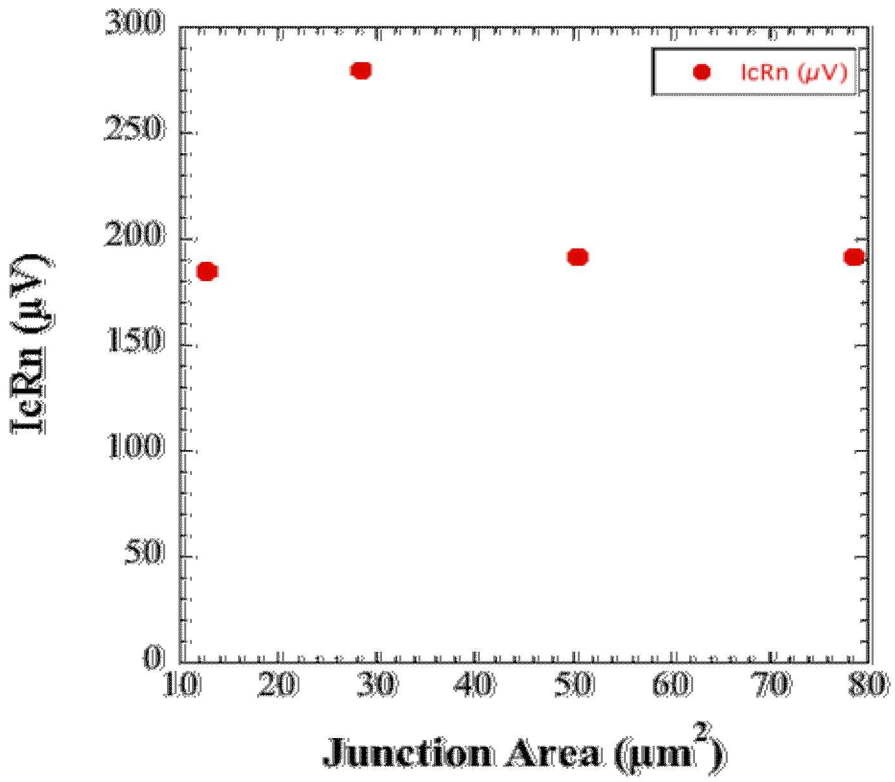
Characterization of Ta_XN based Josephson Junctions





I_c and R_n scale with junction size, while I_cR_n product remains fairly stable for all junction sizes.

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Characterization of Ta_XN based Josephson Junctions

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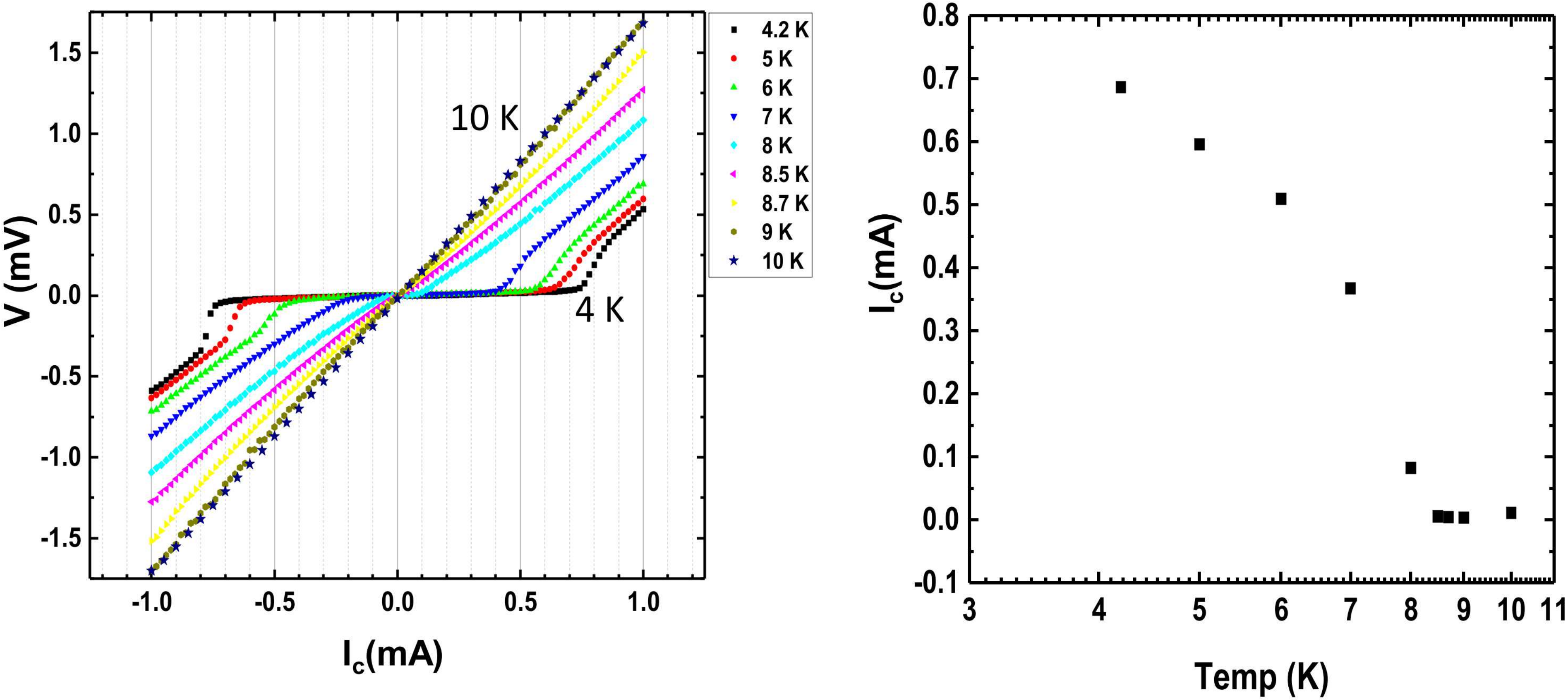

Junctions show clear temperature dependence of I_c

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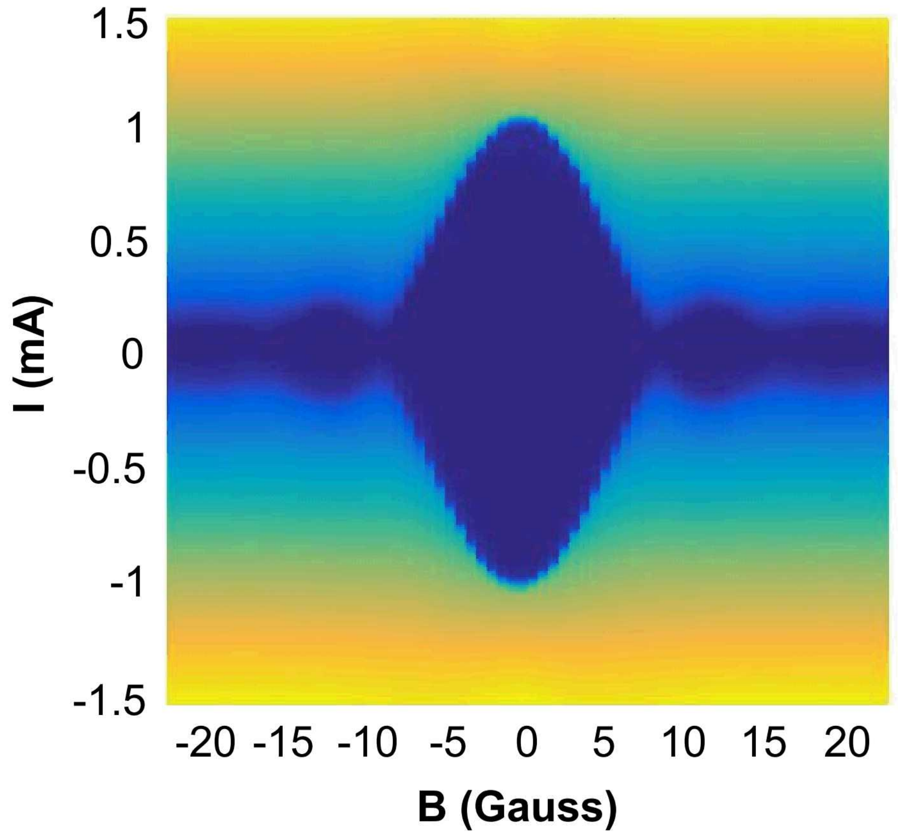
Characterization of Ta_XN based Josephson Junctions



10 µm JJ

15 nm TaN barrier

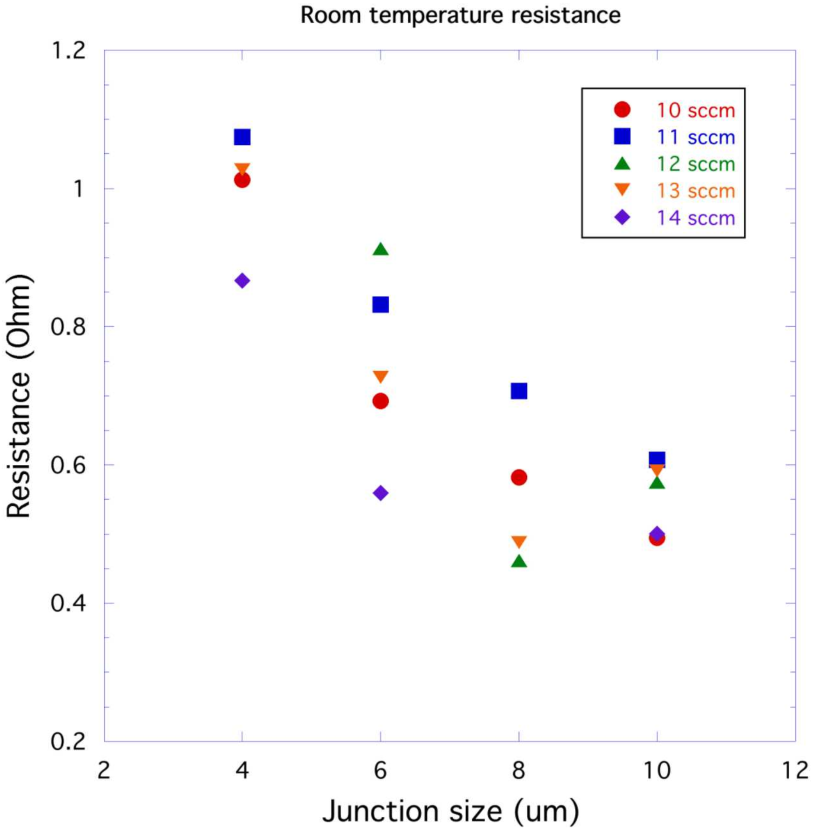
13 sccm N

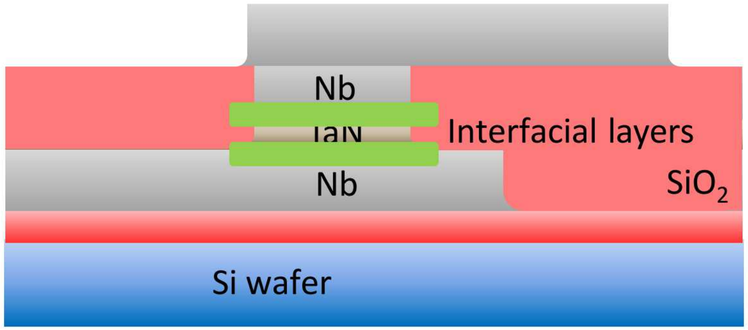
Fraunhofer pattern detectable in magnetic field as expected for Josephson Junctions

mwolak@sandia.gov

Characterization of Ta_XN based Josephson Junctions

- Room temperature resistance scales with junction size
- Junction resistance does not scale monotonically with the N content of the Ta_XN barrier
- This suggests interfacial layers due to Nb affinity to excess N in barrier, creating a serial resistance
- STEM/EDS cross-sectional imaging and SIMS will provide further insight





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Summary and Outlook

- Ta_XN based Josephson Junctions offer promising alternative for next-generation SCE
- Junction behavior can be tuned with barrier thickness and stoichiometry
- Deposition at ambient temperature with thermally stable barriers
- I_c of 1 mA and above can be achieved with I_cR_n products reaching 0.35 mV

- Improve I_cR_n by fine tuning Ta_XN growth conditions
- Analyze N distribution near interface using STEM/EDS cross-sectional imaging and SIMS depth profiling
- In future studies, junctions of less than 4 µm will be investigated
- Stacked multi-junction architectures have been fabricated and will be characterized soon

mwolak@sandia.gov

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Thank you for your attention!

- The SNL team:
  M. D. Henry, R. Lewis, S. Howell, S. Wolfley, L. Brunke and N. A. Missert

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