Preserving Nb Superconductivity in Thin-Film Superconducting Flexible Cables

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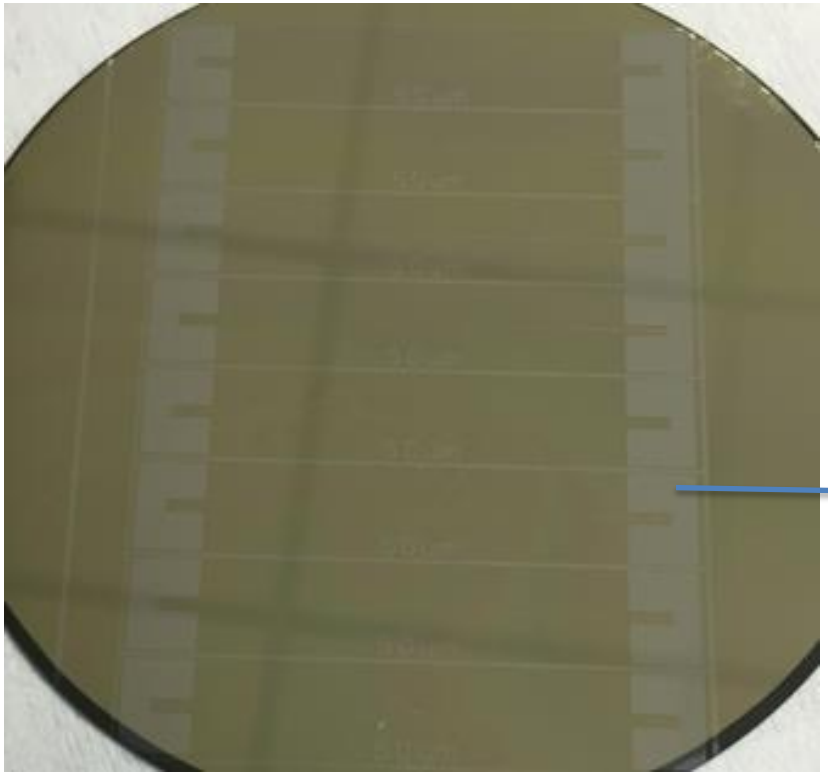
Outline

- Problem statement
- Proposed solution
- Test structure
- Stack ups
- Measurement setup
- Test results
- Future work
- Questions

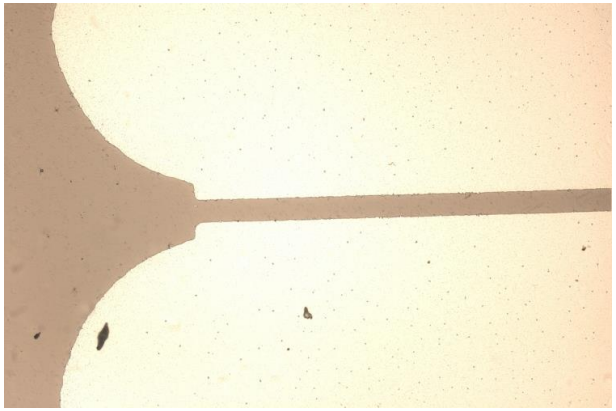
Problem statement

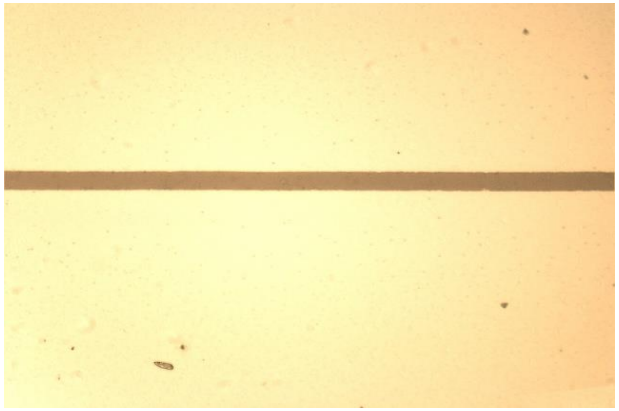
- Reduction in transition temperature (T_c) after polyimide (PI-2611) is cured on top of Niobium (Nb).
- Nb sponge like behavior leads to it being eaten away during polyimide cure
- Curing of PI-2611 at 350℃ leads to diffusion of oxygen, hydrogen, or other degrading materials into the thin Nb films.
- Possible solution: **Capping layer** in between Nb and PI and alternate polymer (Asahi Glass AL-X 2010) with lower curing temperature.

Test structure



Pads





50um line (zoomed in)

- 50 um wide line pattern used to test different stack up layers
- This 50um line is attached to pads on each end for measurement purpose

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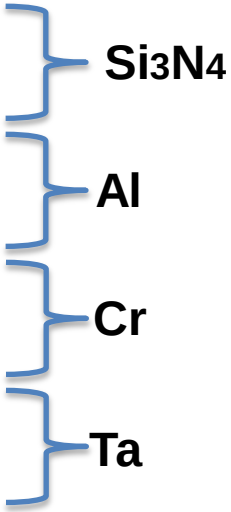
Stack ups

- Below are the stack ups tested:
  - Cr/Al/Nb/PI-2611
  - Cr/Al/PI/Nb/PI-2611
  - Cr/Al/Ti/Nb/PI-2611
  - SiO2/Nb
  - SiO2/PI-2611/Nb
  - SiO2/Nb/Si3N4
  - SiO2/Nb/Si3N4/PI-2611
  - SiO2/Nb/Al
  - SiO2/Nb/Al/PI-2611
  - SiO2/Nb/Cr
  - SiO2/Nb/Cr/PI-2611
  - SiO2/Nb/Ta
  - SiO2/Nb/Ta/PI-2611

Al, Cr and Ta were E-beam evaporated and Nb was DC sputter deposited in a vacuum chamber



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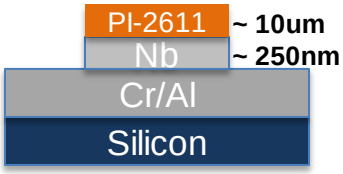
Measurement Setup

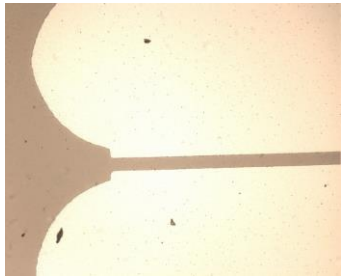
- Transition temperature measurements were carried out in either Liquid Helium (LHe) dewar or pulse-tube (PT) cryostat.
- A sample holder was used to mount the sample.
- 4-point probing method was used for testing to achieve precise resistance measurement.

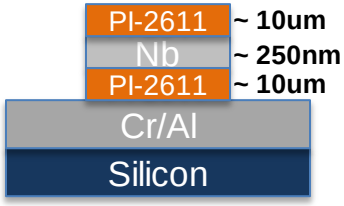
Test results of PI-2611 cured on top of Nb

- All samples were fabricated on Cr/Al release layer
- Measurements were done in LHe Dewar
- PI-2611 was cured at 350℃
- None of the samples transitioned

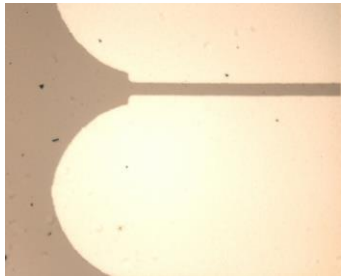


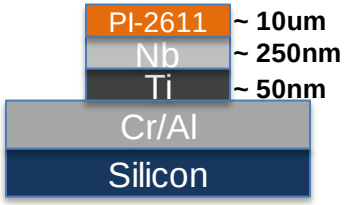
Temperature (K)	Resistance (Ω)
R.T.	0.90
4.2K	0.37



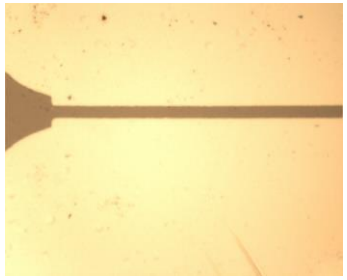


Temperature (K)	Resistance (KΩ)
R.T.	4.18
4.2K	3.49





Temperature (K)	Resistance (Ω)
R.T.	2.37
4.2K	1.29



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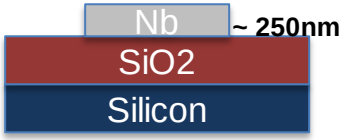
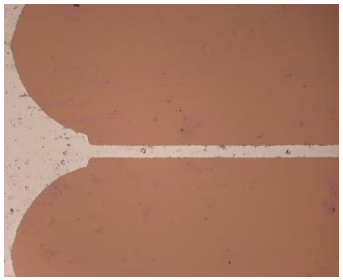
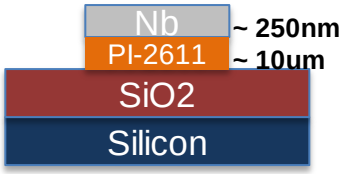
SiO_2/Nb and SiO_2/PI-2611/Nb

- **Measurement were taken in a LHe Dewar**
- **The sample had fully transitioned when measured at 4.2K**

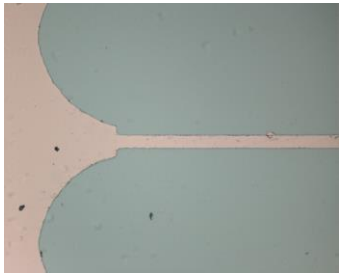


Temperature (K)	Resistance (KΩ)
R.T.	2.1
4.2K	0





Temperature (K)	Resistance (KΩ)
R.T.	2.3
4.2K	0



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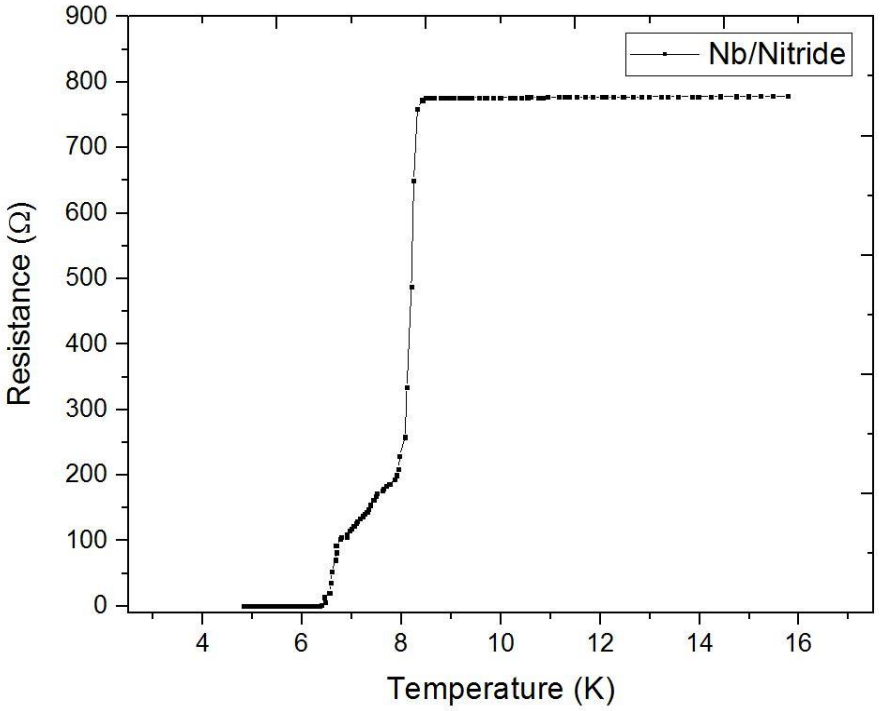
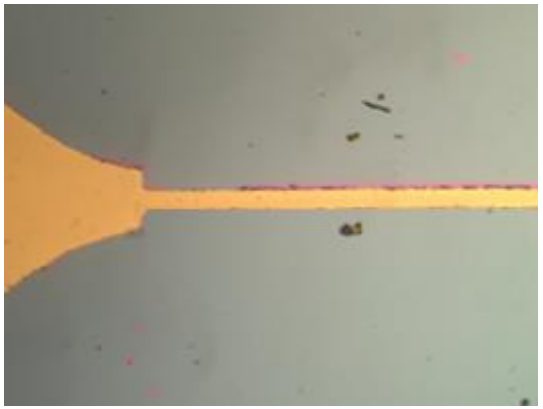
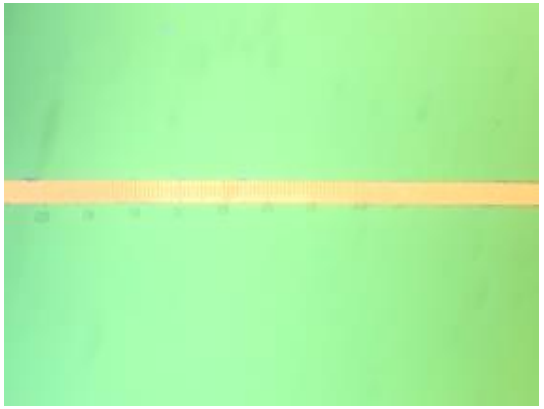
$SiO_2/Nb/Si_3N_4$







Nb (250 nm) / Si_3N_4 (200 nm)

- **Thickness of Silicon nitride (PECVD) is approximately 200nm**
- **Nitride processing time is for 1 min at 300℃**

T_c (K)
6.3

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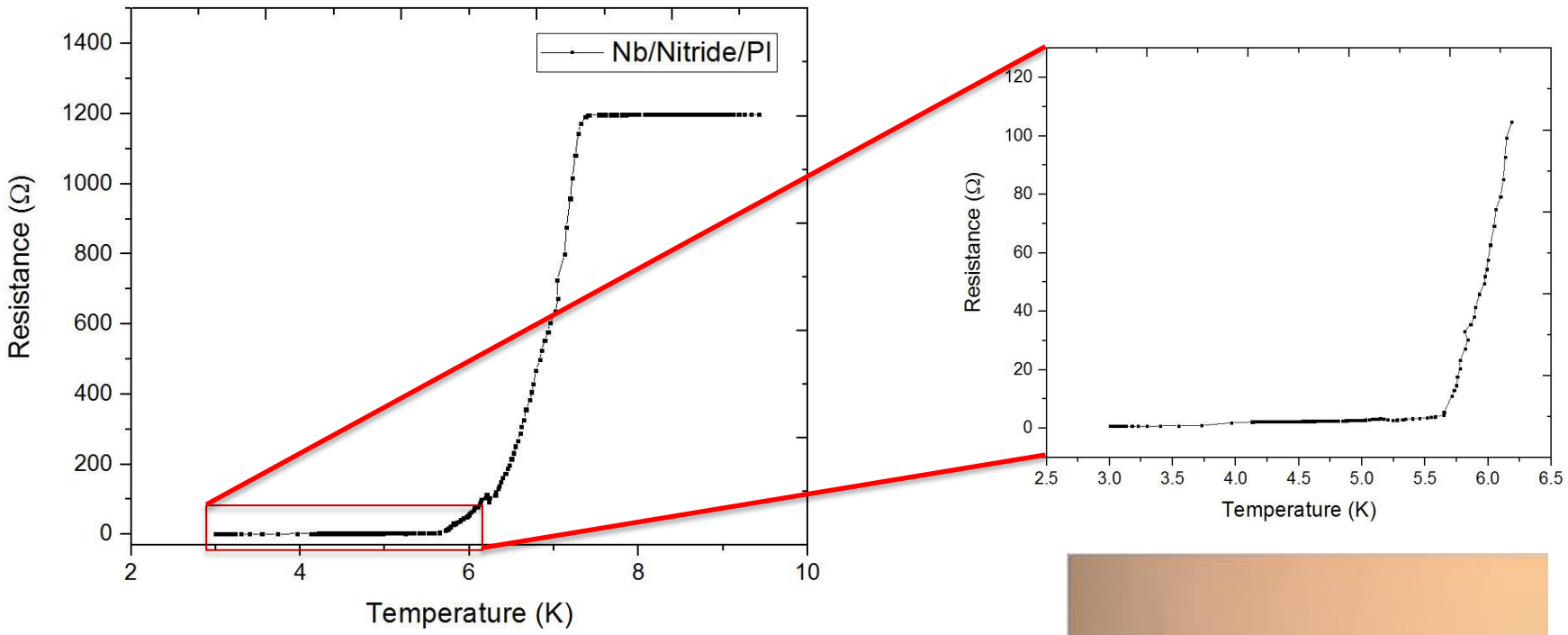
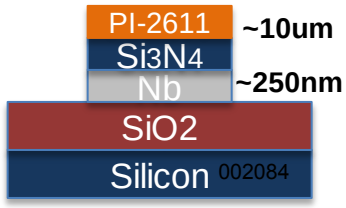
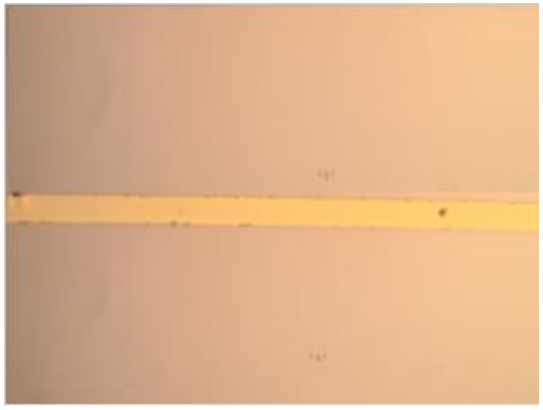
$SiO_2/Nb/Si_3N_4/PI\text{-}2611$



- **Slower transition was observed on the sample with cured polyimide on top**
- **Deposition temperature of Silicon Nitride was 300℃**

T_c (K)
5.1





Nb (250 nm) / Si_3N_4 (200 nm) / PI-2611 (10μm)

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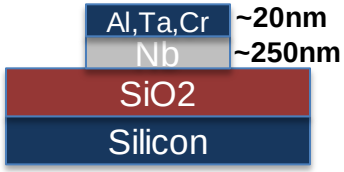
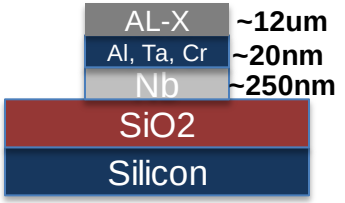
T_c Comparison for Capping layer Al, Cr and Ta





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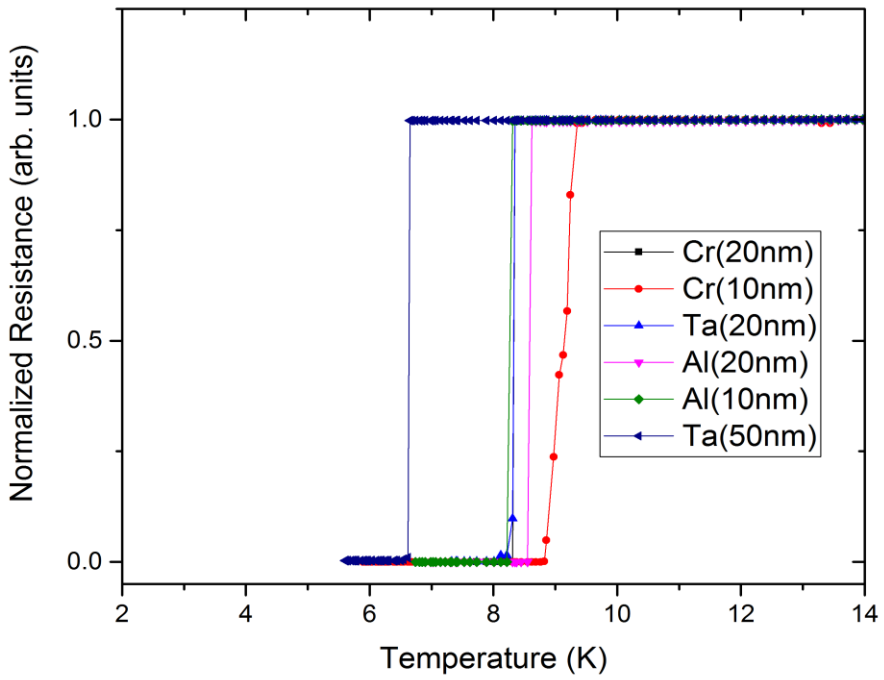
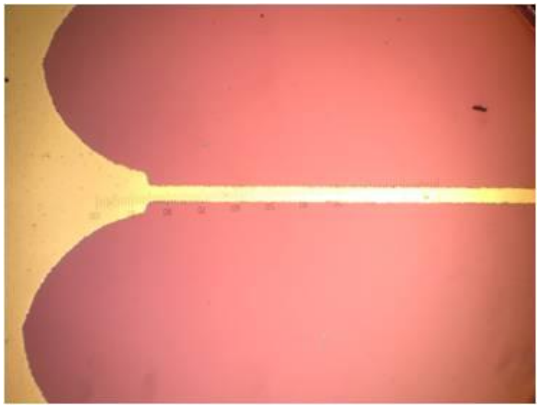
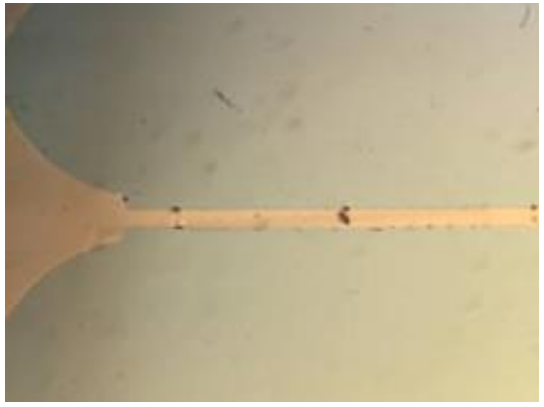
Capping layer



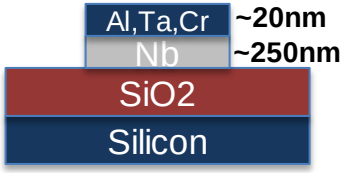


Nb (250 nm) / Al (10 nm)



Nb (250 nm) / Cr (10 nm)

- **Capping layer on top of Nb with no polymer overcoat**
- **Different metal thickness were tested**
- **10 nm of Cr and 20 nm of Al exhibited the highest T_c values**



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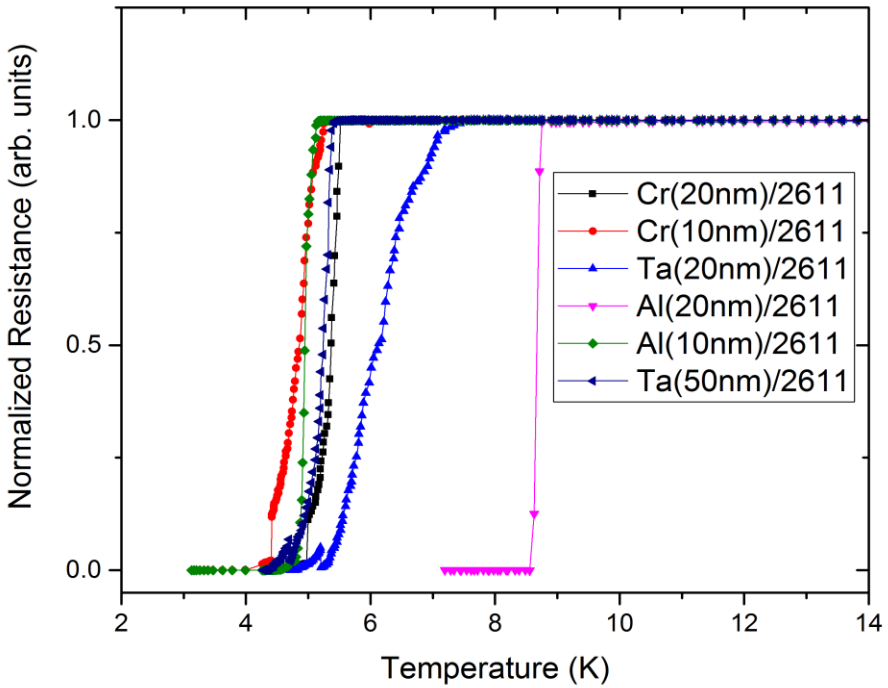
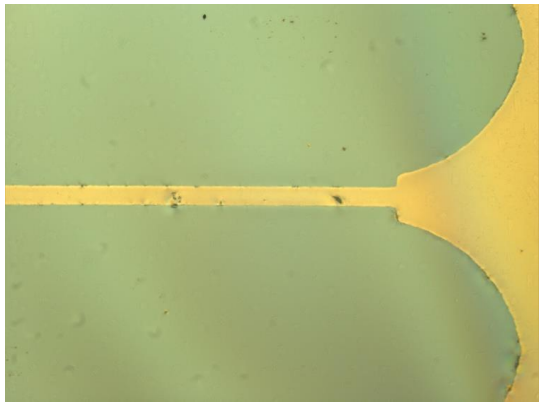
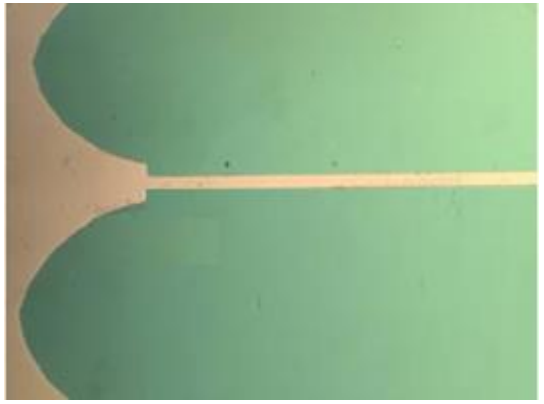
Capping layer/PI-2611





Nb (250 nm) / Al (20 nm) / PI-2611 (10μm)



Nb (250 nm) / Cr (10 nm) / PI-2611 (10μm)

- **10μm of PI-2611 on top of capped samples**
- **PI-2611 was cured at 350℃ in N_2**
- **Significant degradation in T_c can be seen**

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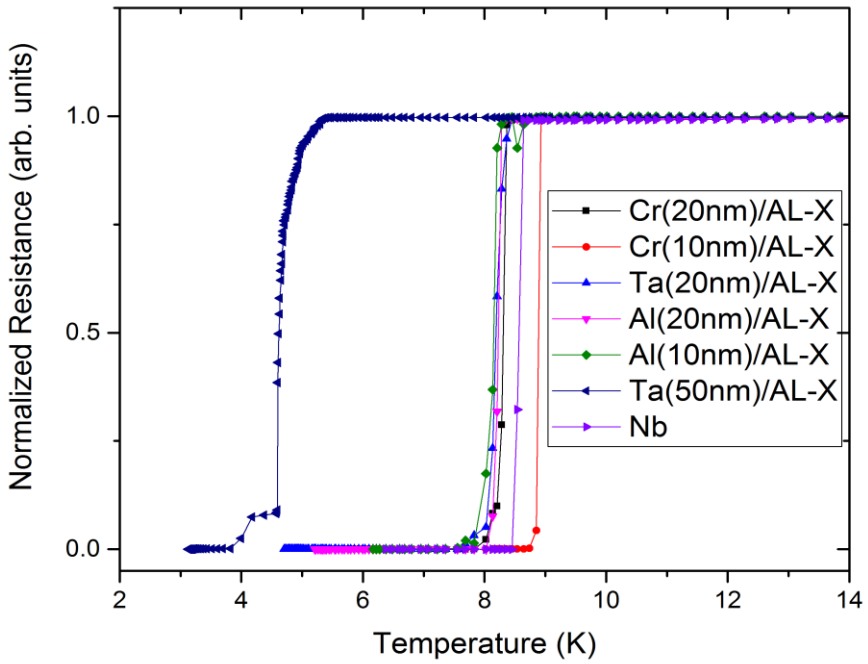
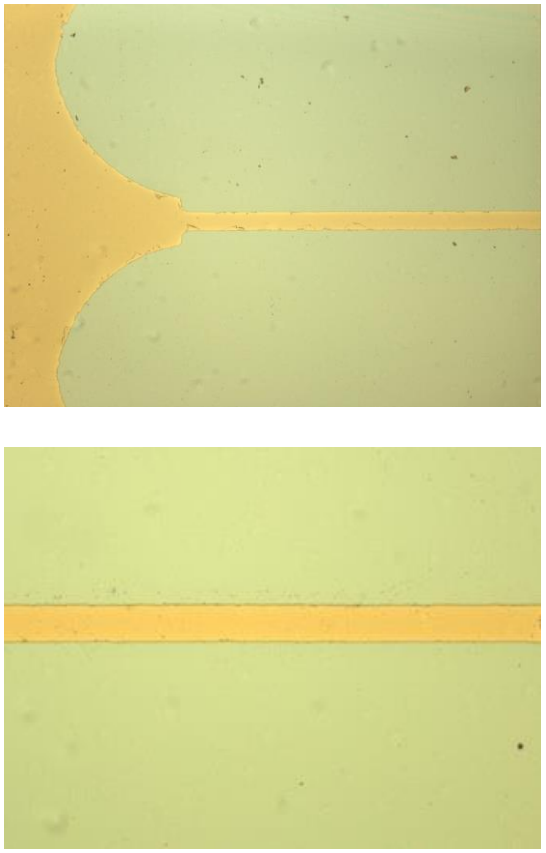
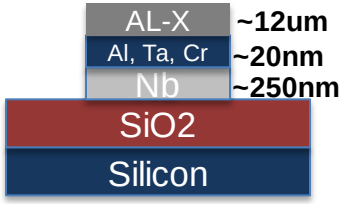
Capping layer/AL-X 2010





- 12µm of AL-X 2010 on top of capped samples
- AL-X 2010 was cured at 190℃ in N_2
- All capping layers exhibited minimal degradation



Nb (250 nm) / Al (20 nm) / AL-X 2010 (12µm)

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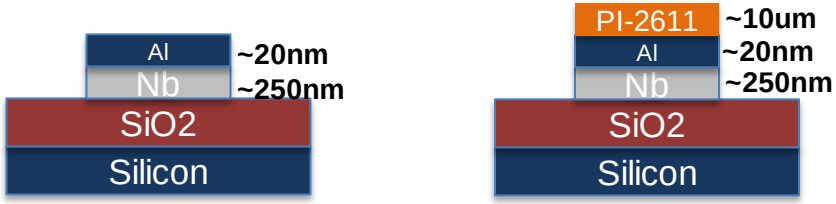
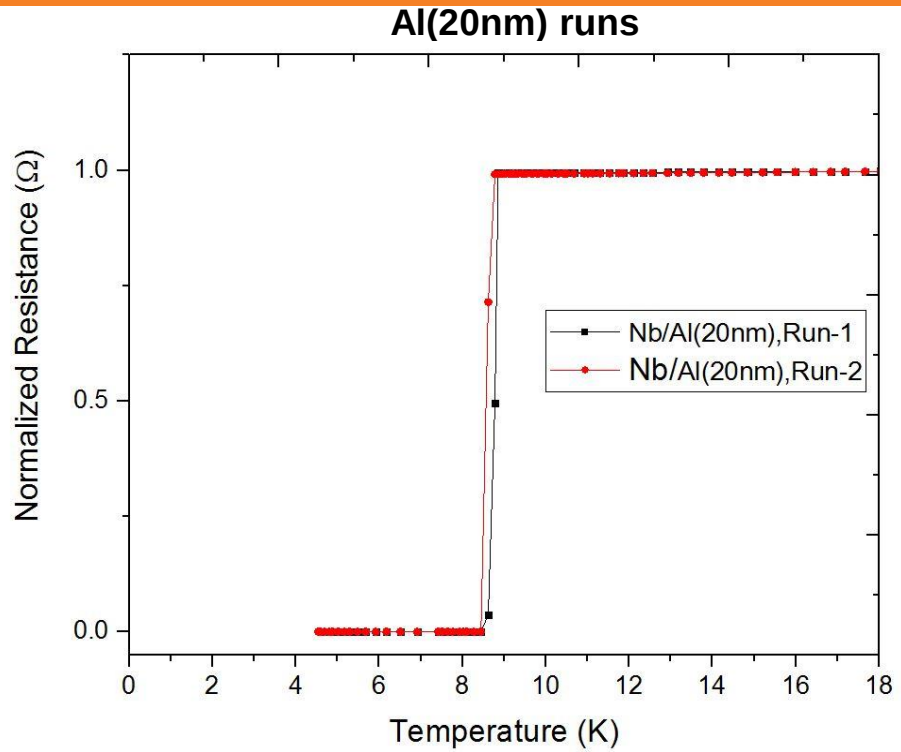
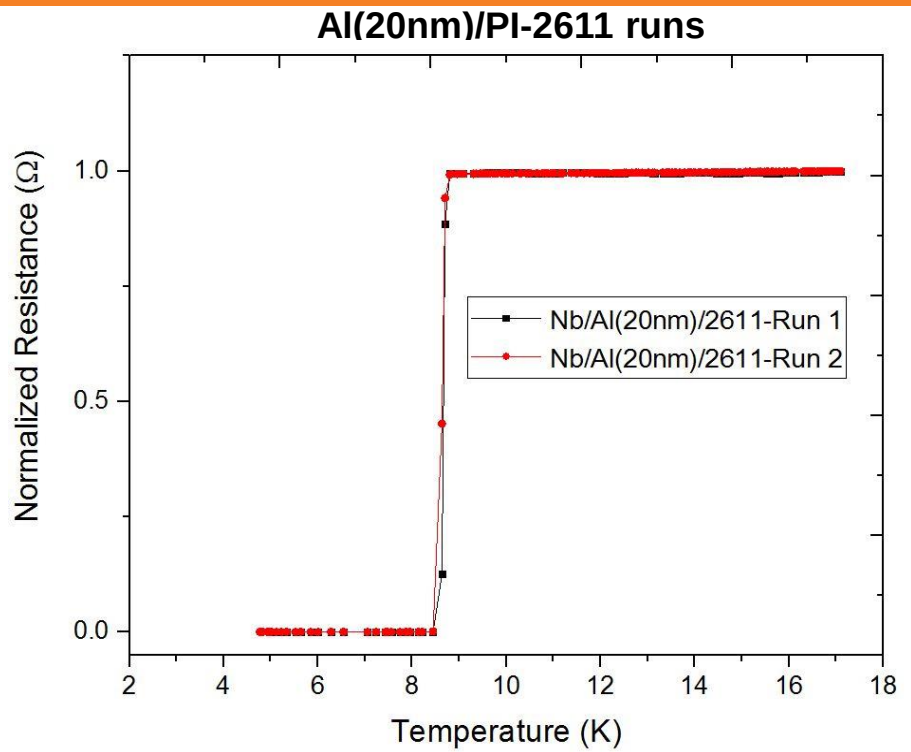
Al(20nm), Run 1 and Run 2 Comparison

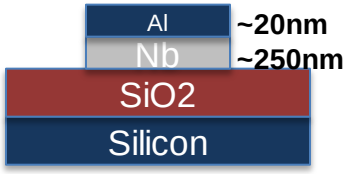


Comparison for Al(20nm) different runs

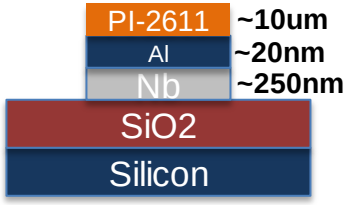




- **Comparison of two runs for Al(20nm) capping layer with and without PI-2611**
- **PI-2611 is cured at 350˚C**



Sample	Run 1	Run 2
	T_c	T_c
Nb/Al(20nm)	8.5	8.5
Nb/Al(20nm)/2611	8.4	8.4



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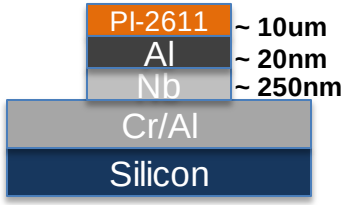
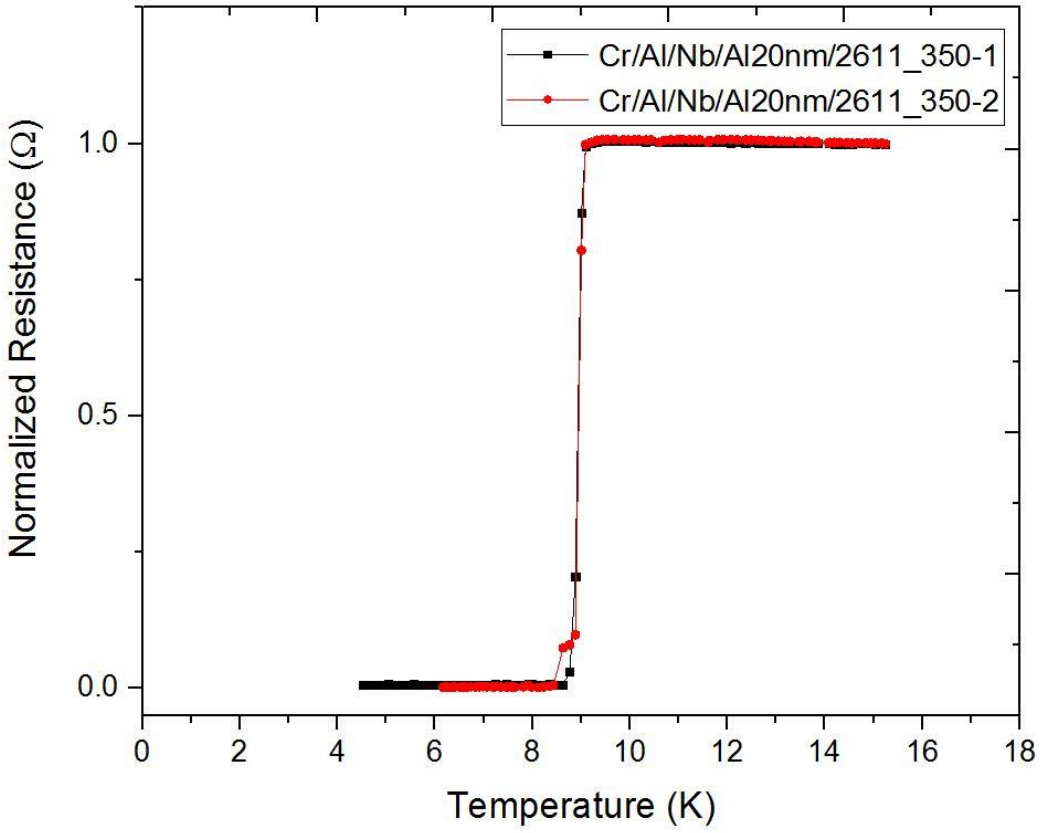
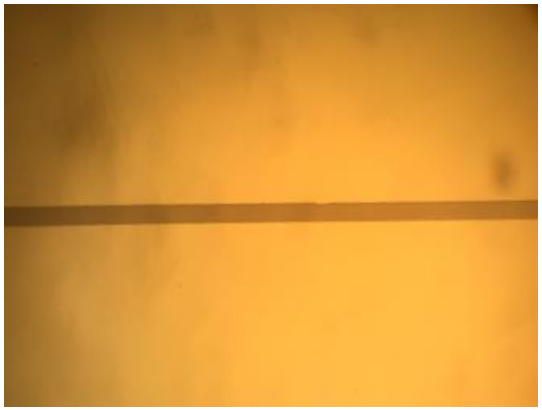
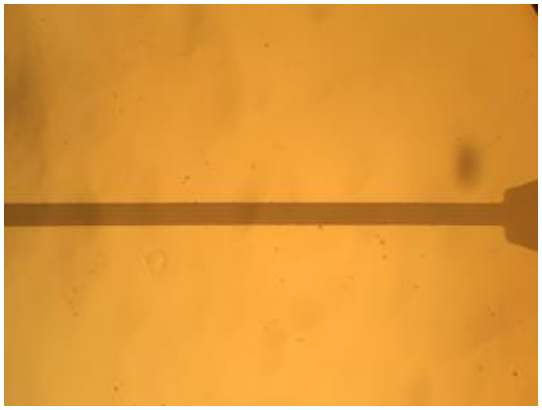
Nb/Al(20nm)/PI-2611@350C on Cr/Al release layer



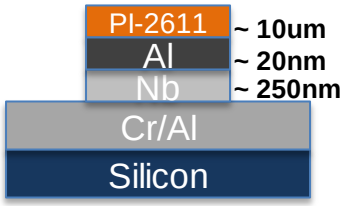
Cr/Al/Nb/Al(20nm)/2611 cured at 350˚C







Sample	T_c
Sample1	8.7
Sample 2	8.6



Nb (250 nm) / Al (20 nm) / PI-2611(10μm)

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Conclusion

- Multiple material stack up have been tested with a goal to protect Nb superconductivity
- Al(20nm) substantially prevented degradation of Nb traces by acting as a combination of diffusion barrier, oxygen getter and strain buffer.
- Low temp. cure cycle polymer (Asahi Glass AL-X 2010) is protective of Nb superconductivity.

Future work

- Evaluation of alternate polymers with lower recommended curing temperatures
- Testing different curing temperatures for these various polymers
- Embedded structures