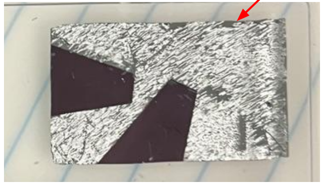
SLAC Fab Update

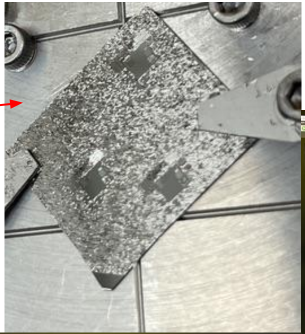
SQUAT/QPD Measurement Workshop | Oct. 29th, 2025

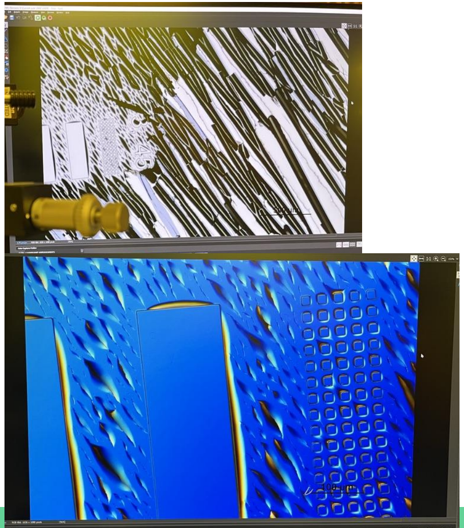
Riley Carpenter
On behalf of DMQIS

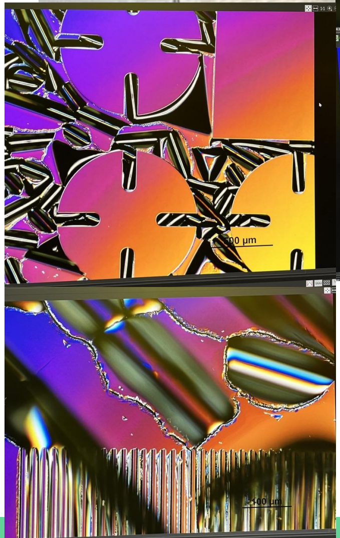
Hf Optical Fab: The ugly

65 nm Ti getter @ 2 Å/s +
200 nm Hf @ 2 Å/s

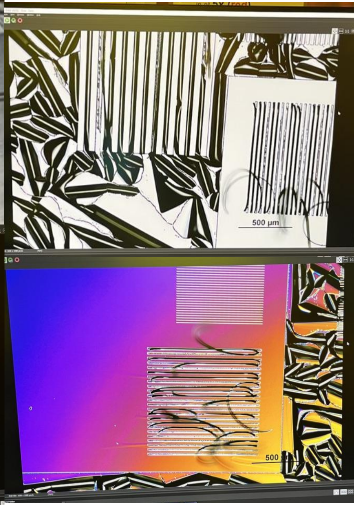








Micrographs pre-liftoff (resist included)

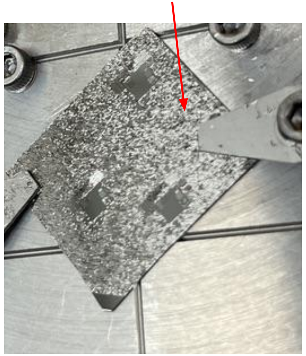


Colored images are using the microscope in Nomarski differential interference contrast (DIC) mode

Micrographs post-liftoff (resist stripped)

Hf Optical Fab: The good!

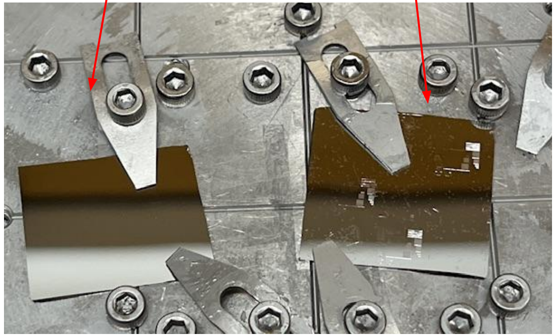
Previous chip

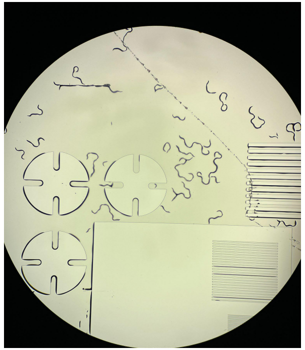


VS

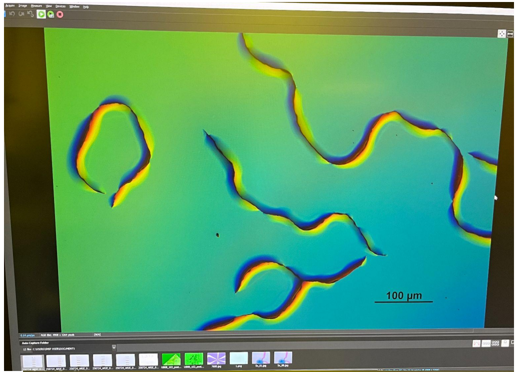
Blanket coated
(no resist)

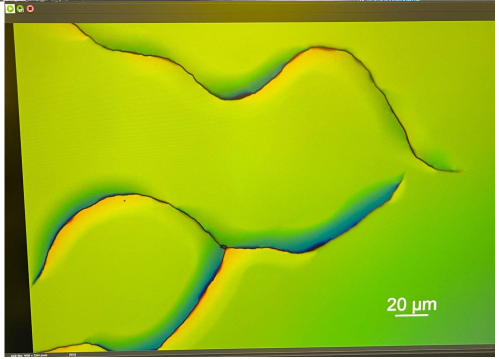
Round 2 chip w/
resist pattern



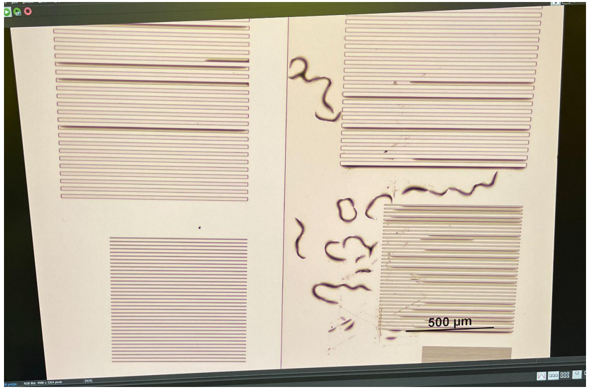


Micrographs pre-liftoff (resist included)





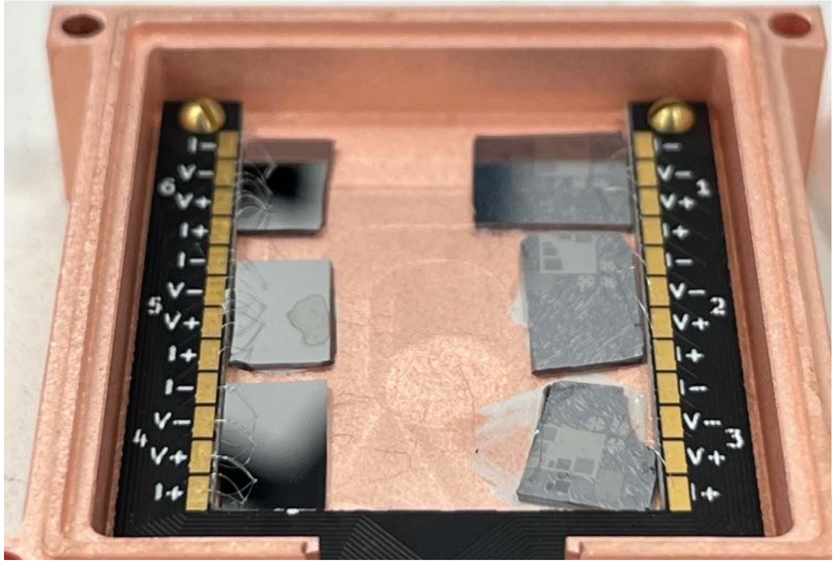
Process Changes:
- NO Ti getter (backscattered electron exposure still found to occur without line-of-sight to crucible)
- Overnight pumpdown for similar base pressure ~5e-8 Torr w/o getter (and to give resist more time to offgas *in vacuo*?)
- Only **100** nm Hf @ 2 Å/s (less heat/electron exposure)
- Add a **60s hard bake** @ 90°C immediately before deposition to drive of nitrogen

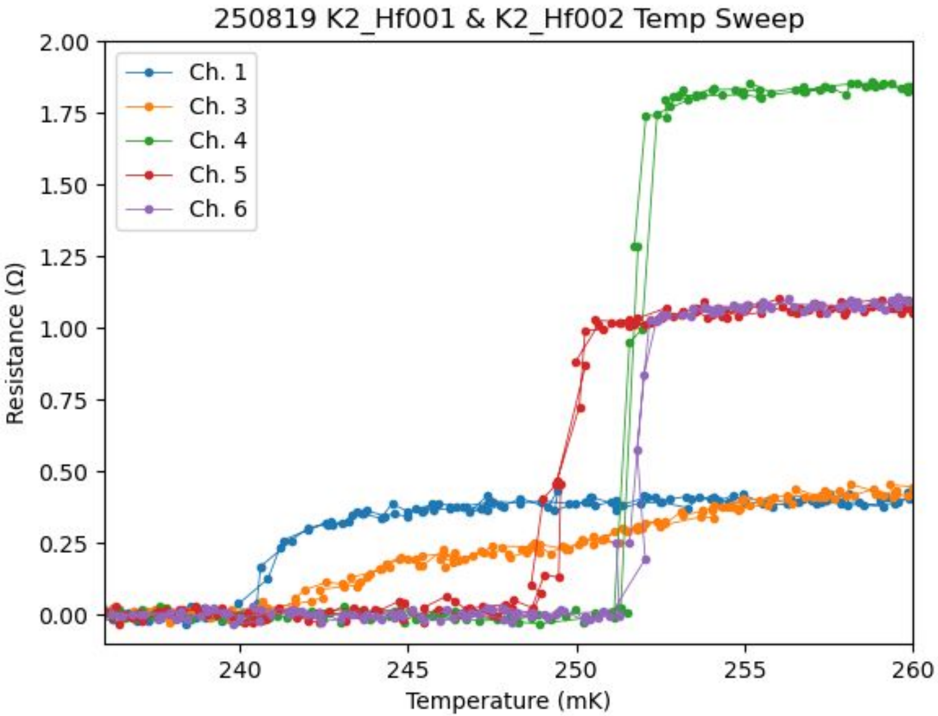


Results: WAY less cracking/ blistering of the resist

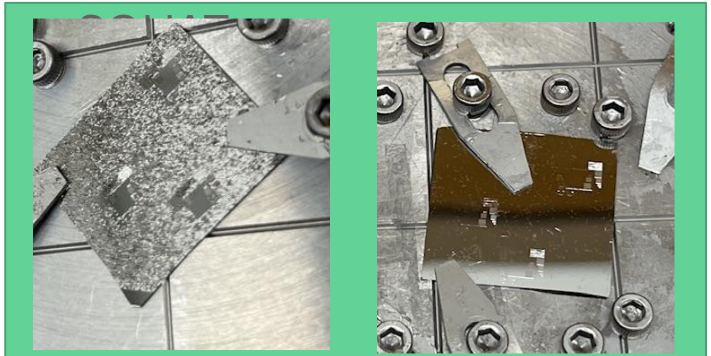
First Hf T_c samples transition

- T_c ~ 250 mK for 100 nm blanket coated Hf

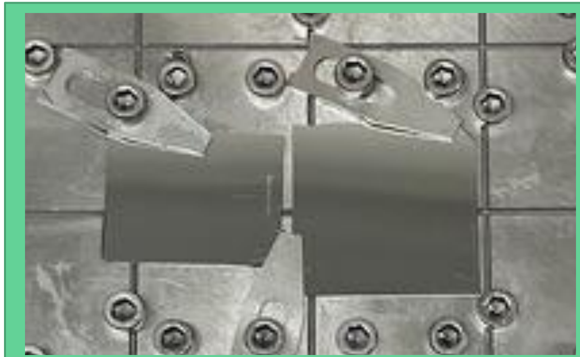




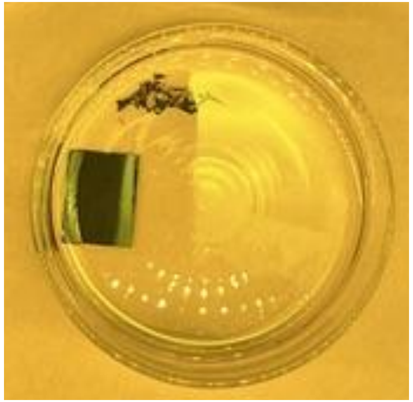
First Hf junction attempt: EBL w/ junctions only



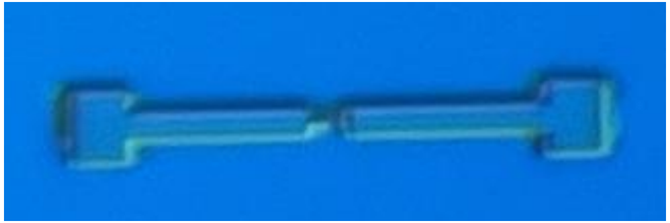
Roughness problems w/ optical resist (two photos above)



Much smoother films upon switching to e-beam resist!



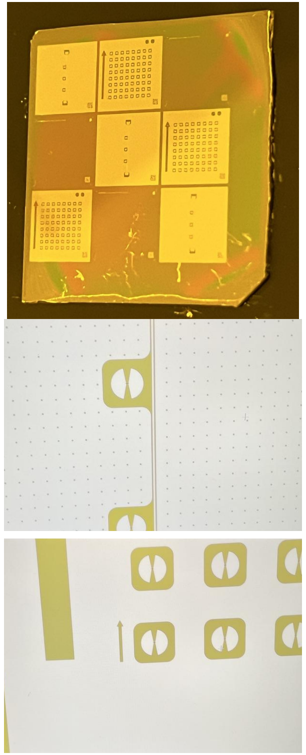
E-beam lift-off more successful than previous attempts

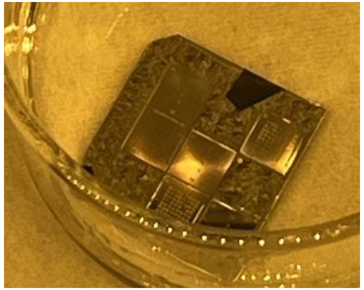


- First attempt at Hf junctions in-progress (DIC optical micrograph post-liftoff seen above)
- ~610 nm MMA beneath ~400 nm PMMA

Adding liftoff Al features afterwards

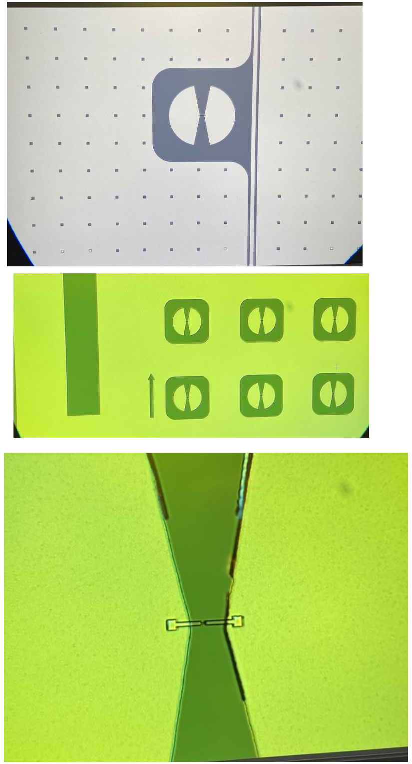
Pre-deposition





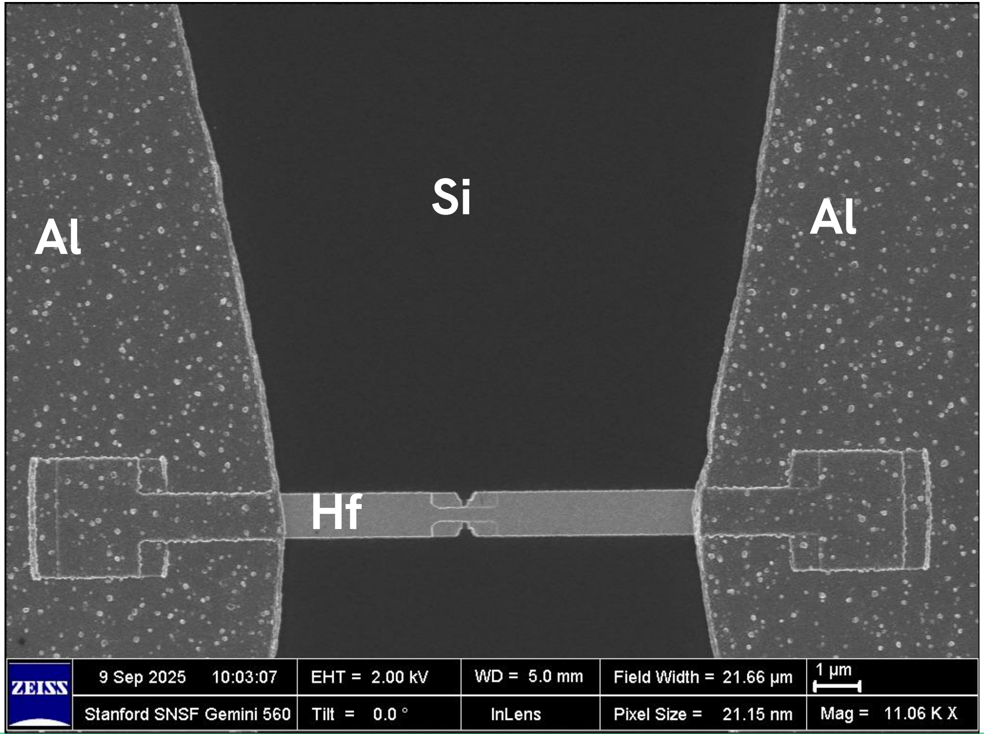
200 nm Al evap + liftoff

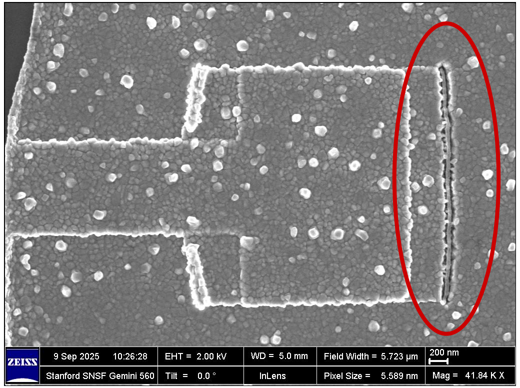
Post-liftoff

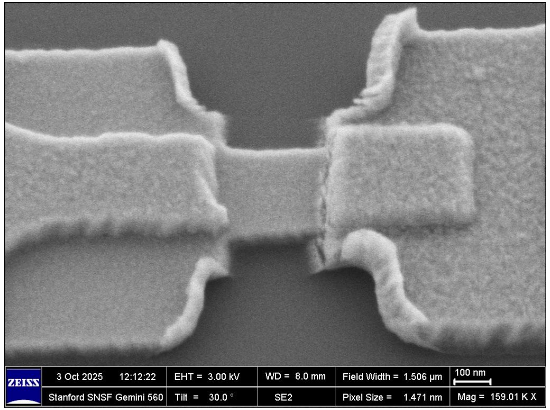


- HDMS prime in 150°C oven
- Single layer 1.6 μm SPR 3612 optical resist
- Some Al flags remain on sidewalls ➔ somewhat mitigated with ultrasonic agitation

SEM of Hf JJs w/ Al pads



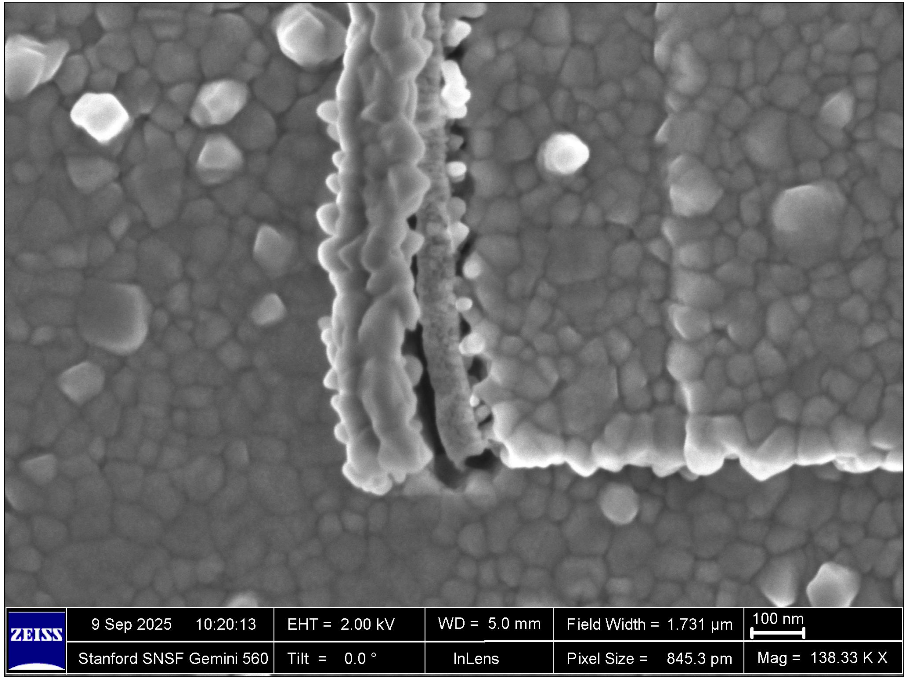


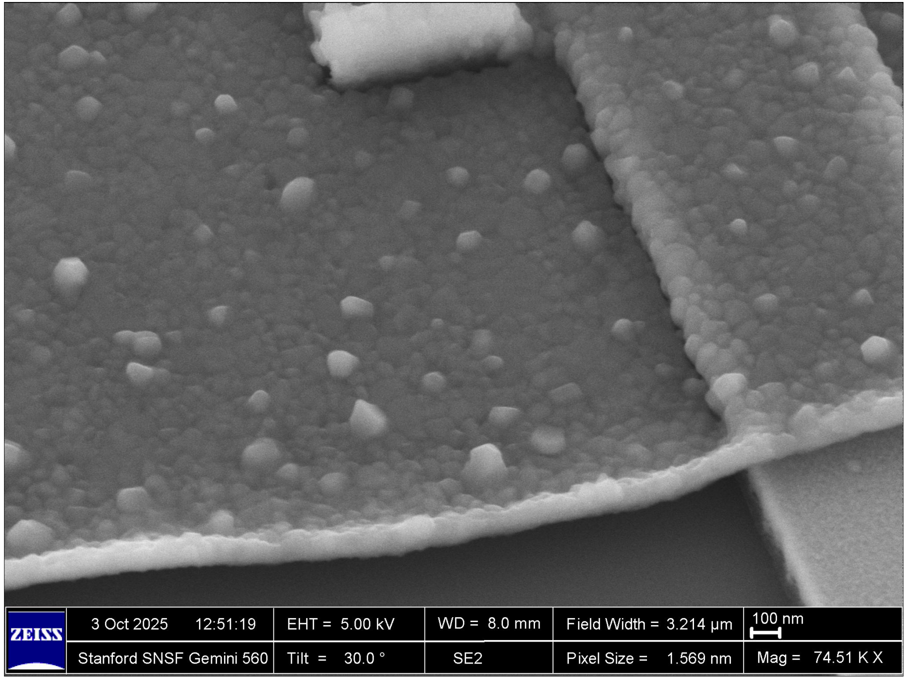


Poor junction shape on edges attributed to lack of proximity effect correction in this first e-beam exposure recipe

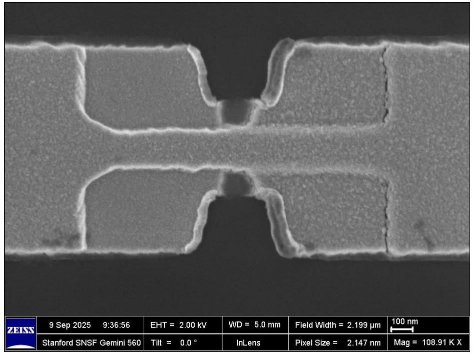
Questionable connectivity?

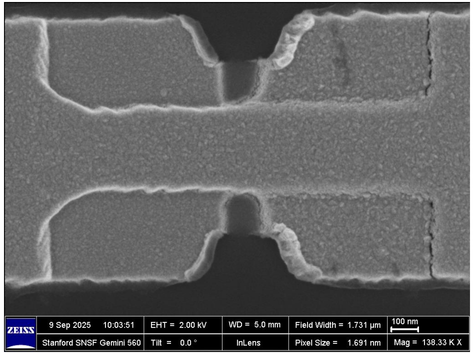
Some “gaps” or film breaks at the interface between the Al on top of the junctions and the Al directly on the substrate.

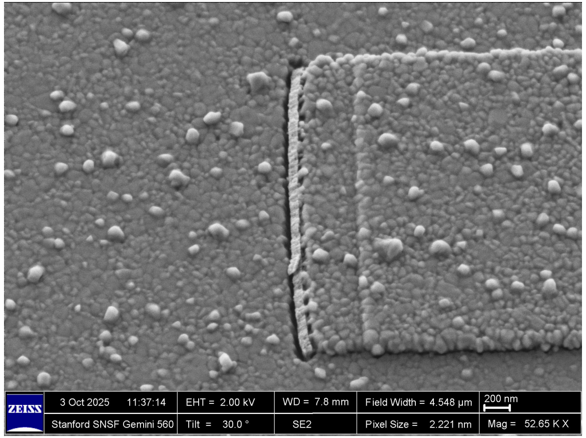


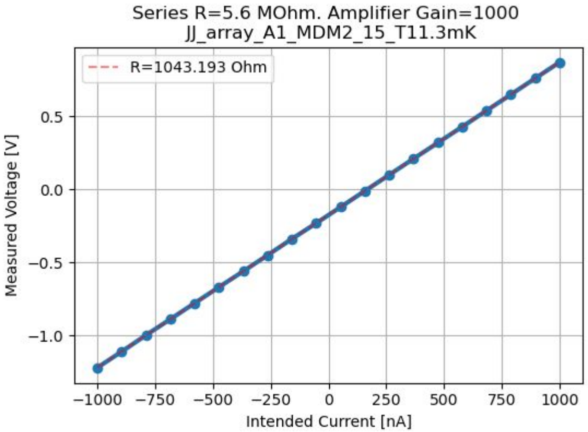


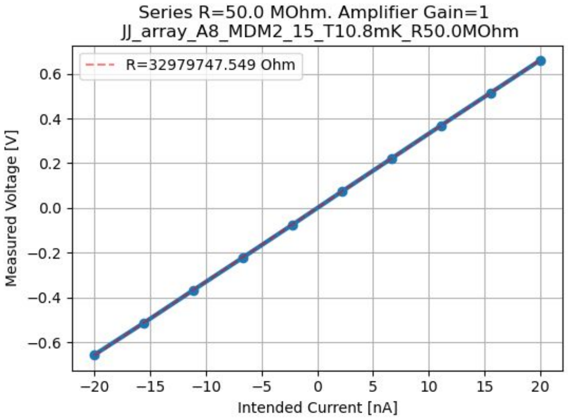
Preliminary IV curves for (shorted) Hf JJs w/ Al pads









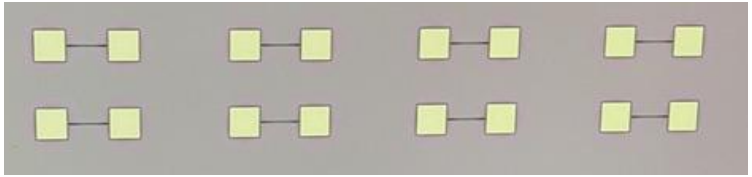


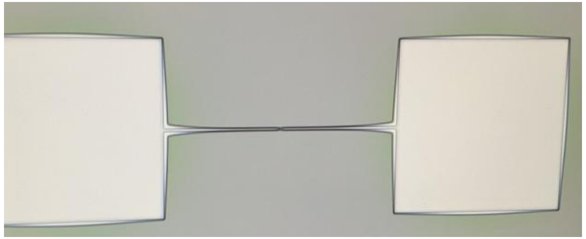
Way different resistances for two **shorted** junctions

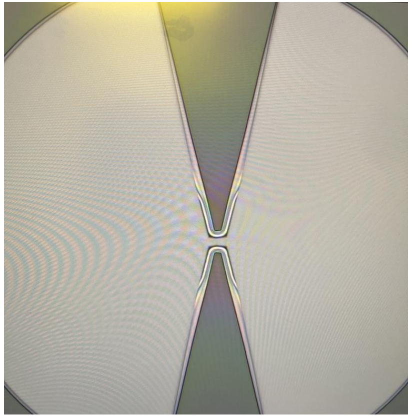
➡ Inconsistent film connectivity

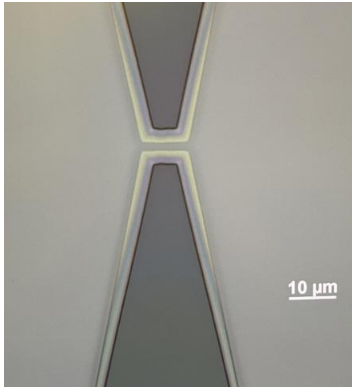
Avoiding the problem: Hf-only structures!

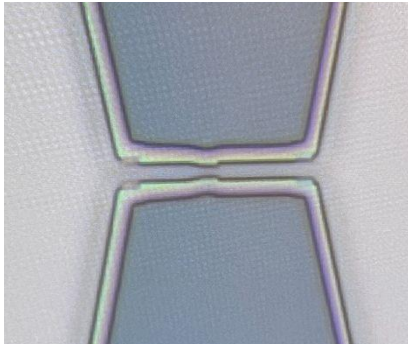
- Removes need for interfacing between Hf and a different metal ➔ temporary solution while ion milling unavailable in KJL2
- Success w/ wire-bondable junctions w/ 80 µm square pads for direct JJ testing
- Iterating towards Hf-only SQUATs, but still limited by proximity effect (seeing improvements with each iteration)

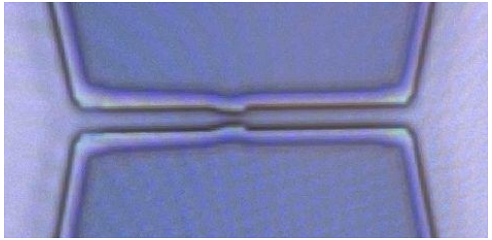






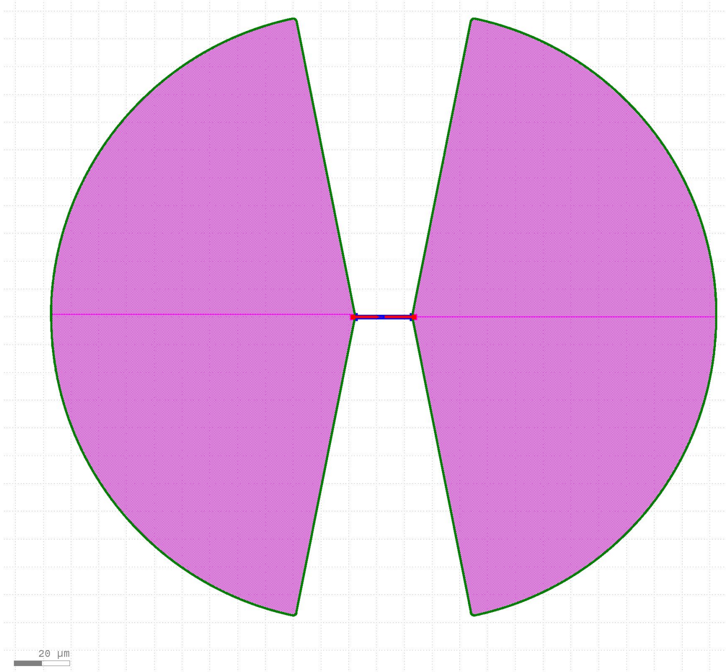


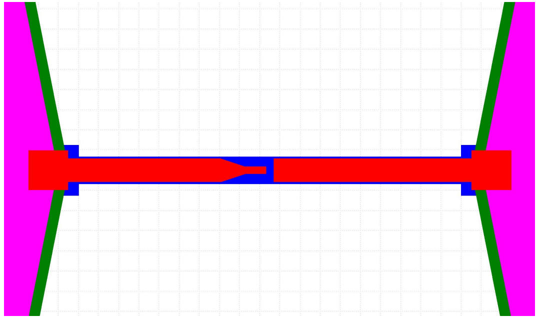




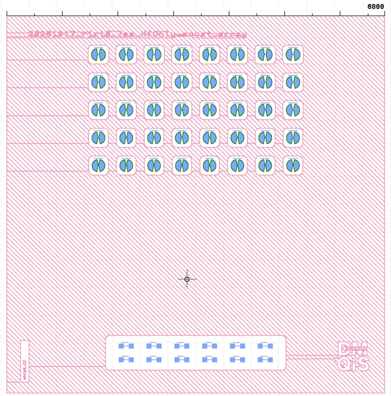
Better accounting for the proximity effect:

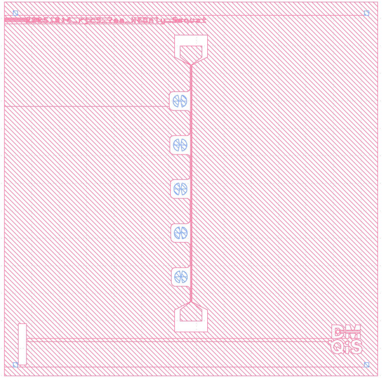
Testing “bulk+sleeve” methods for mixed beam currents





Nominal doses (inputs to numerical PEC algorithm in BEAMER)
Pads bulk: 1800 µC/cm^2
JJ: 1800 µC/cm^2
Pads sleeve: 1350 µC/cm^2
JJ under: 450 µC/cm^2 (or set to zero!)





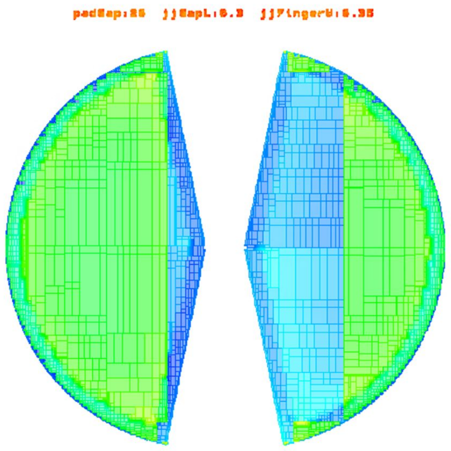
Proximity effect correction (PEC)

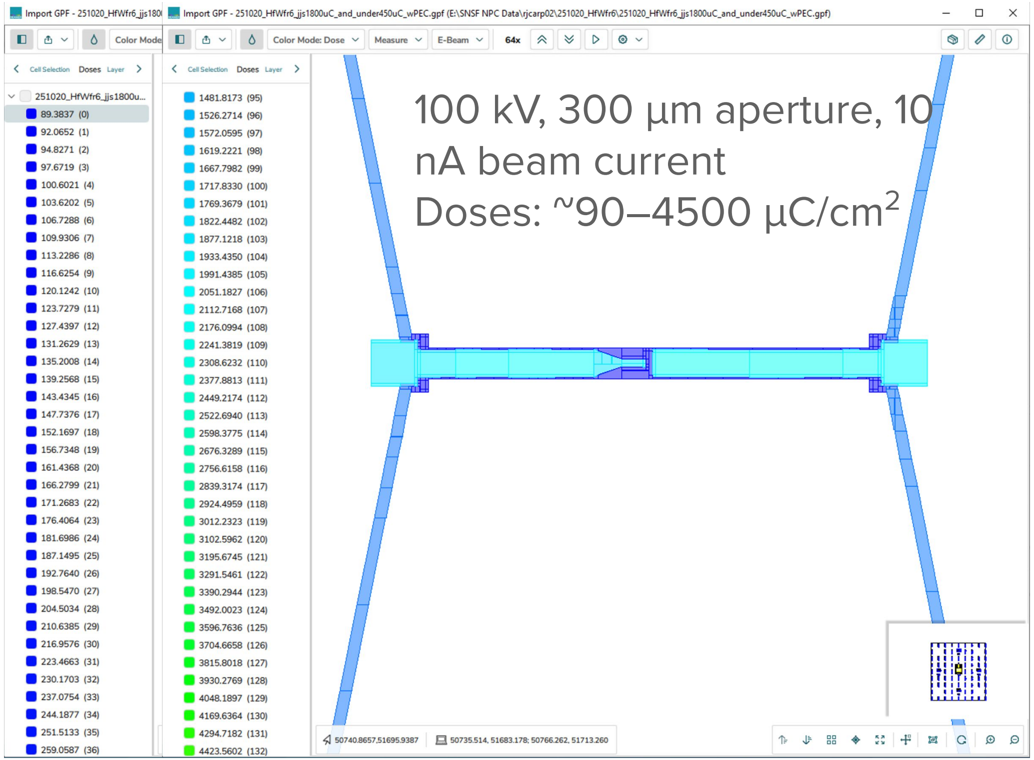
Separate exposures for the bulk of the pads versus other critical features

251020_HfWfr6_jjBigPads...
728.9559 (0)
750.8243 (1)
773.3493 (2)
796.5497 (3)
820.4463 (4)
845.0594 (5)
870.4115 (6)
896.5237 (7)
923.4193 (8)
951.1222 (9)
979.6557 (10)
1009.0454 (11)
1039.3165 (12)
1070.4961 (13)
1102.6109 (14)
1135.6897 (15)
1169.7598 (16)
1204.8527 (17)
1240.9987 (18)
1278.2283 (19)
1316.5756 (20)
1356.0728 (21)
1396.7546 (22)
1438.6572 (23)
1481.8173 (24)
1526.2714 (25)
1572.0595 (26)
1619.2221 (27)
1667.7982 (28)
1717.8330 (29)
1769.3679 (30)
1822.4482 (31)
1877.1218 (32)
1933.4350 (33)
1991.4385 (34)

100 kV, 600 µm aperture, 75 nA beam current

Doses: ~700-2500 µC/cm^2





251020_HfWfr6_jjs1800u...
89.3837 (0)
92.0652 (1)
94.8271 (2)
97.6719 (3)
100.6021 (4)
103.6202 (5)
106.7288 (6)
109.9306 (7)
113.2286 (8)
116.6254 (9)
120.1242 (10)
123.7279 (11)
127.4397 (12)
131.2629 (13)
135.2008 (14)
139.2568 (15)
143.4345 (16)
147.7376 (17)
152.1697 (18)
156.7348 (19)
161.4368 (20)
166.2799 (21)
171.2683 (22)
176.4064 (23)
181.6986 (24)
187.1495 (25)
192.7640 (26)
198.5470 (27)
204.5034 (28)
210.6385 (29)
216.9576 (30)
223.4663 (31)
230.1703 (32)
237.0754 (33)
244.1877 (34)
251.5133 (35)
259.0587 (36)

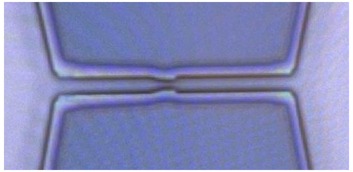
1481.8173 (95)
1526.2714 (96)
1572.0595 (97)
1619.2221 (98)
1667.7982 (99)
1717.8330 (100)
1769.3679 (101)
1822.4482 (102)
1877.1218 (103)
1933.4350 (104)
1991.4385 (105)
2051.1827 (106)
2112.7168 (107)
2176.0994 (108)
2241.3819 (109)
2308.6232 (110)
2377.8813 (111)
2449.2174 (112)
2522.6940 (113)
2598.3775 (114)
2676.3289 (115)
2756.6158 (116)
2839.3174 (117)
2924.4959 (118)
3012.2323 (119)
3102.5962 (120)
3195.6745 (121)
3291.5461 (122)
3390.2944 (123)
3492.0023 (124)
3596.7636 (125)
3704.6658 (126)
3815.8018 (127)
3930.2769 (128)
4048.1897 (129)
4169.6364 (130)
4294.7182 (131)
4423.5602 (132)

100 kV, 300 µm aperture, 10 nA beam current

Doses: ~90–4500 µC/cm^2

Hf-Only EBL process results

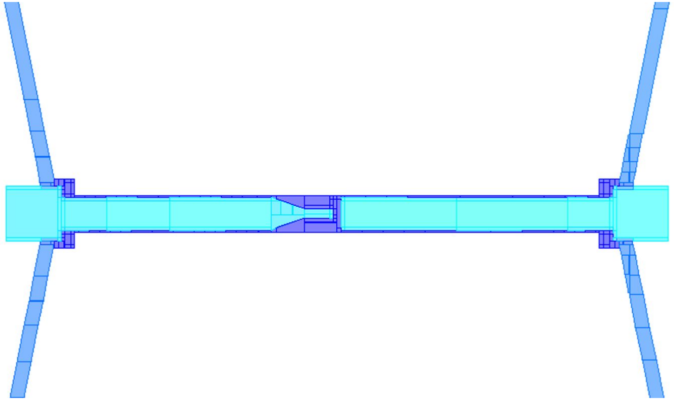
Last time: no bridges



Nominal Resist Bridge Dimensions:

Finger width = 400 nm

Gap (resist bridge) width = 300 nm



Top Layer Profile in Focus

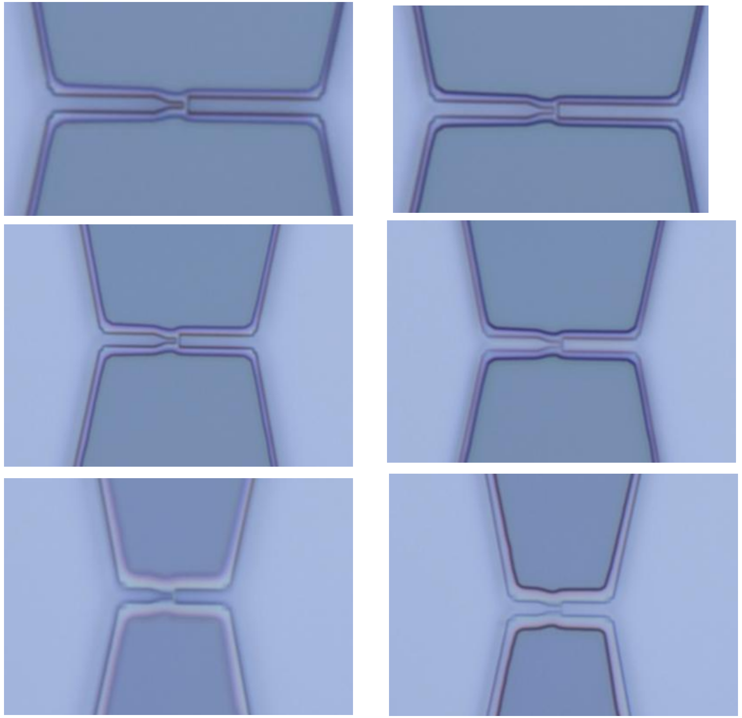
Undercut Layer in Focus

Pad Gap

25 µm

15 µm

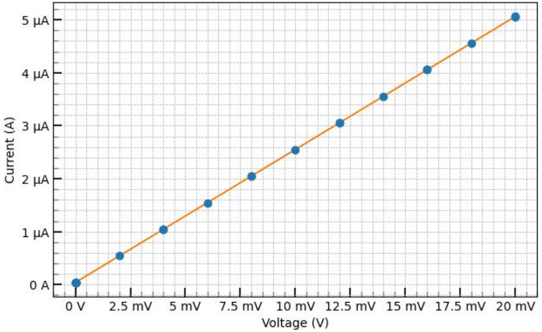
10 µm



300 K Probe Station IV Curves

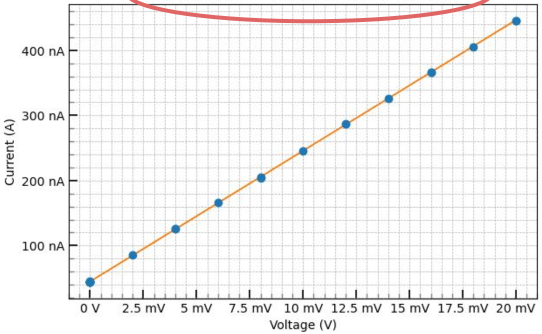
K2_Hf_SVM251015-1, Sample 1, Chip 1

Resistance: 3981.0 Ω ± 1.0 Ω



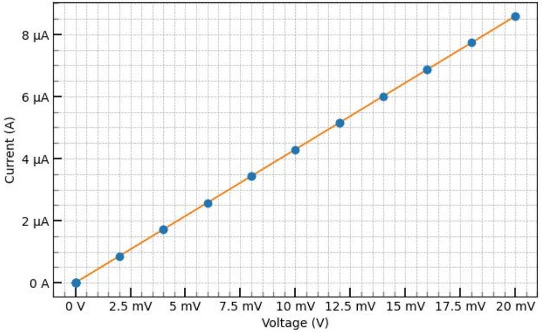
K2_Hf_SVM251015-1, Sample 2, Chip 1

Resistance: 49750.0 Ω ± 60.0 Ω



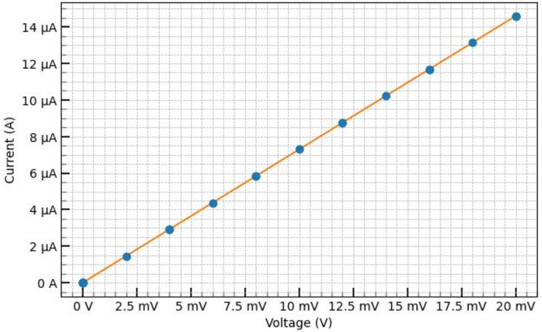
K2_Hf_SVM251015-1, Sample 3, Chip 2

Resistance: 2329.0 Ω ± 0.5 Ω



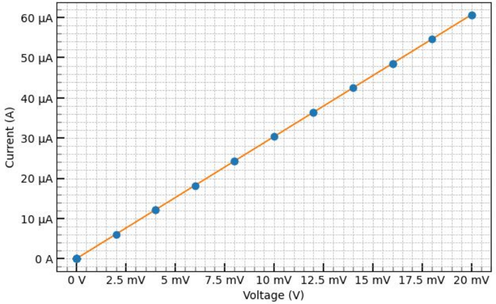
K2_Hf_SVM251015-1, Sample 4, Chip 1

Resistance: 1370.6 Ω ± 0.2 Ω



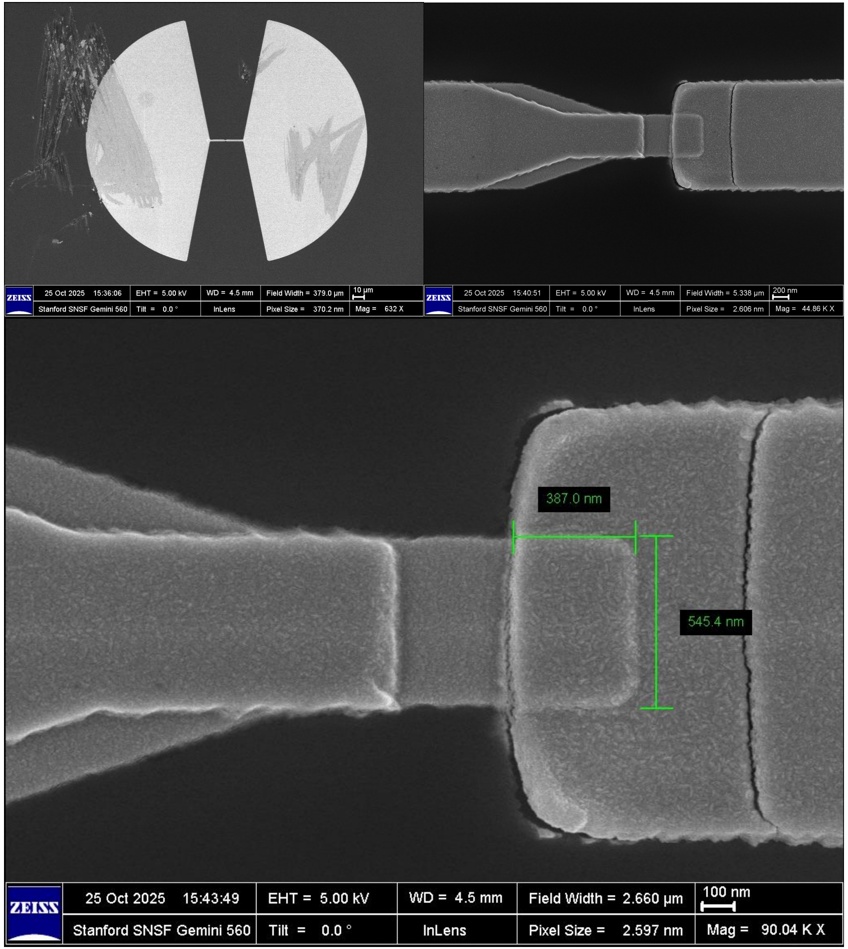
K2_Hf_SVM251015-1, Sample 5, Chip 1

Resistance: 329.54 Ω ± 0.01 Ω

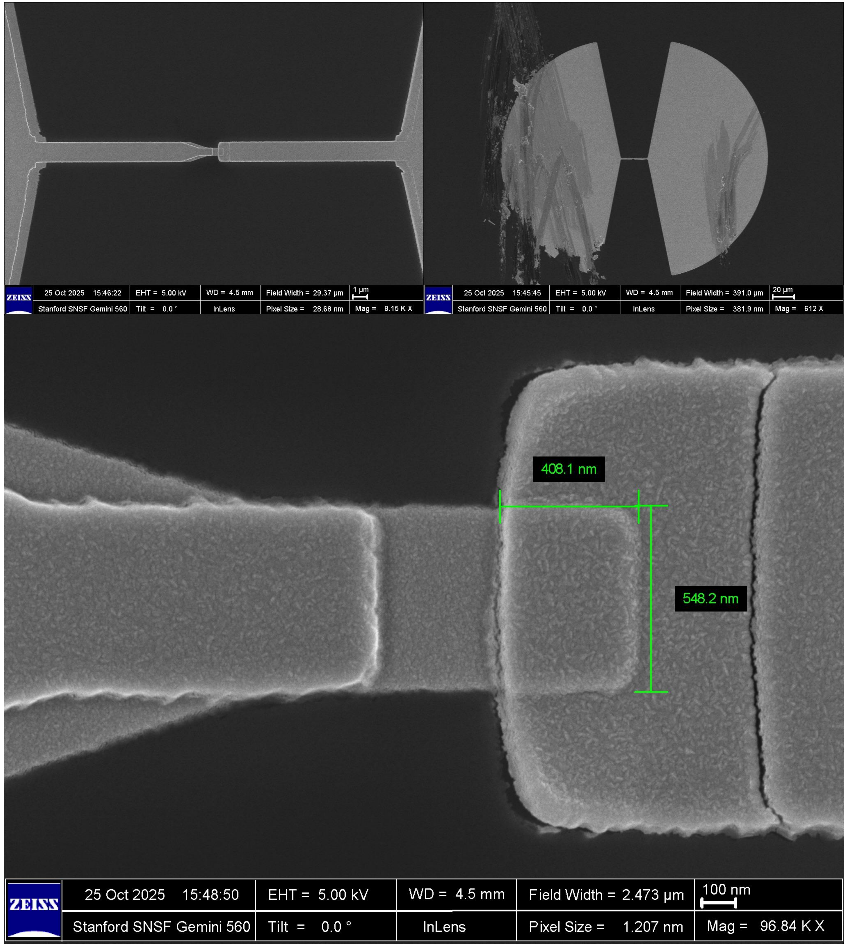


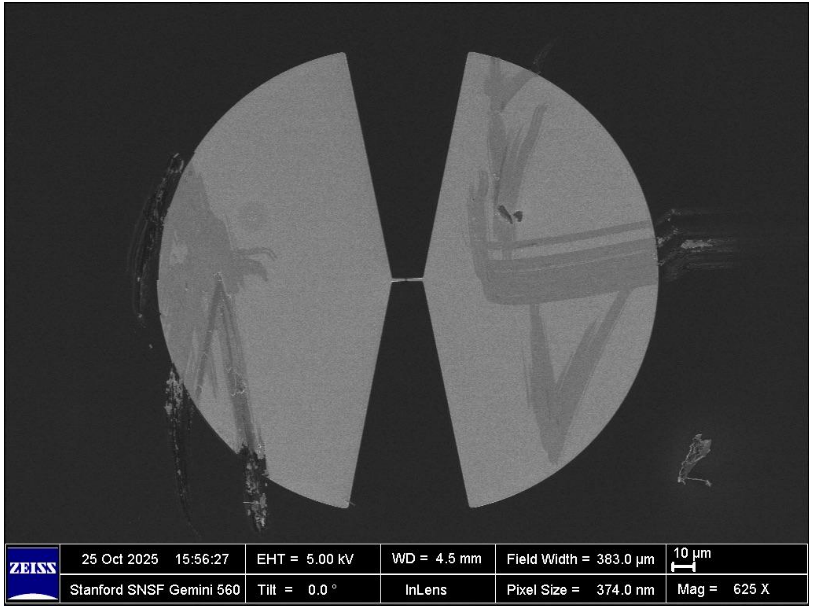
- Overlap area increasing from sample 1→5
- Resistances roughly reflect this trend
- Sample 2 resistance high due to inability to contact pads well

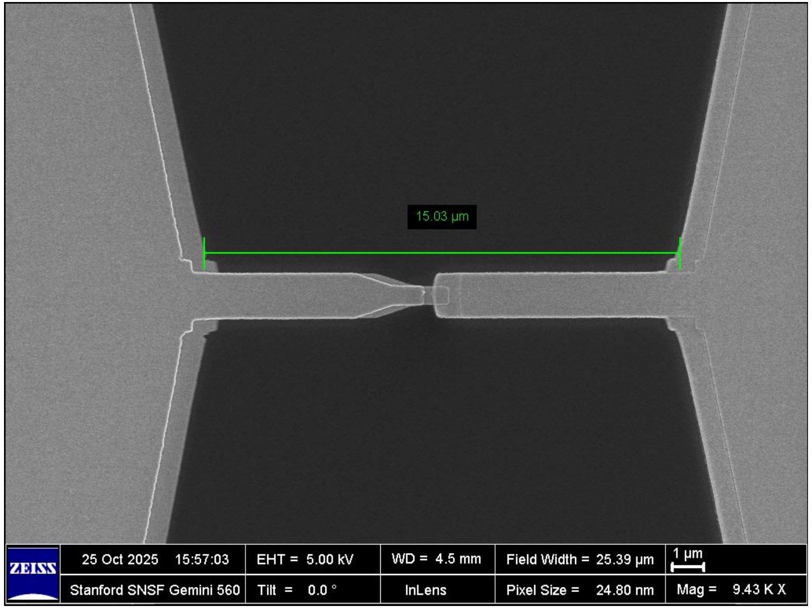
Chip 1, Sample 1

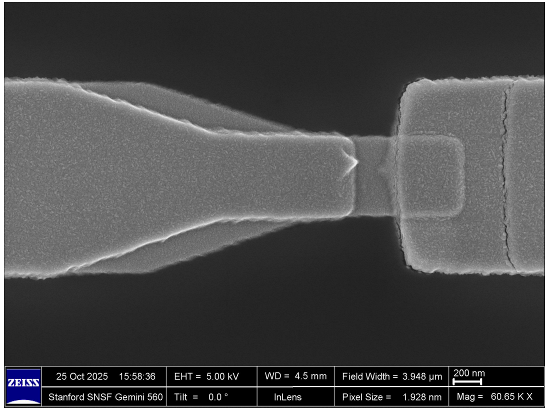


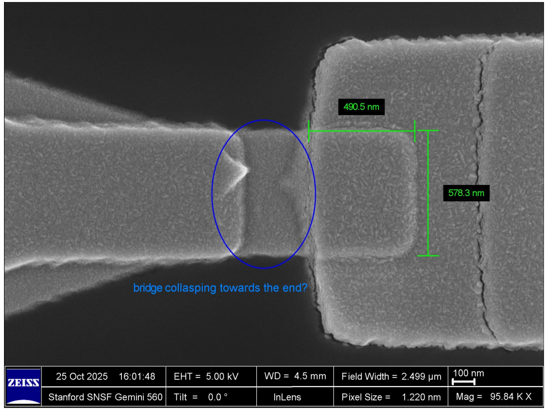
Chip 1, Sample 2







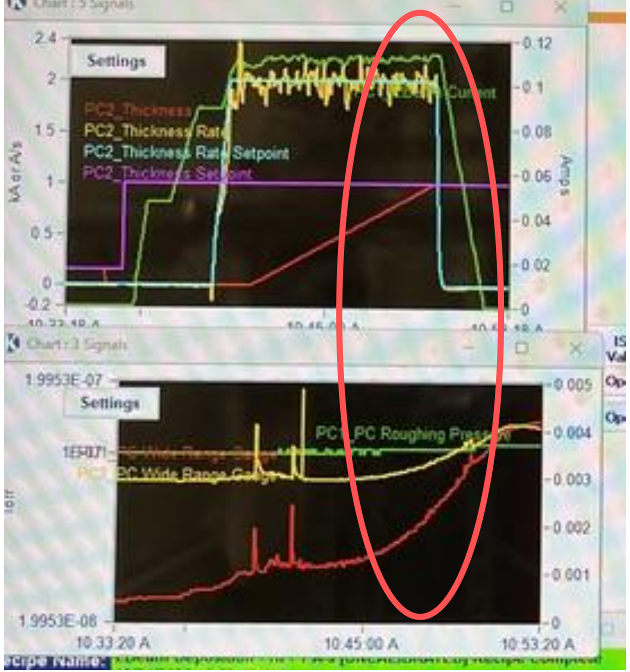


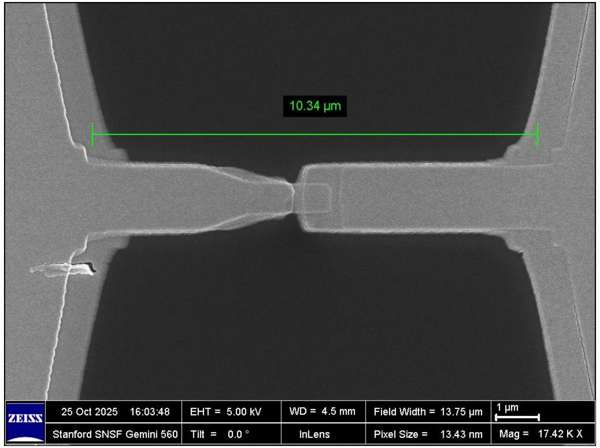


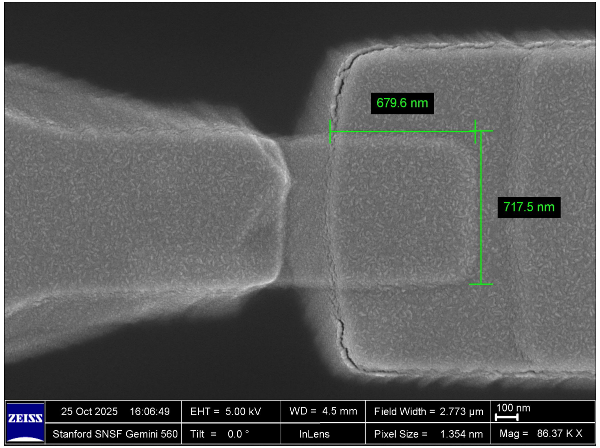
bridge collasping towards the end?

Bridge collapse at small pad gaps?

- Narrowest bridges potentially collapse during deposition of 90 nm upper electrode
- Can be potentially correlated to an unexpected rise in chamber pressure during the second half of the second deposition

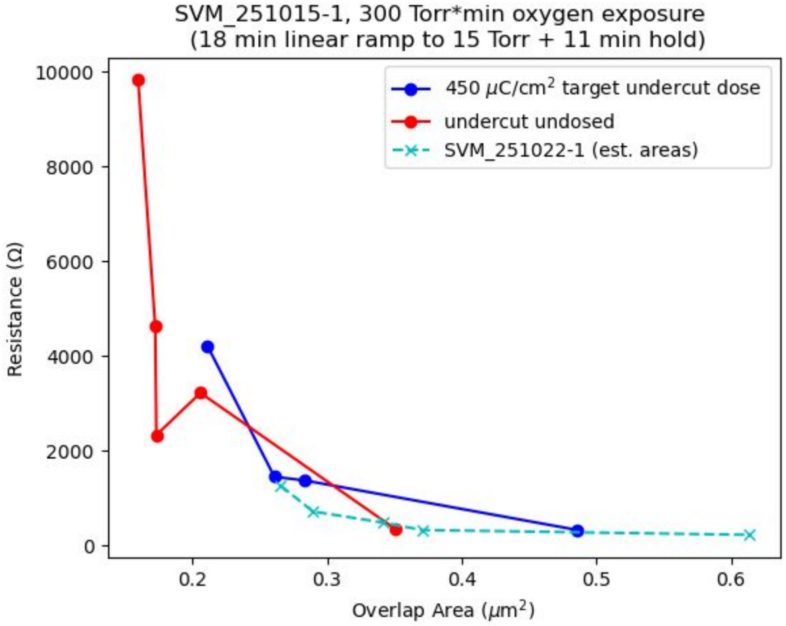


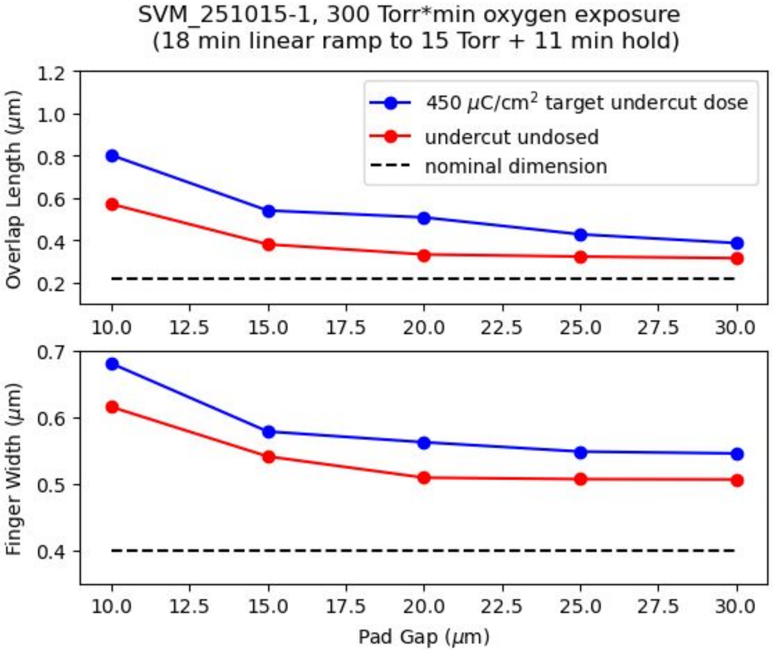




First (semi-reasonable) 300 K resistances

- Resistances roughly scale with inverse area (though with significant variability)
- Designed junction dimensions seem shifted from fab by a constant offset plus a pad-gap dependent factor

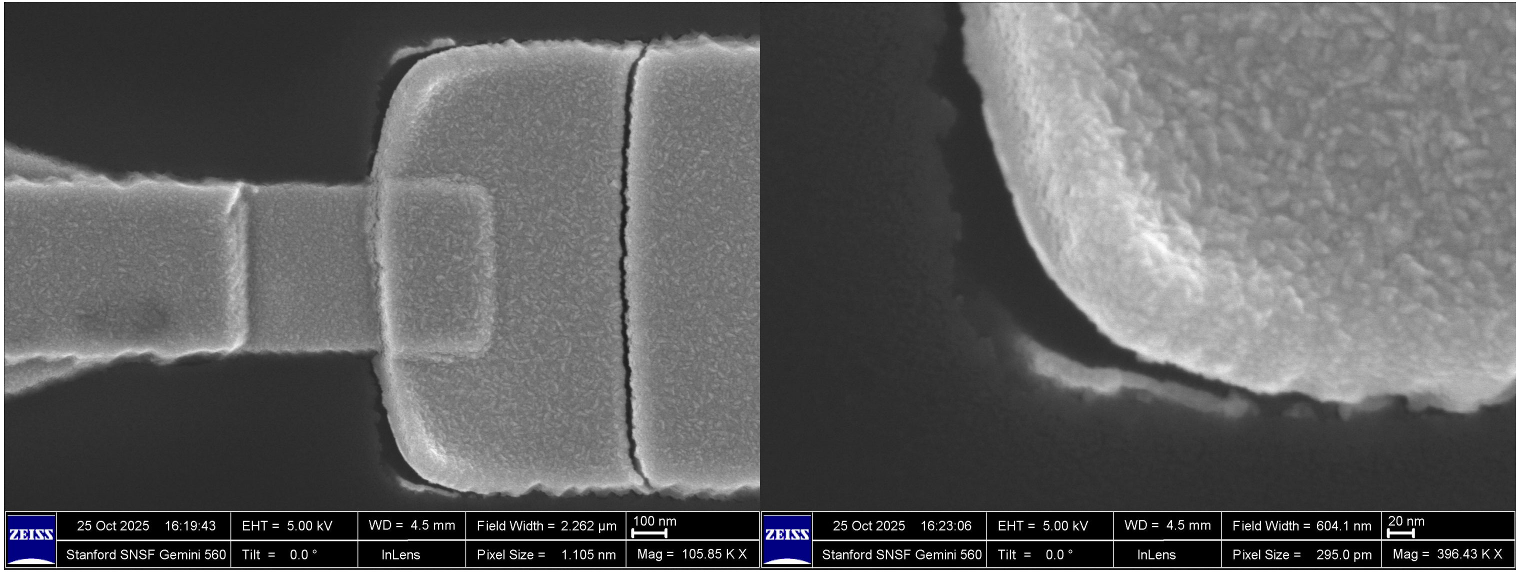




Further Fabrication Concerns

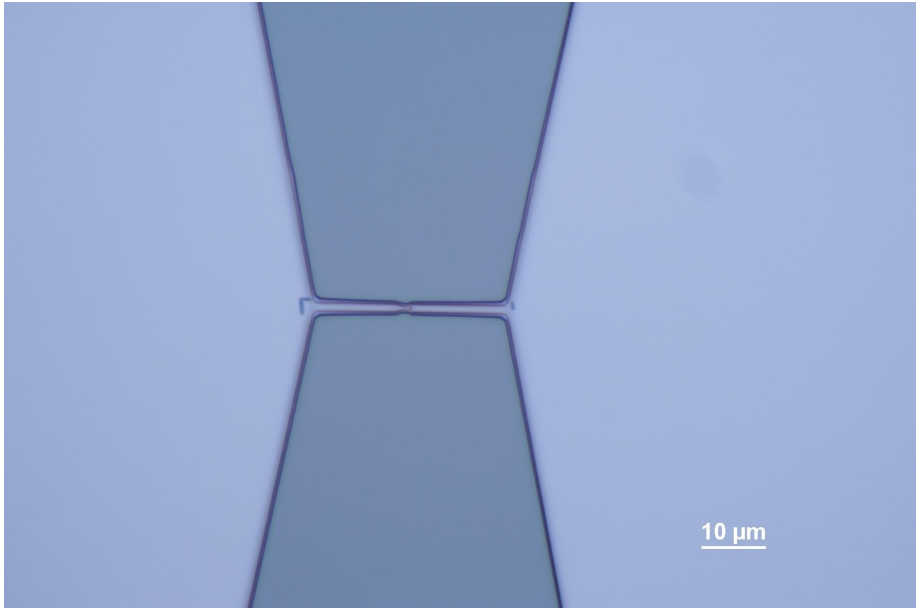
Residues under resist bridge affecting adhesion?

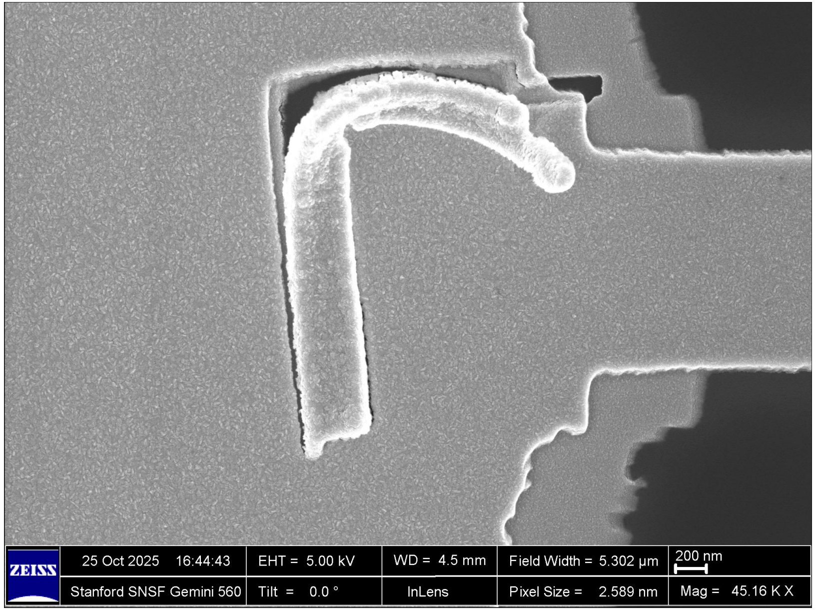
Hard to tell for sure from just top-view SEM, but the corners of the bandage seem to possibly be peeling slightly upwards?



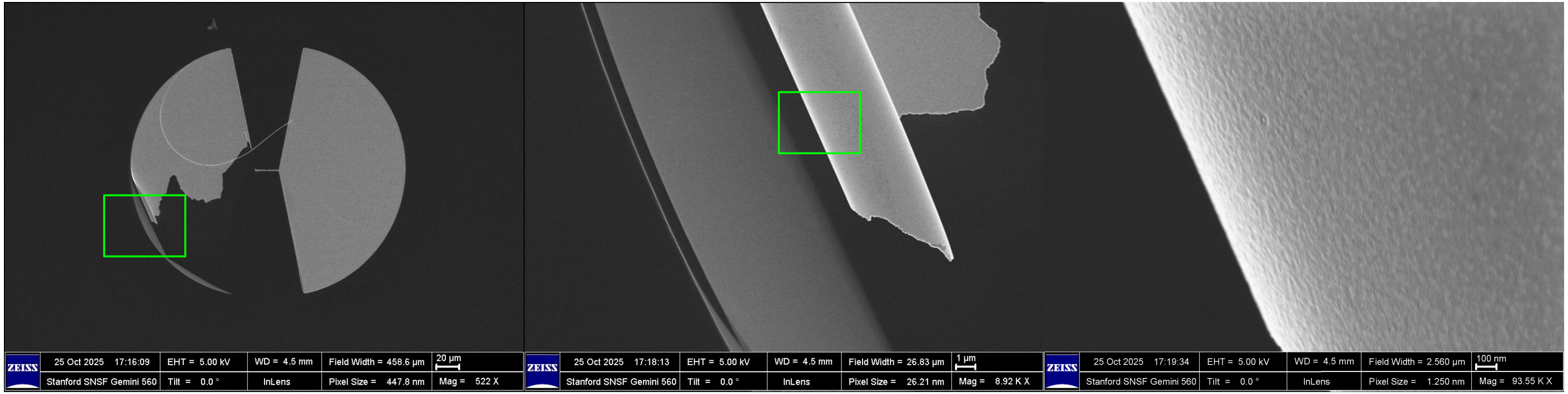
Residues under resist bridge affecting adhesion?

Corroborating evidence:
Some optically visible residue was remaining on a sample with unintended under-dosing results in peeling Hf upon deposition

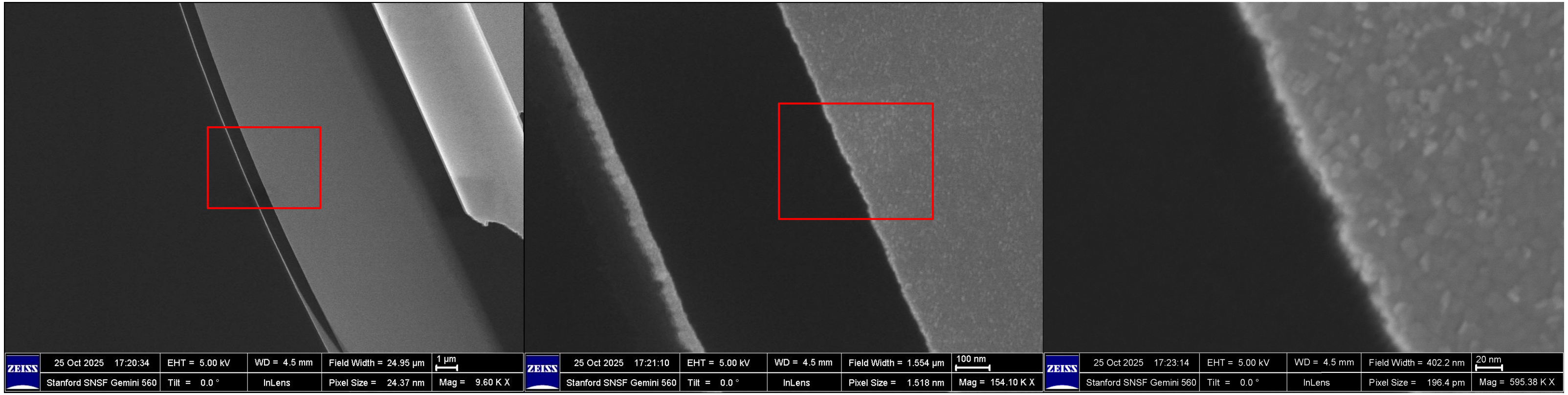




Device w/ ~25% reduced dose for pads layer: severe peeling **between** the two Hf layers!



Upper (peeling) layer in focus

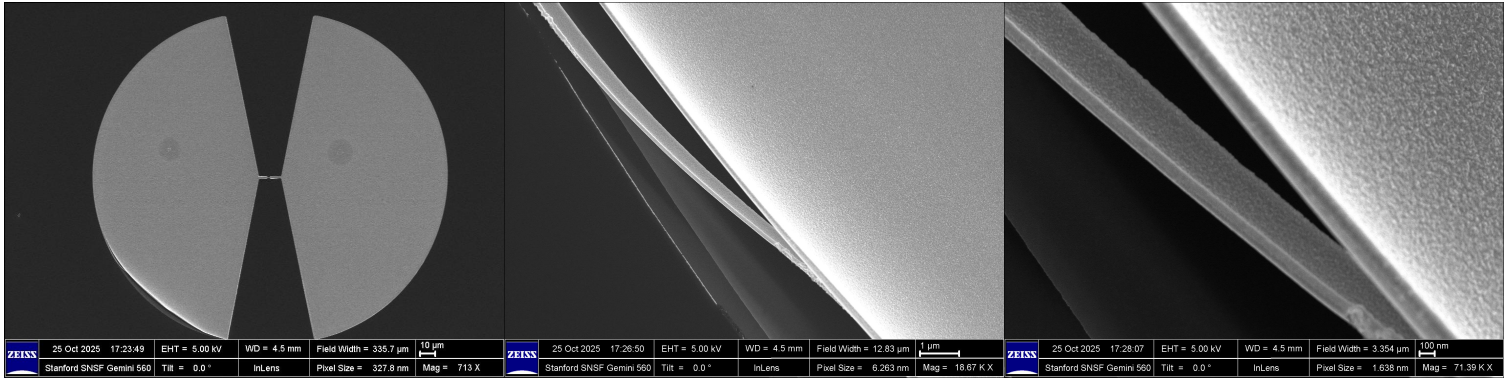


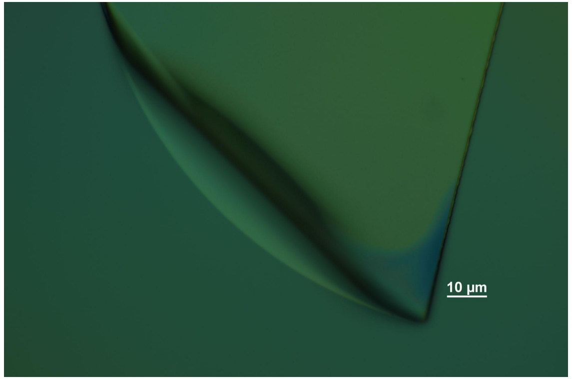
Lower layer in focus

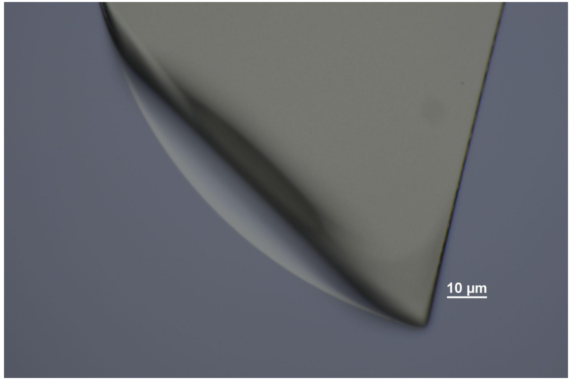
Next steps

- Take cold IV curves for these junctions with SQUIDs, after the methods used by Toki's group, with multiplexed SQUID support from Shawn Henderson
- If JJs look good:
    - Add transmission line and ground plane to these Hf-only SQUATs for potential RF measurements
    - Options for ground plane / transmission line material include Al, Nb, Ta
    - If no ground plane: could try adding Al transmission line on wafer of existing SQUATs by liftoff with PMMA/MMA bilayer and e-beam lithography?
- Once KJL2 ion milling is back:
    - Fabricate SQUATs with non-Hf absorbers
- Longer term:
    - Start transferring the process over the Ge substrates

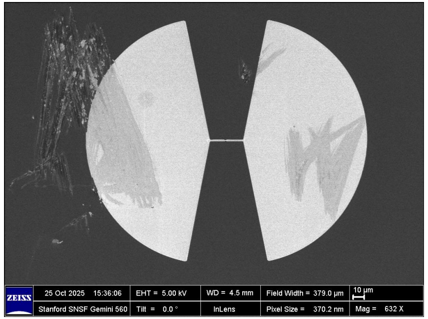
Backup examples of bad adhesion:



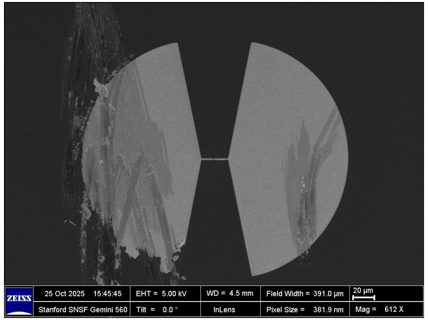




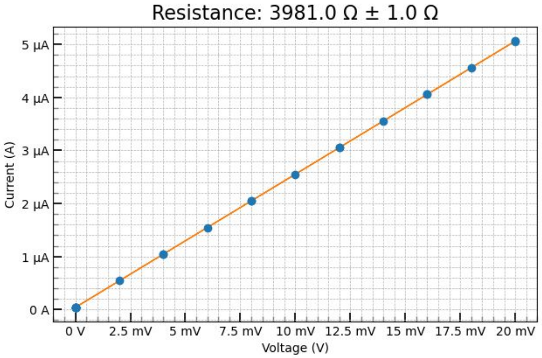
Side-by-side: Difficulties in sufficiently contacting the pads with probes

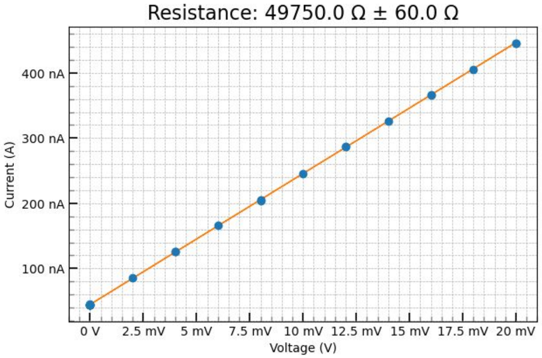


K2_Hf_SVM251015-1, Sample 1, Chip 1



K2_Hf_SVM251015-1, Sample 2, Chip 1


Resistance: 3981.0 Ω ± 1.0 Ω


Resistance: 49750.0 Ω ± 60.0 Ω