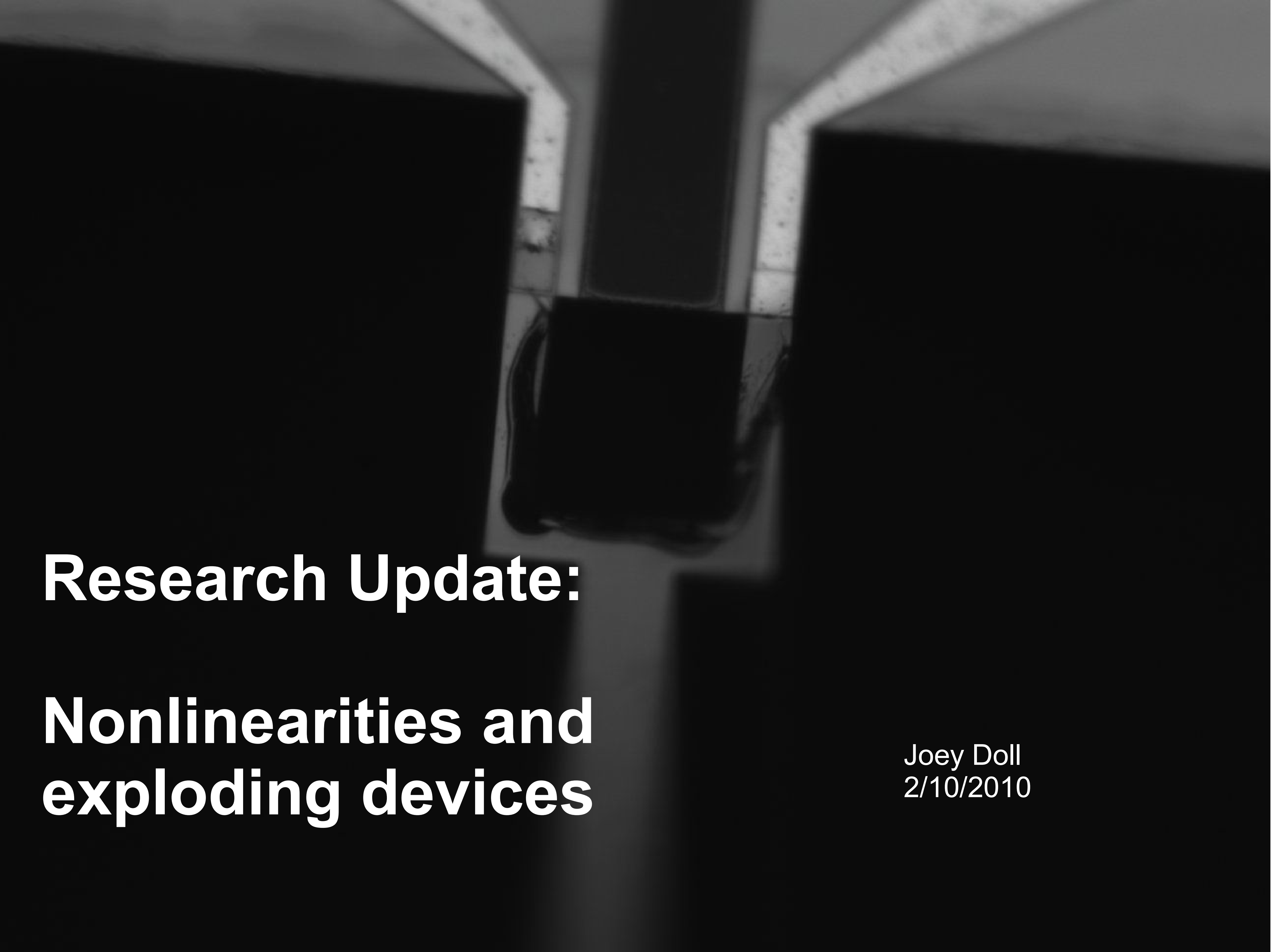
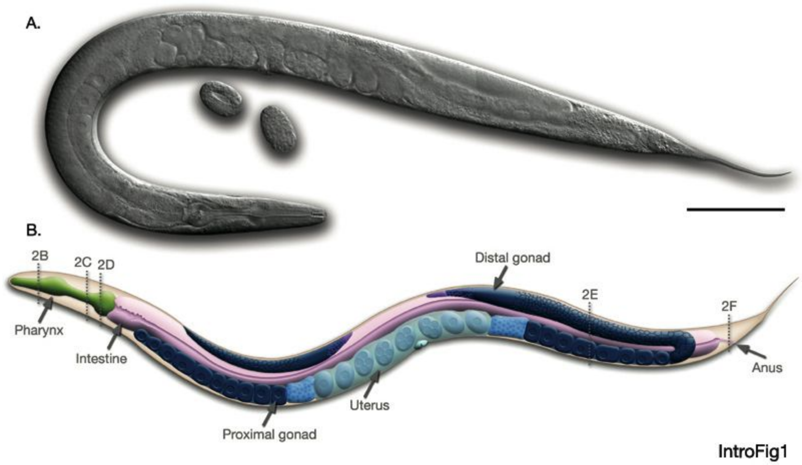


Research Update:

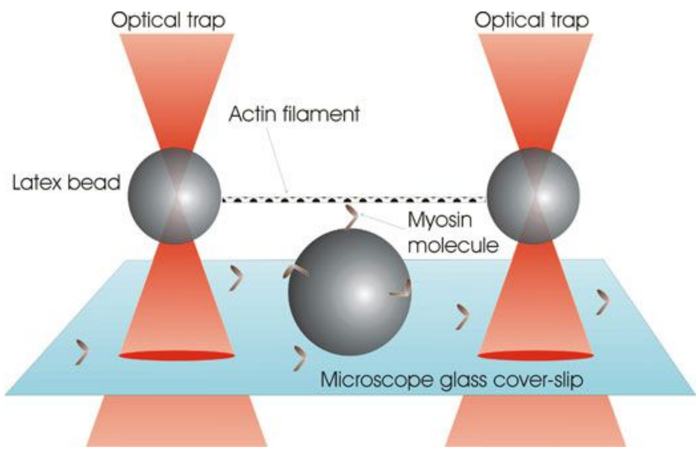
Nonlinearities and exploding devices

Joey Doll
2/10/2010

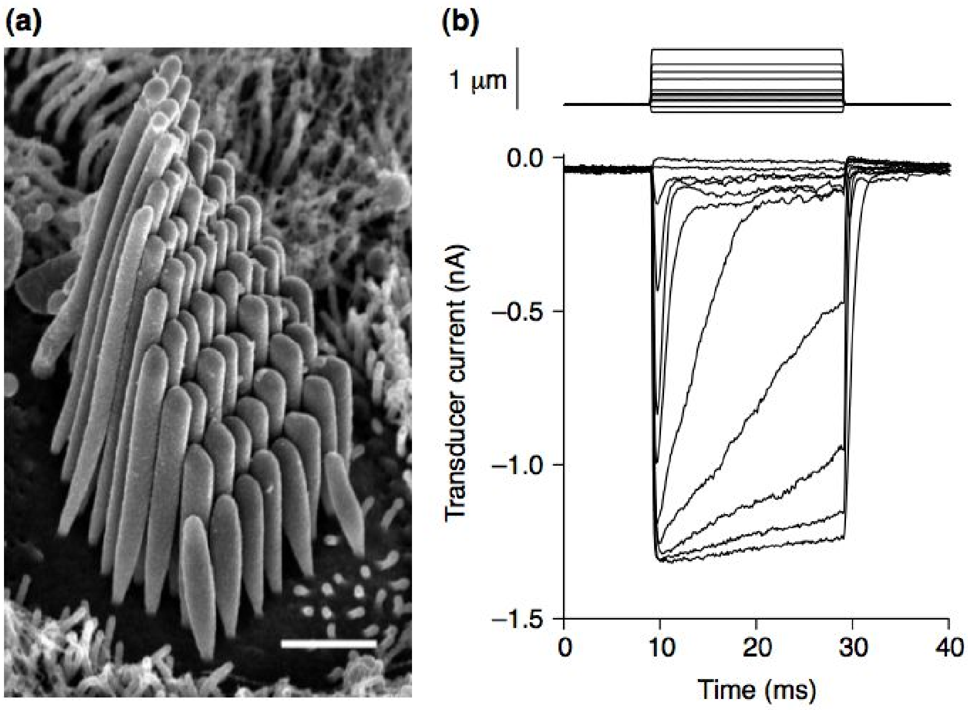
Motivation



Sense of touch (TRNs)



Single Molecule Force Spectroscopy (SMFS)



Sense of hearing (hair cells)

Images from Worm Atlas, http://www.scienceinschool.org/print/210 and
Clues to the cochlear amplifier from the turtle ear, Fettiplace, Ricci and Hackney, 2001

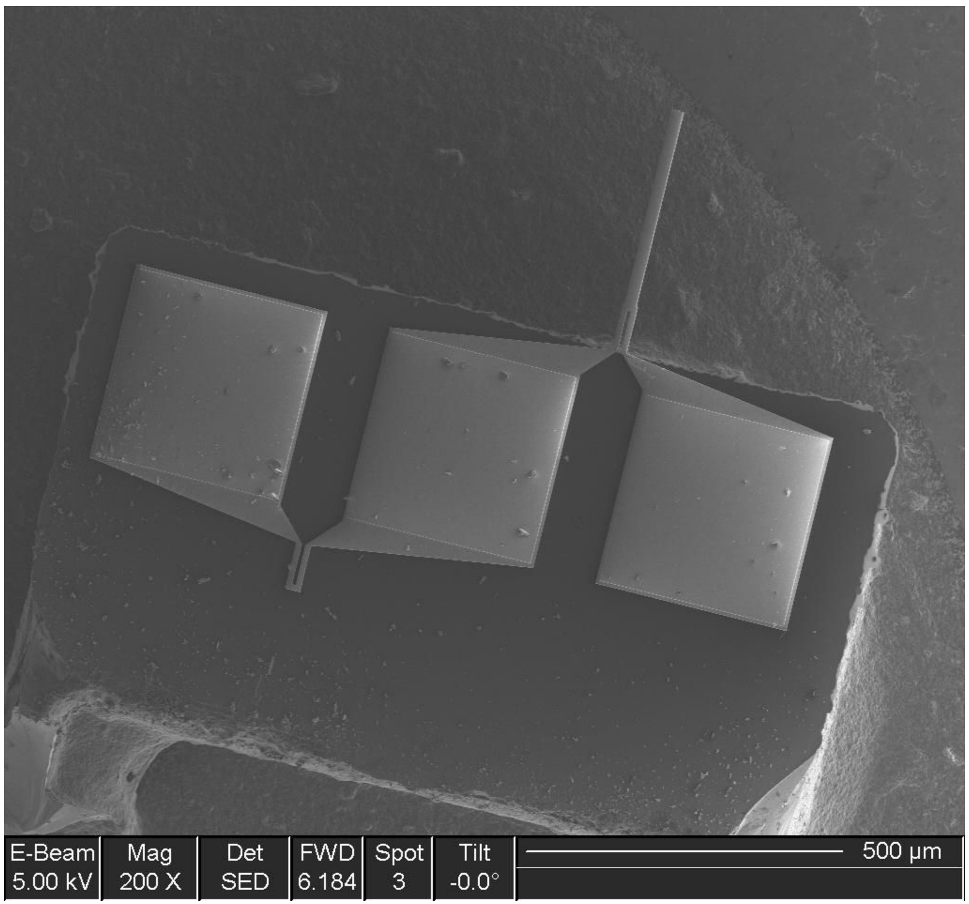
Performance Goals

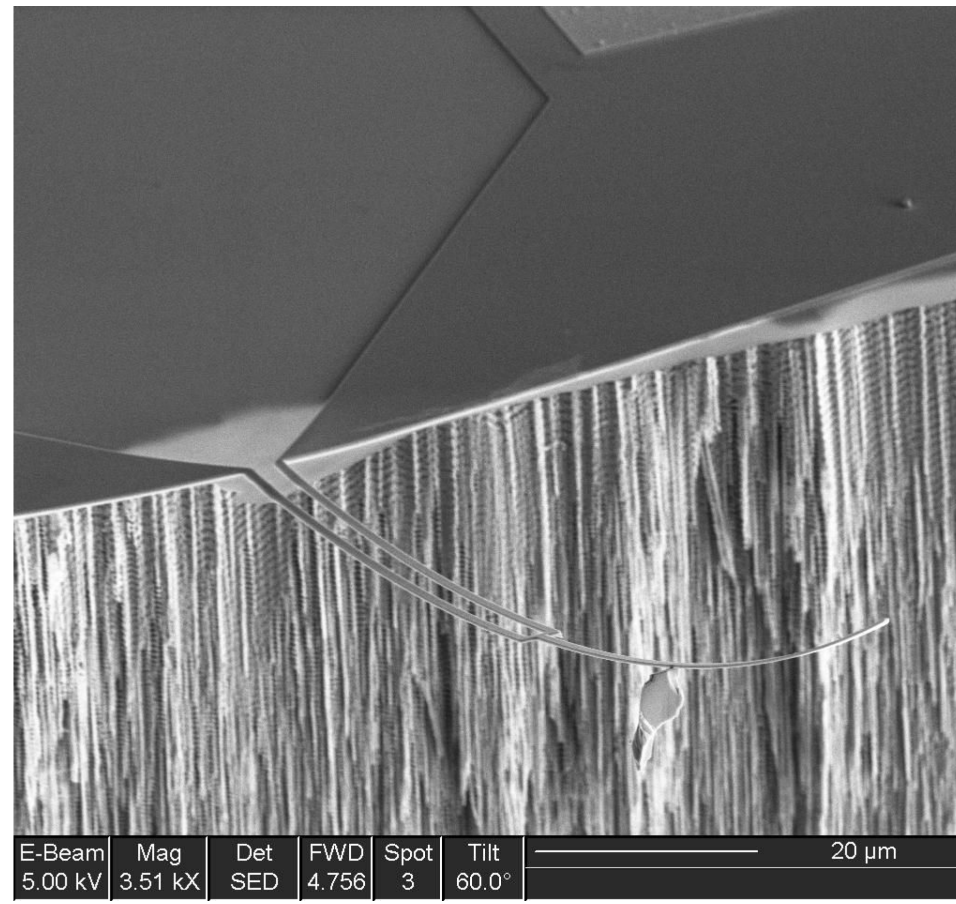
- Rise time
  - 10 microseconds (turtle hair cell)
  - 1 microsecond (mammalian hair cell)
- Force resolution
  - 50 pN, 1 Hz – 300 kHz (mammalian)
  - 30 pN, 1 Hz – 30 kHz (turtle)
  - 10 pN, 1 Hz – 10 kHz (TRN, single molecule)
- Closed loop force control
- Operation in fluid

Overview

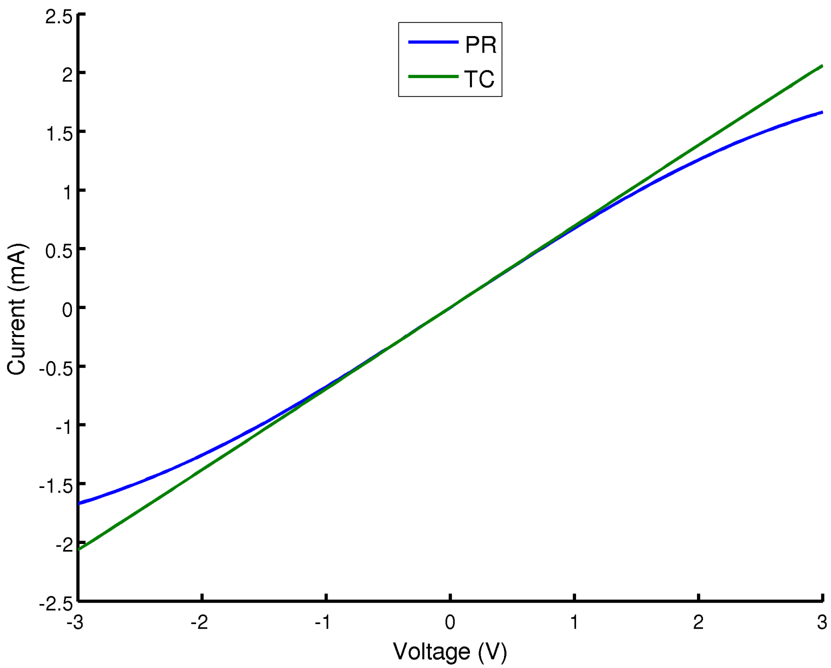
- PR devices
  - I-V characteristics
  - Voltage-displacement response
  - Progress towards SMFS
- PRPE devices
  - I-V characteristics
  - Voltage-force response
  - Cross-talk

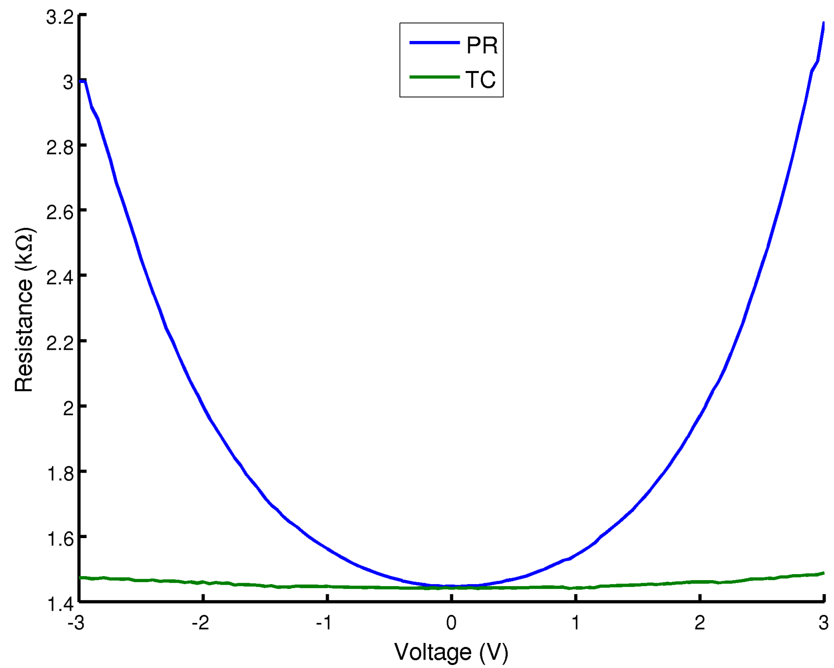
The PR Device





Typical I-V Curve

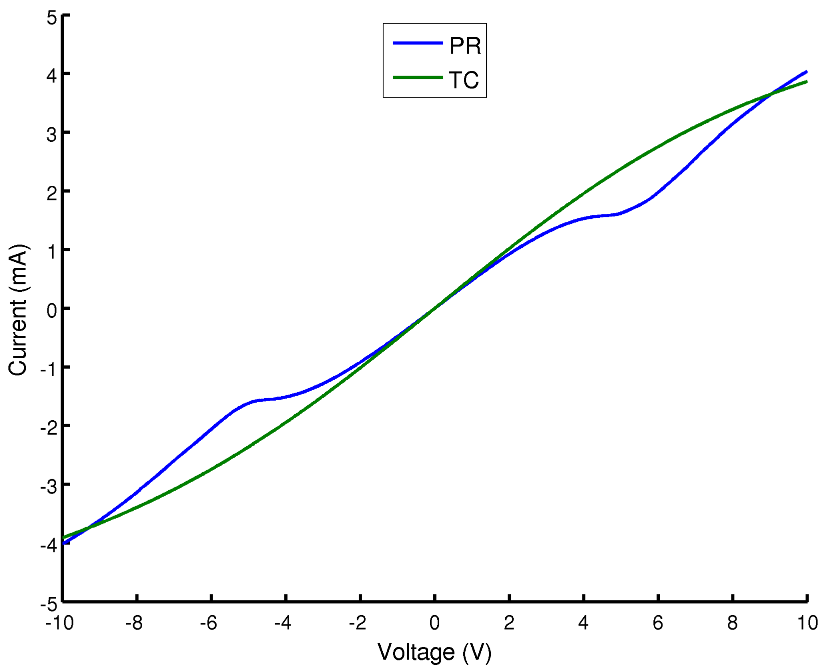


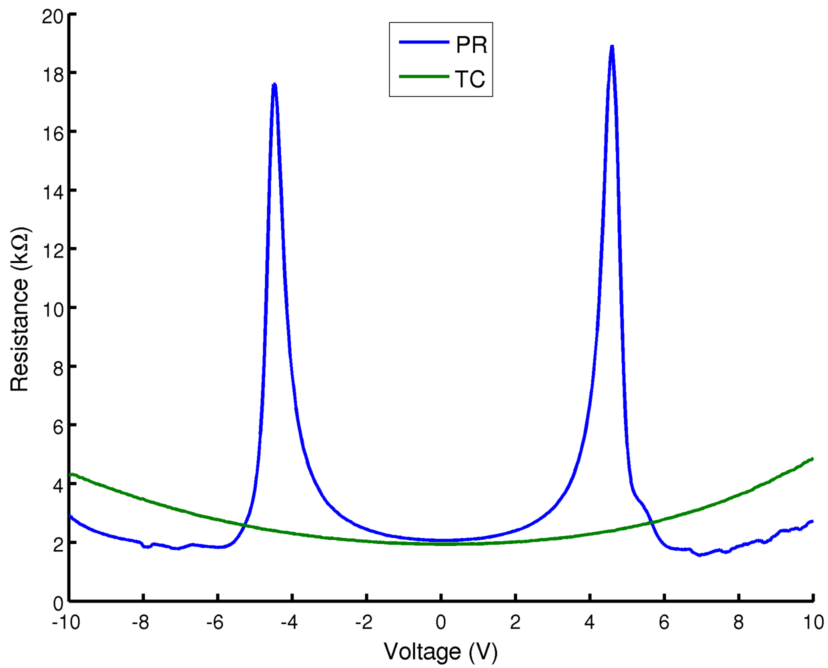


Doping: 850C POCL for 15 minutes
PR: 3um wide, 23um long
Cantilever, 6um wide, 87um wide

Resistance, mobility and temperature

Thermal Breakdown



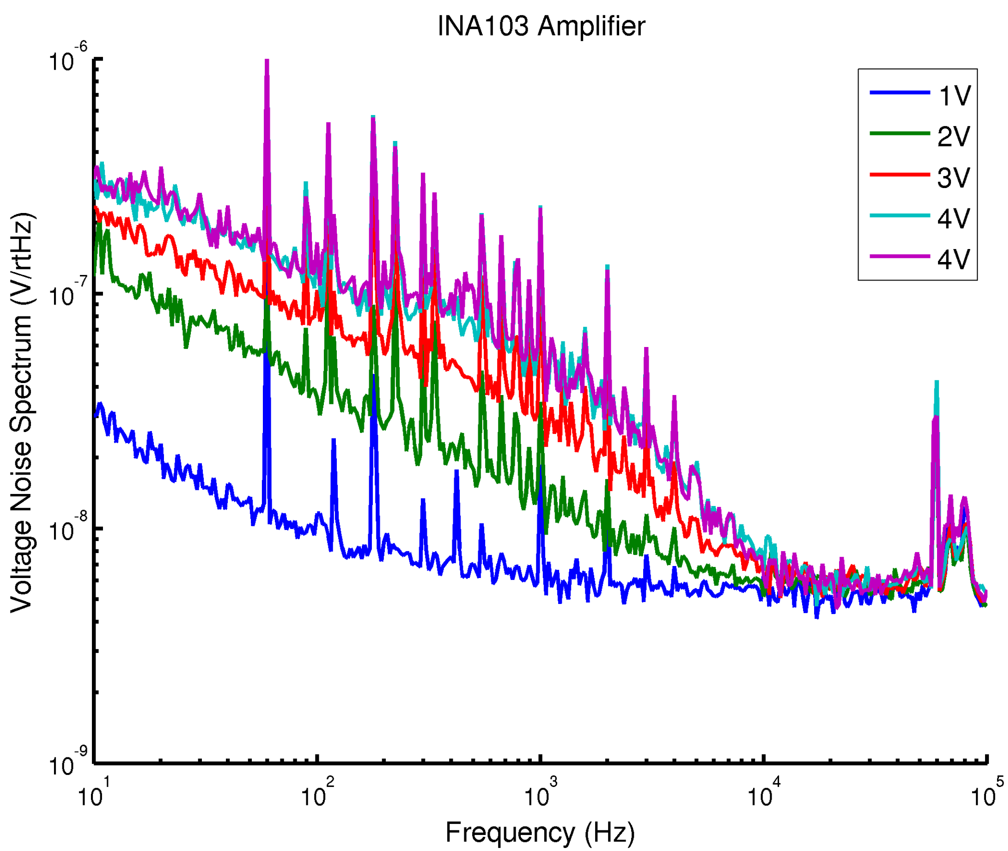


Device broke on the 3rd repeat (open circuit partway through I-V)

Runaway due to thermally generated carrier concentration becoming large.

Failure by cantilever cracking/vaporizing and aluminum vaporizing.

Noise and Power Dissipation



DC Bias, 1000x gain, 1 mHz HP filter.
4 V = 2.5 mW in PR

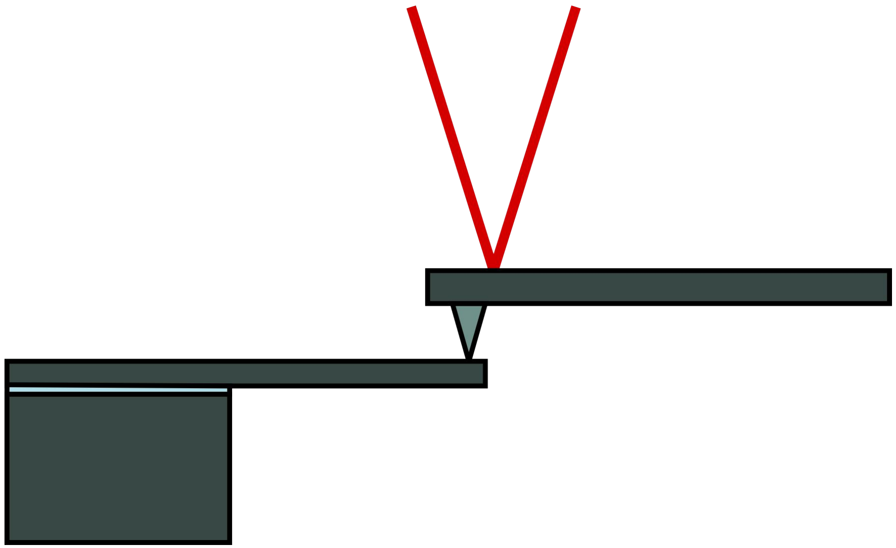
Thermal noise bump (returns to 1/f at 10 Hz). Bump frequency varies with device.

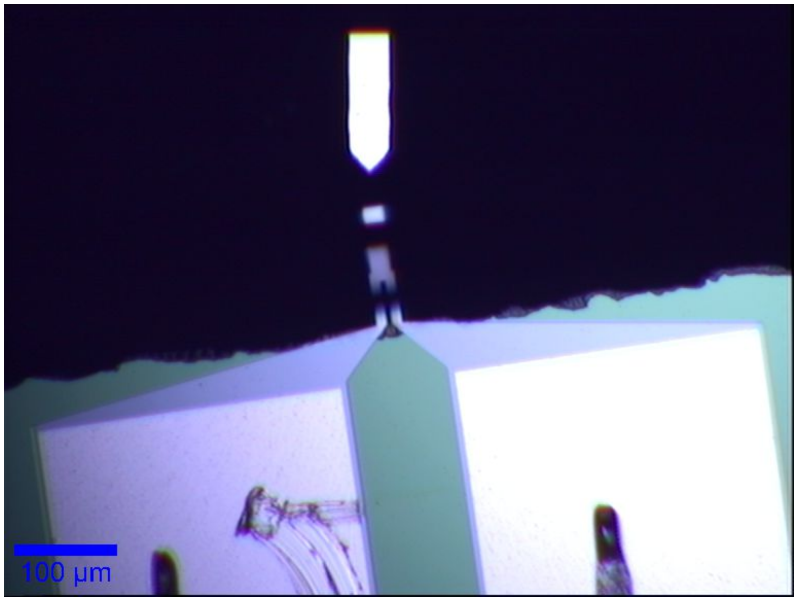
Measurements show that the noise spectrum is independent of amplifier (INA103, AD8221)

Lots of open questions. Affects the choice of optimal bias point, but not a huge problem.

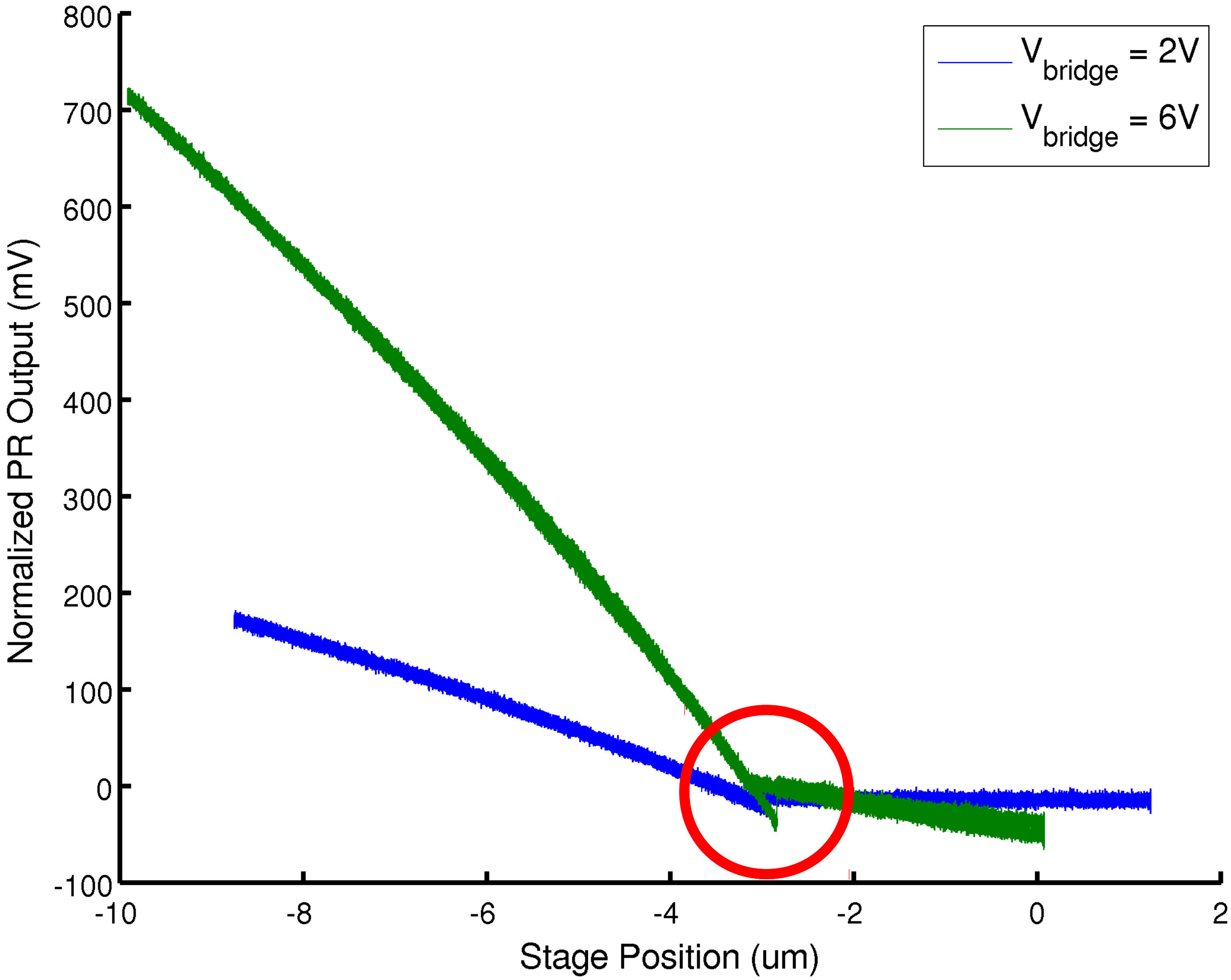
Measuring PR Sensitivity

- Standard sensitivity calibration uses a piezoelectric shaker and LDV
- LDV has given me some trouble (mentioned last time)
  - Aluminum foil reduced the capacitive cross-talk 50x, should work now
- Wanted to measure the PR response more directly using AFM

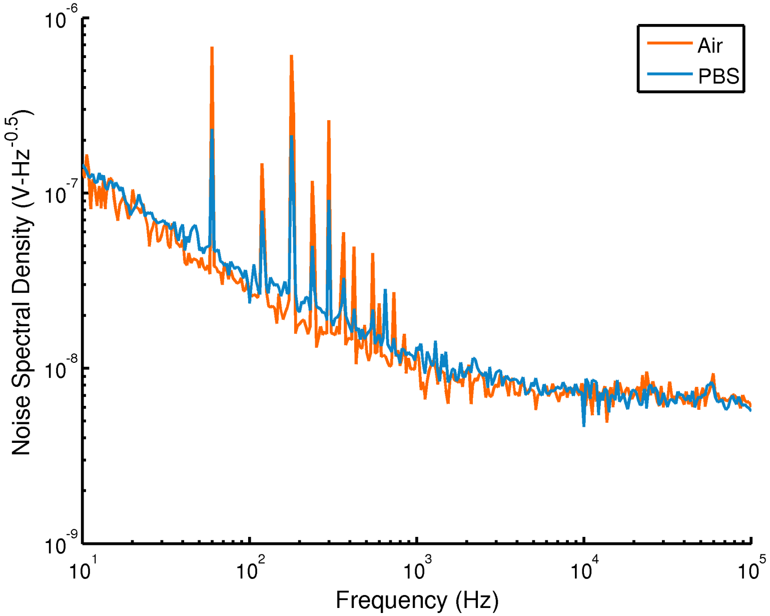


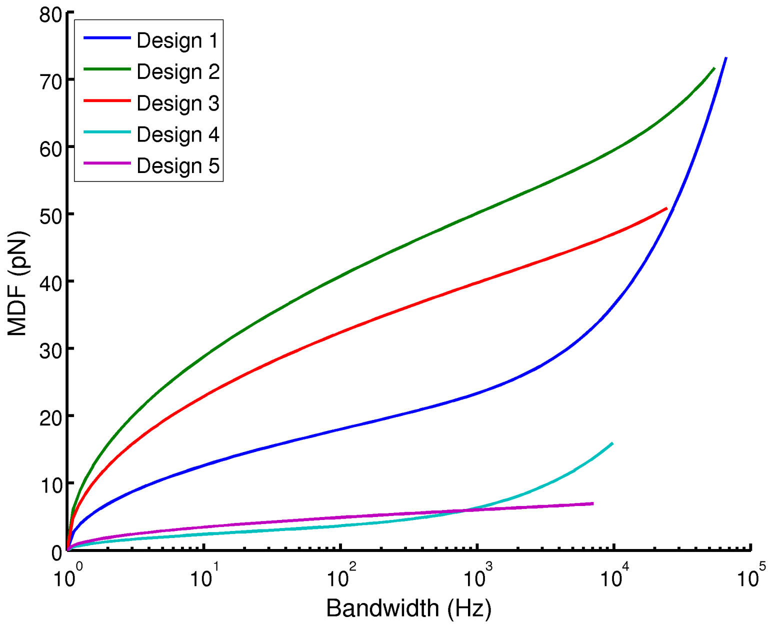


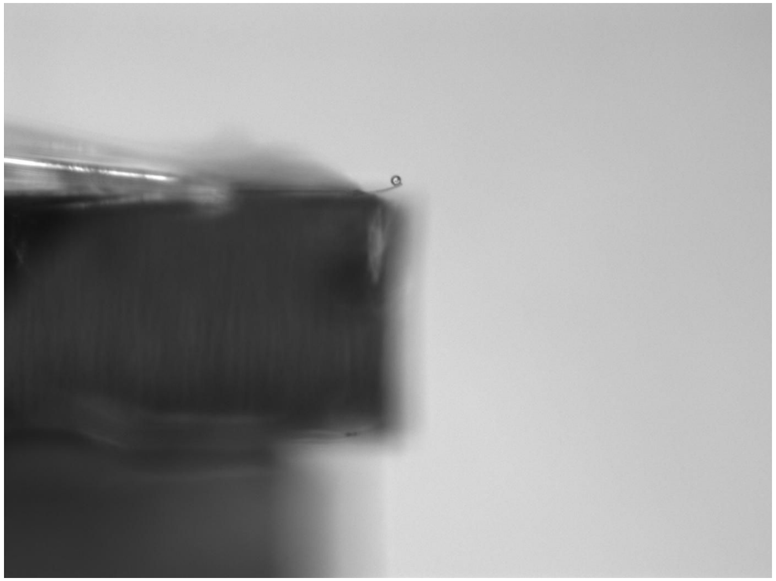
PR-Only Sensitivity

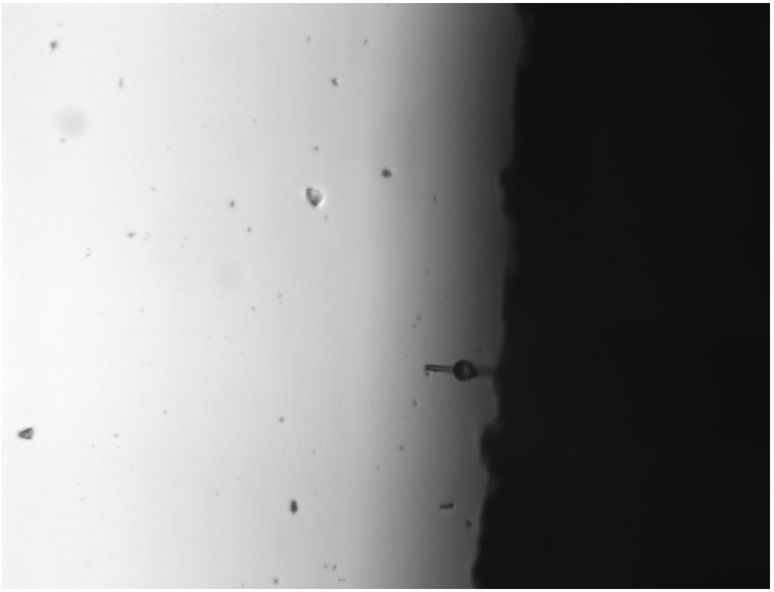


Progress Towards SMFS

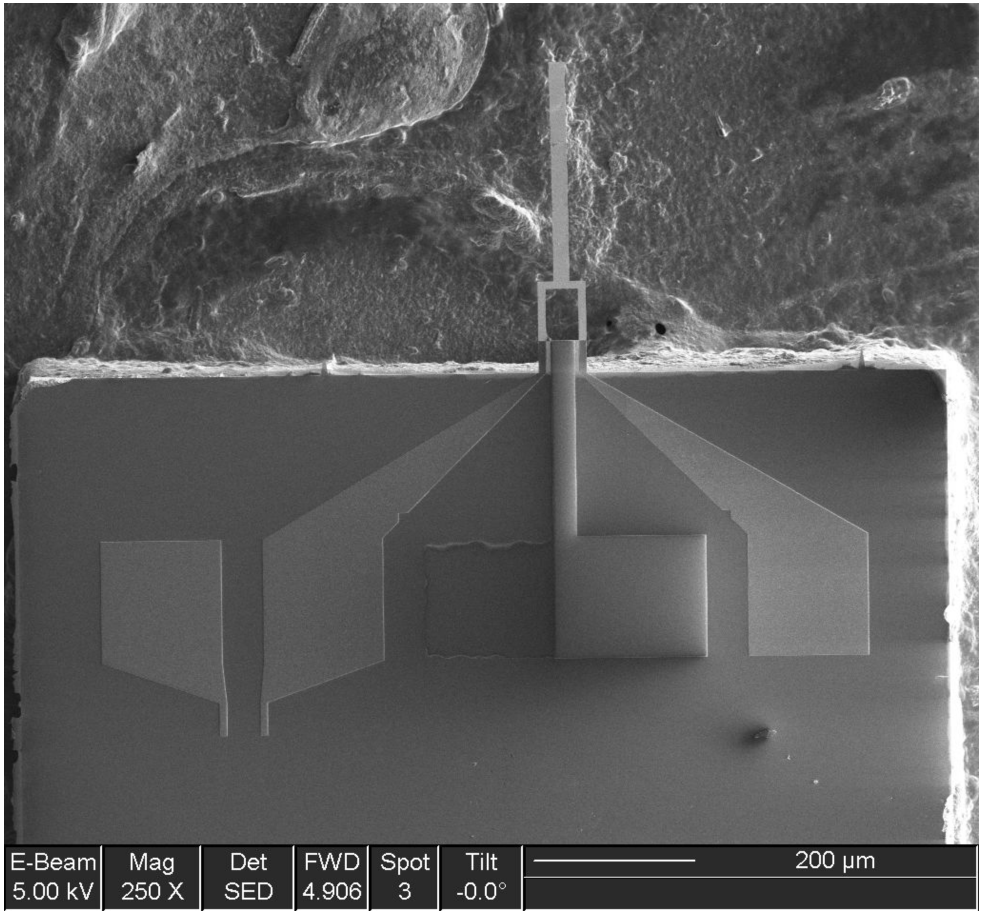


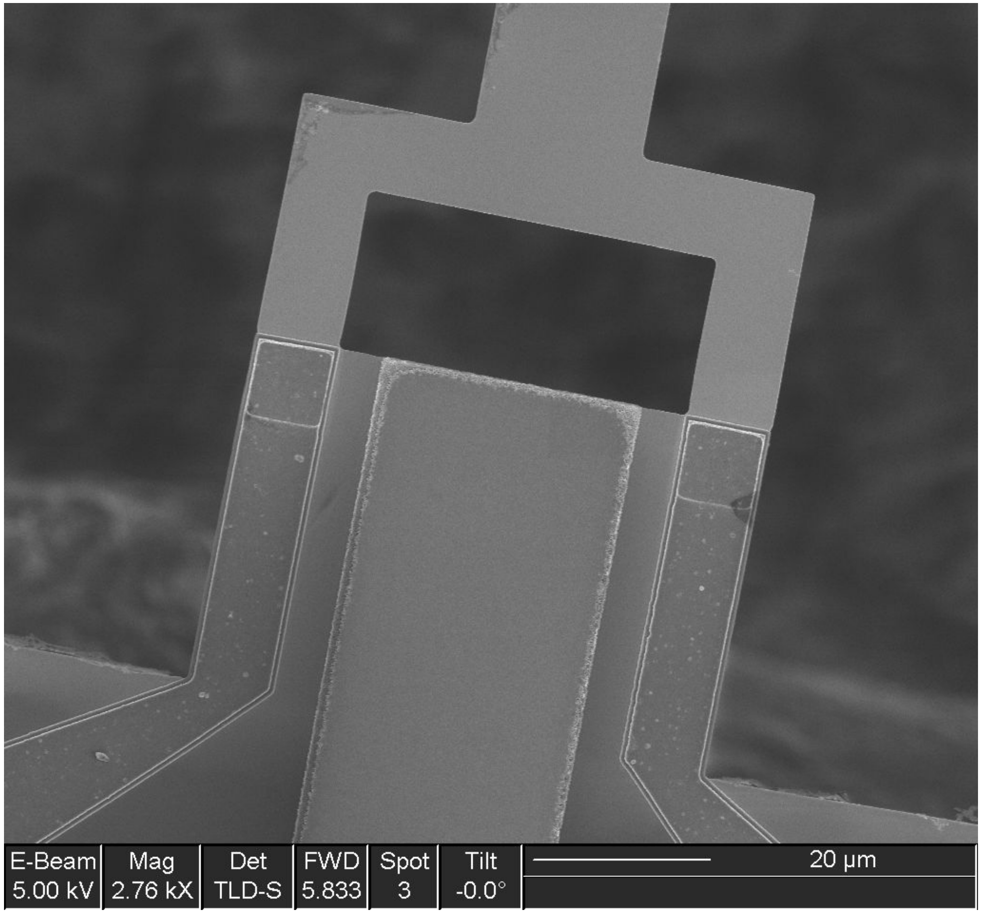






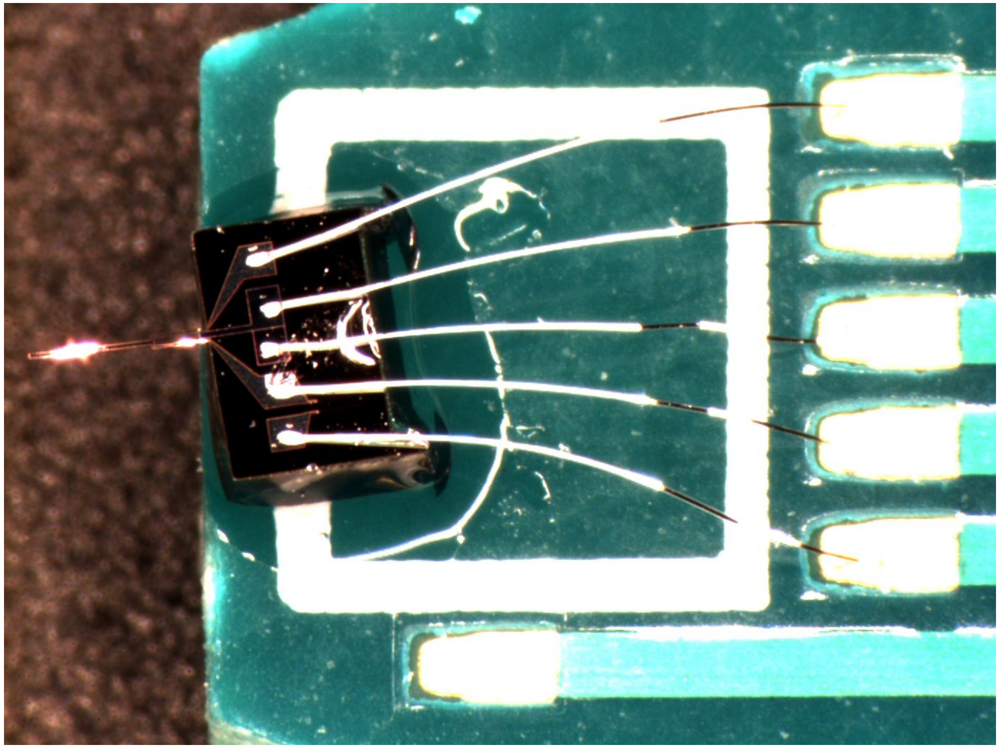
The PRPE Device

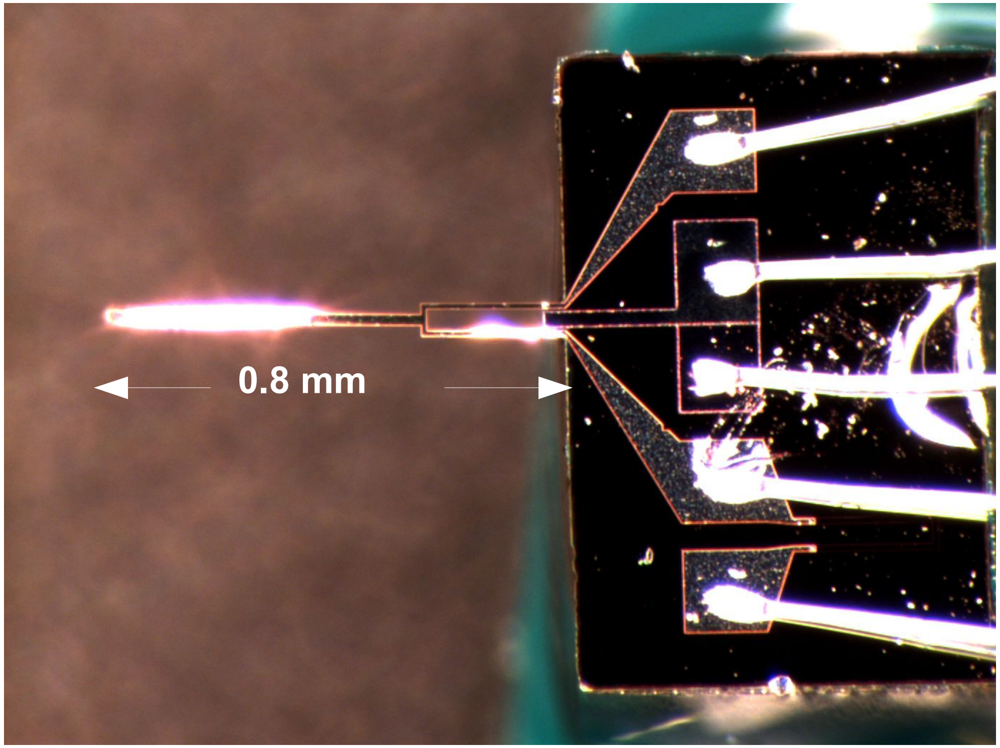




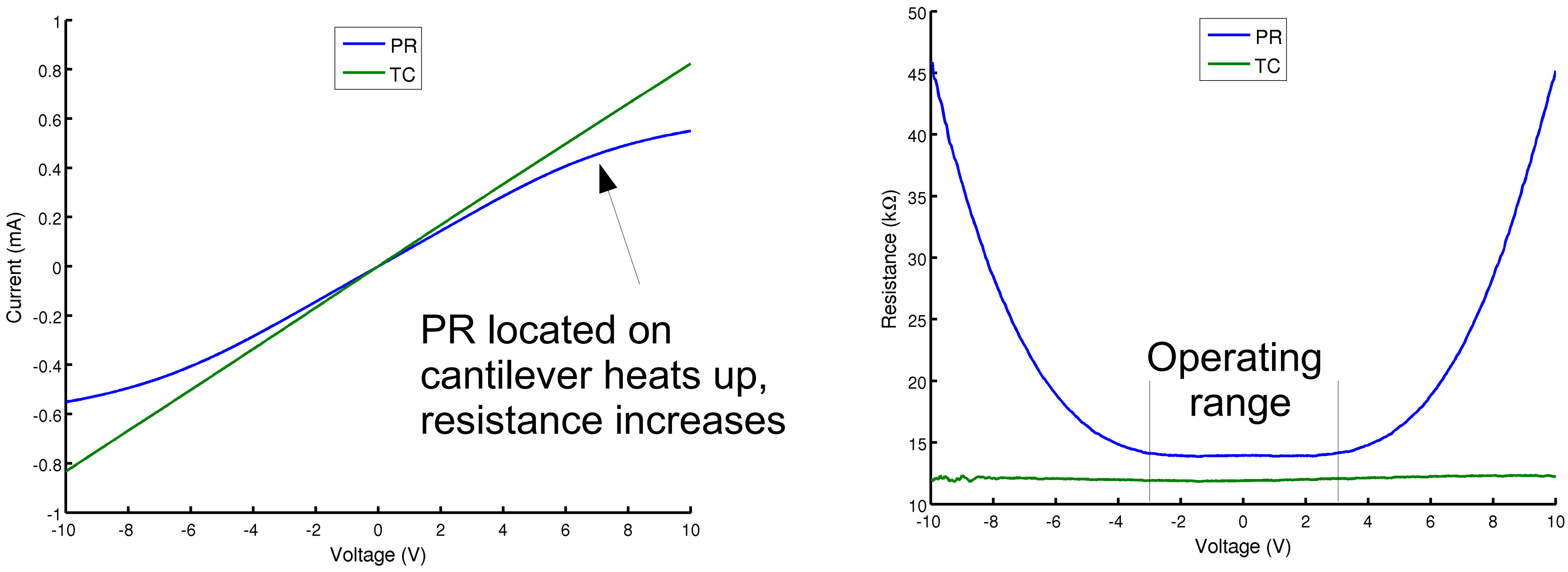
Piezoresistive force detection
Piezoelectric actuation

The PRPE Device





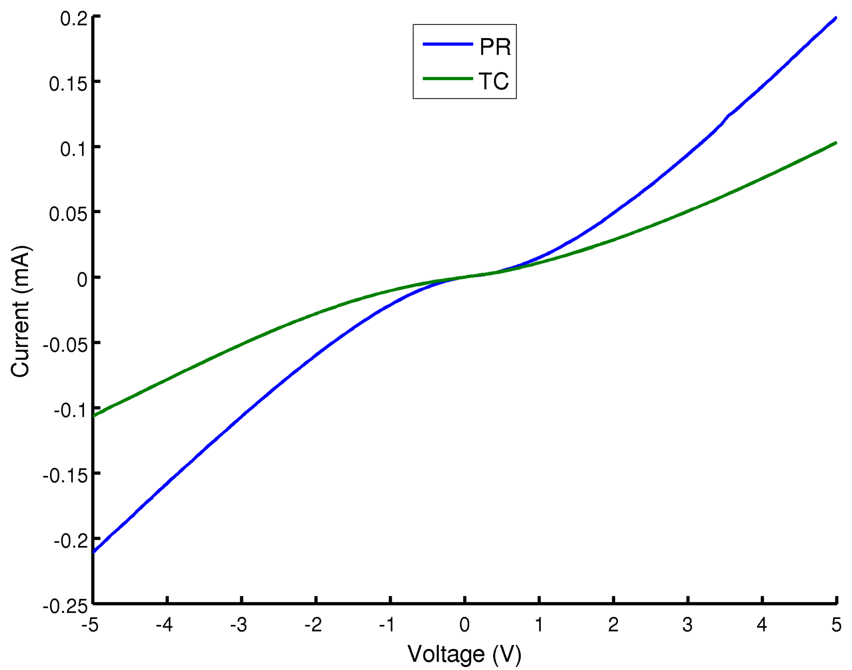
Good I-V Curves

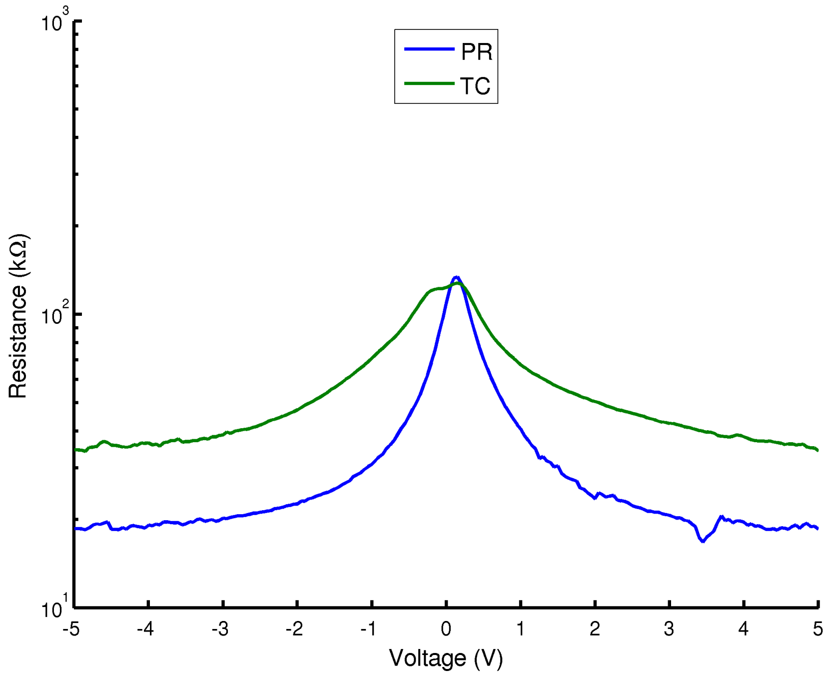


Typical devices from a good wafer

Bad I-V Curves

Structure = 2 metal-semiconductor junctions
(electrons go from M → S and S → M)

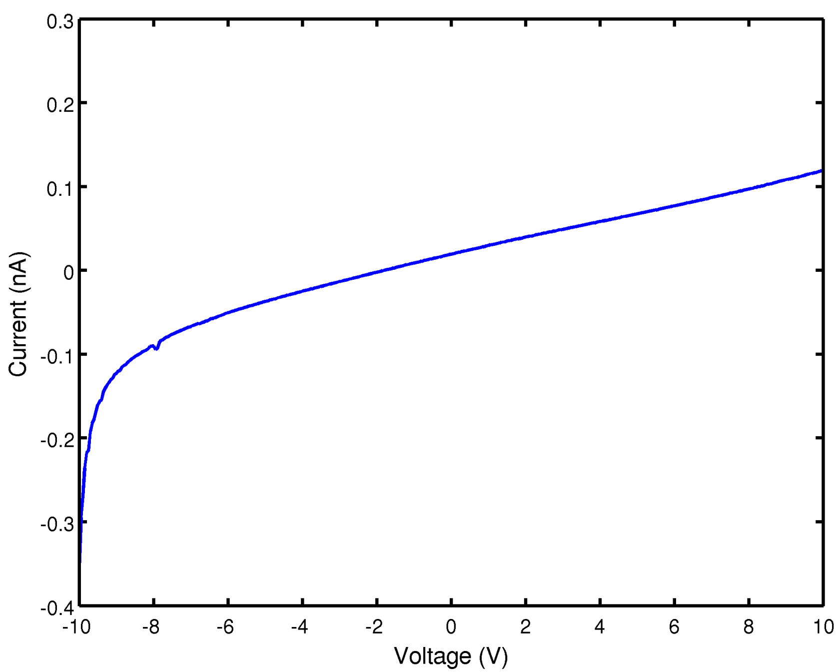


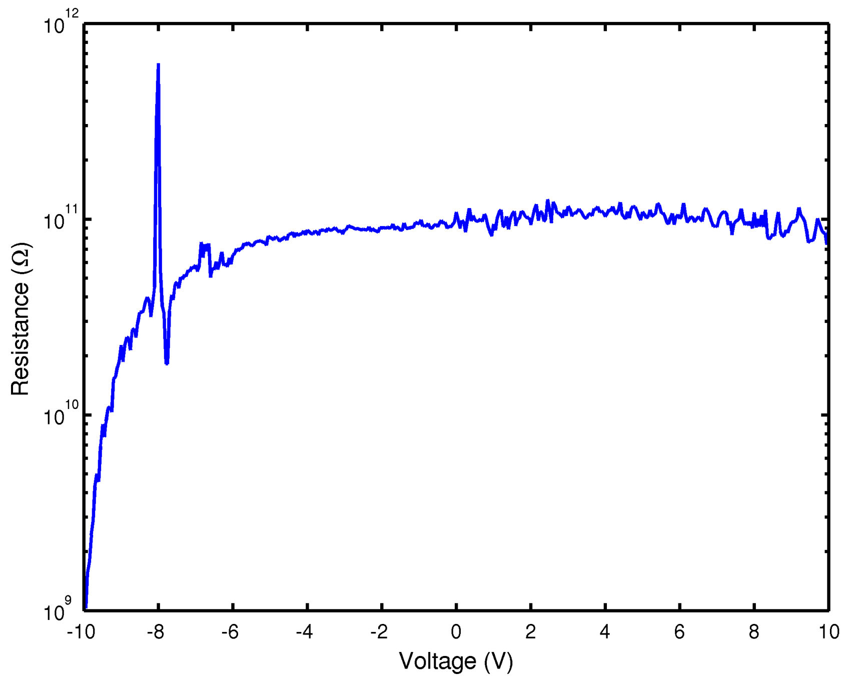


Three problems:
- Exponential I-V near zero bias → large parasitic contact resistances reduce deltaR/R
- Ratio of resistances varies with voltage → hard to balance the Wheatstone bridge
- Resistances don't match at high bias → low Wheatstone bridge sensitivity even at high bias

Likely due to reduced surface dopant concentration from pre-AlN surface clean

Good I-V (Piezoelectric)



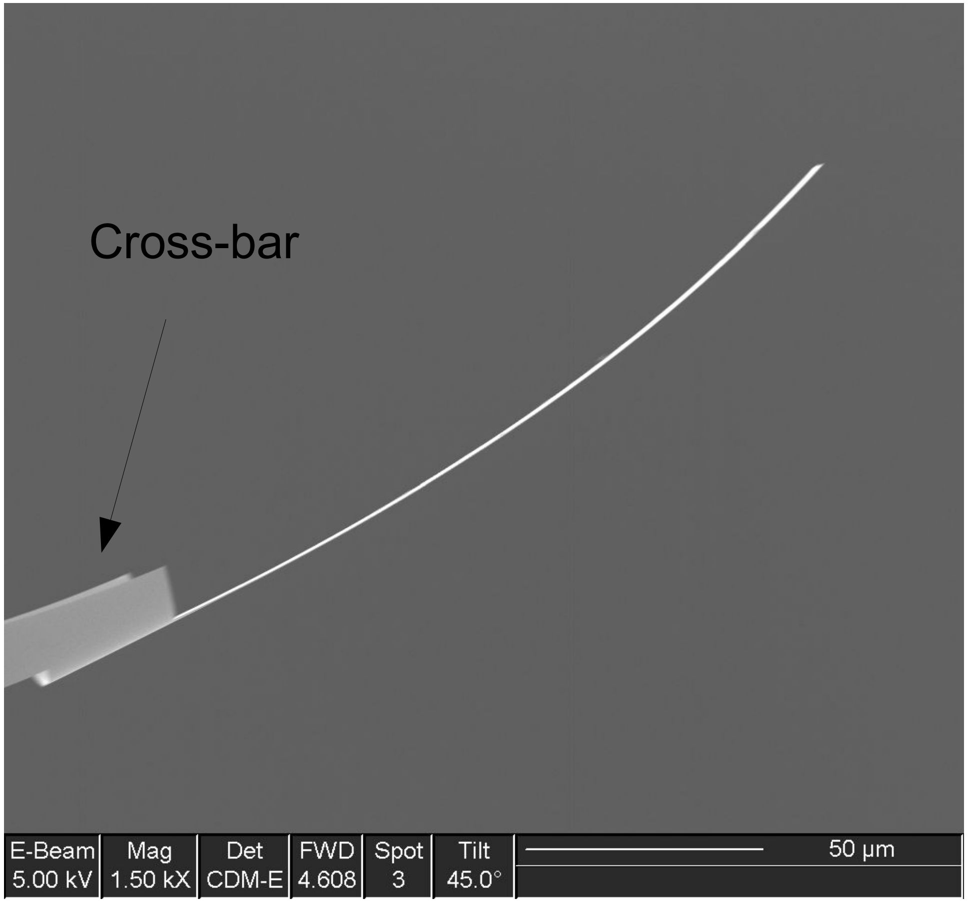


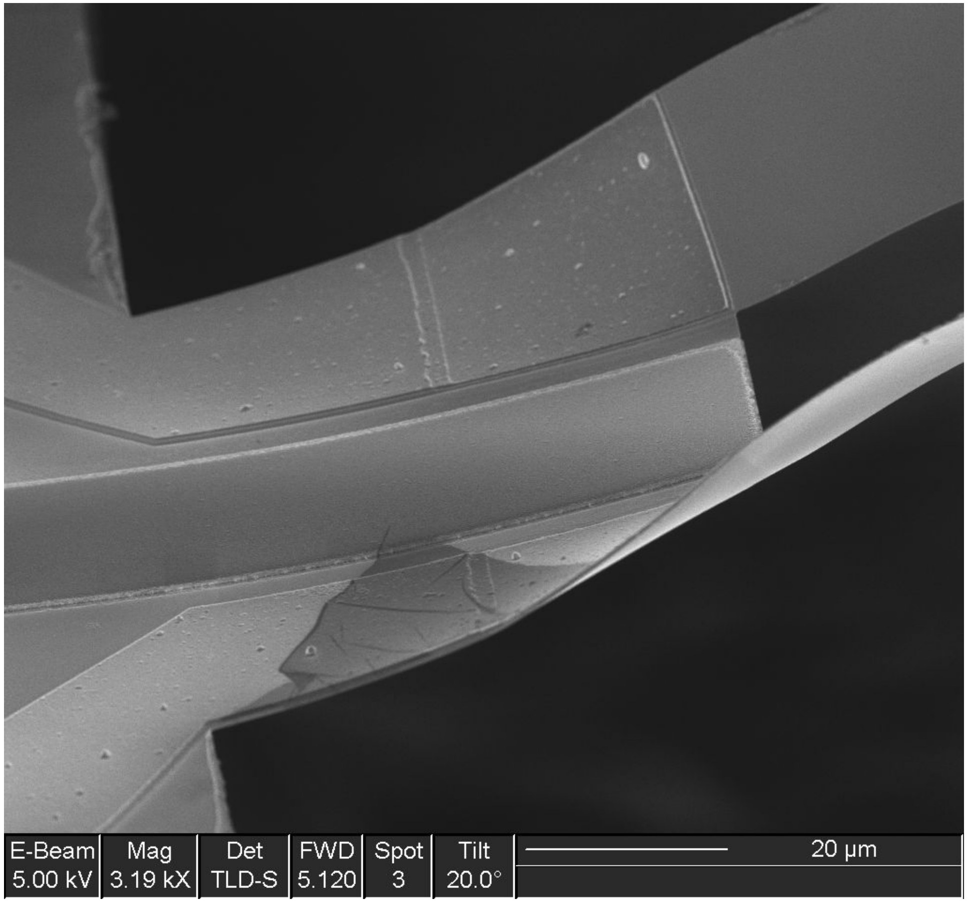
AlN film resistance in the gigaohm range. Higher is better.

PRPE Sensitivity

- Calibration on LDV has never worked (in contrast with the PR devices)
- From AFM testing, PR output doesn't change until the device has been visibly deformed
- After pushing some more, the PR output changes drastically (“buckles”) and behaves linearly after that

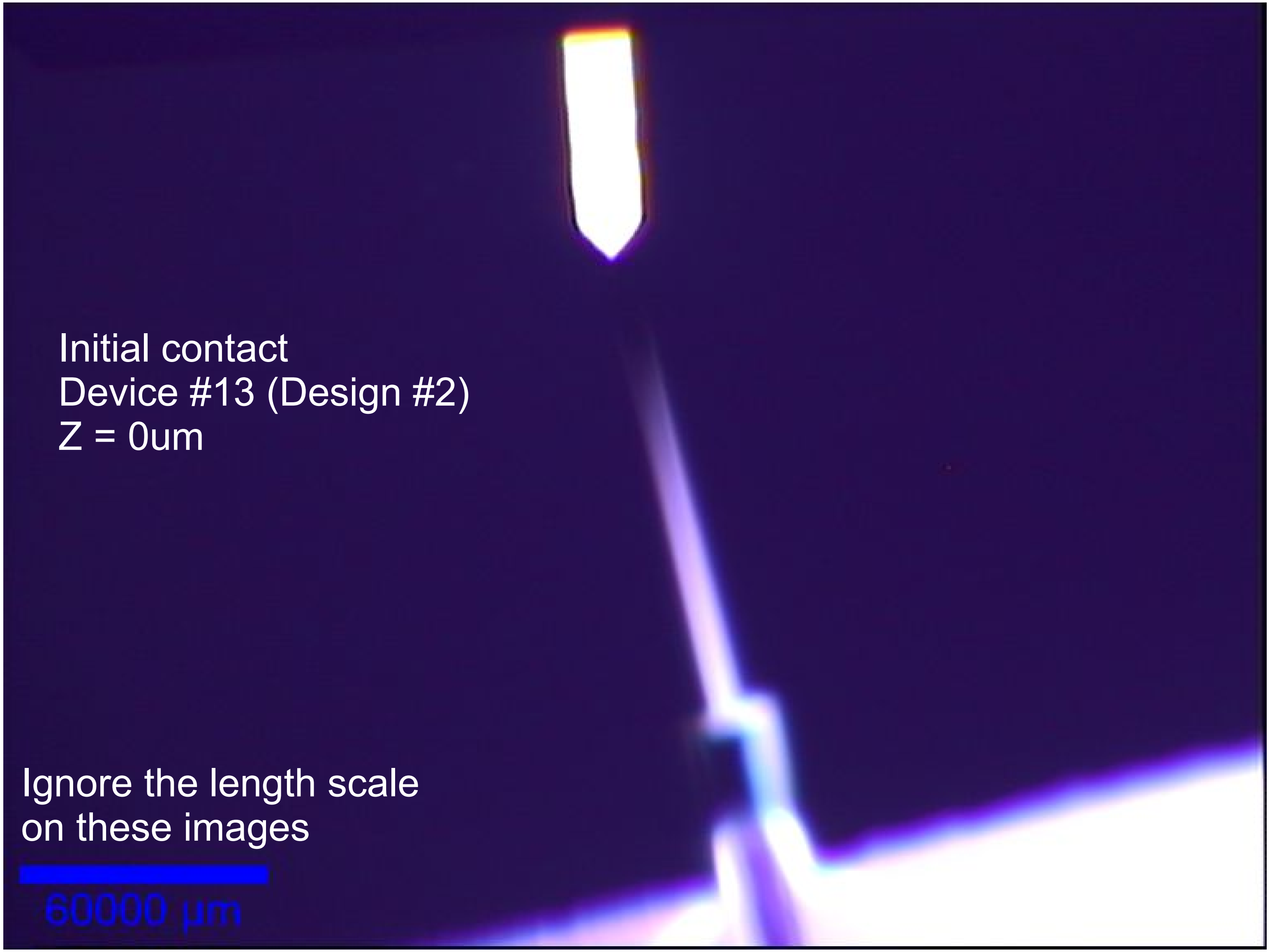
Potato Chipping (SEM)



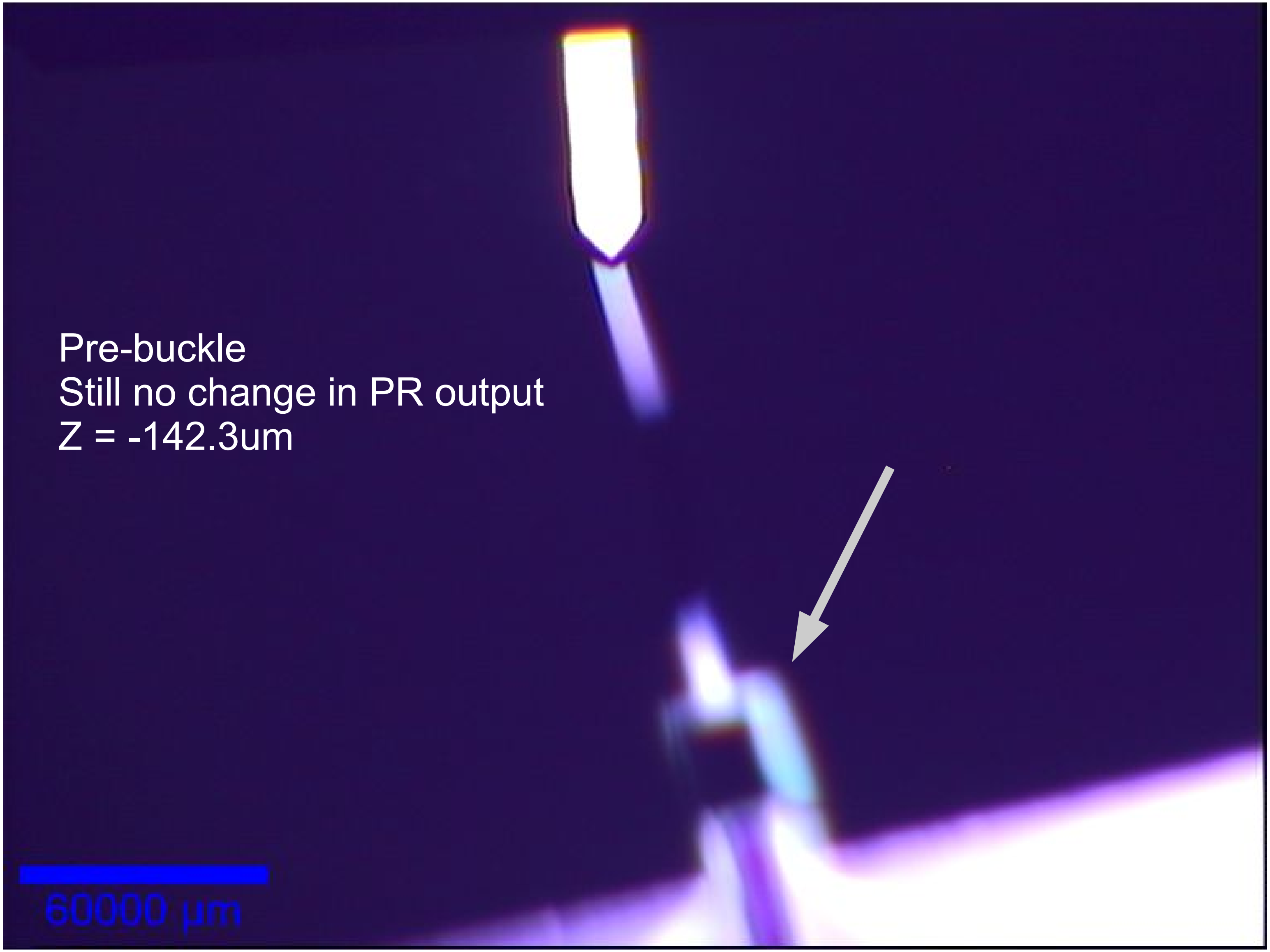


Hypothesis: the lateral bending stiffens the cross-bar region so that force applied to the tip of the cantilever doesn't initially bend the PR region (left of the cross-bar in the first SEM)

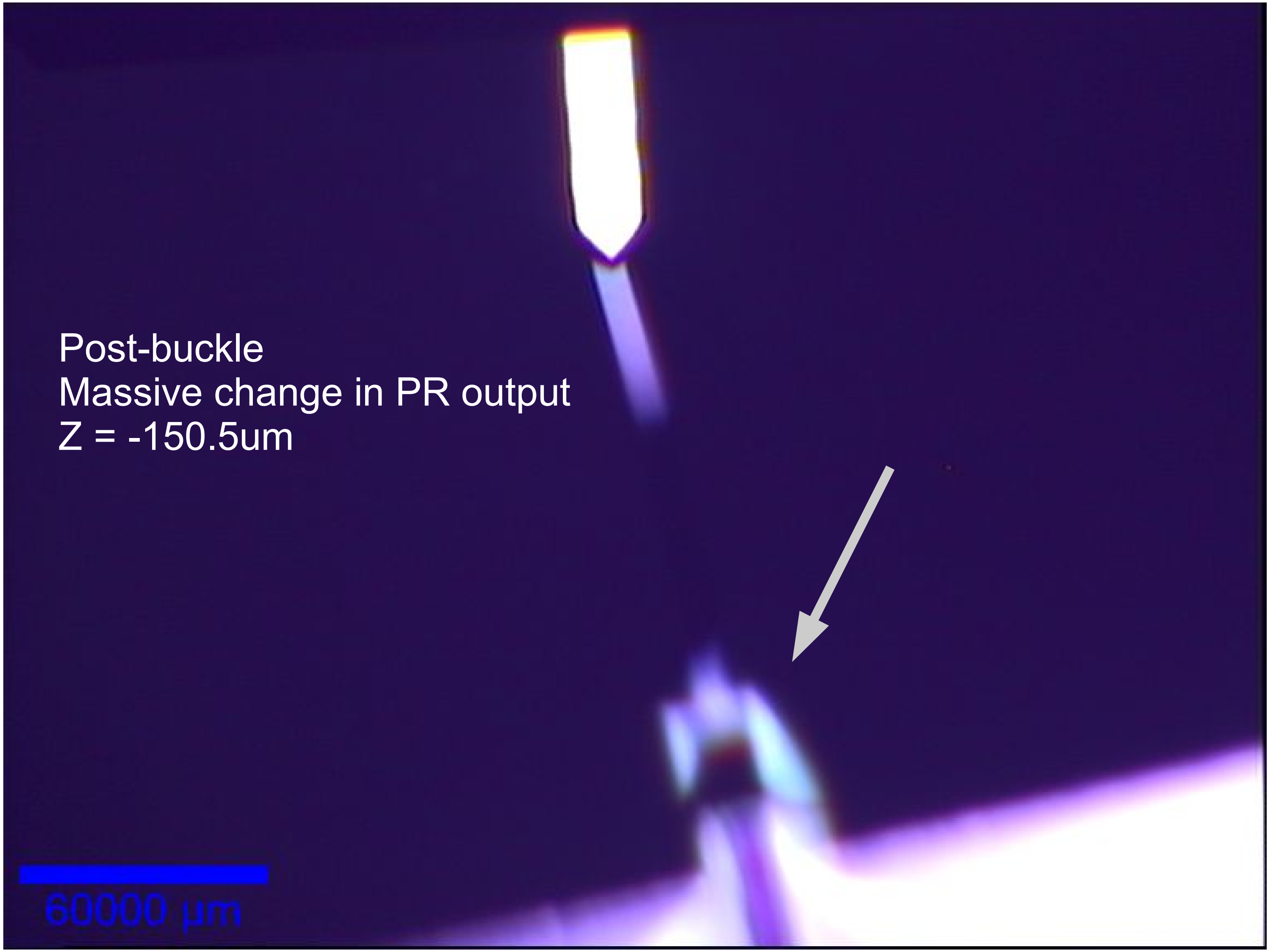
PR+PE Buckling



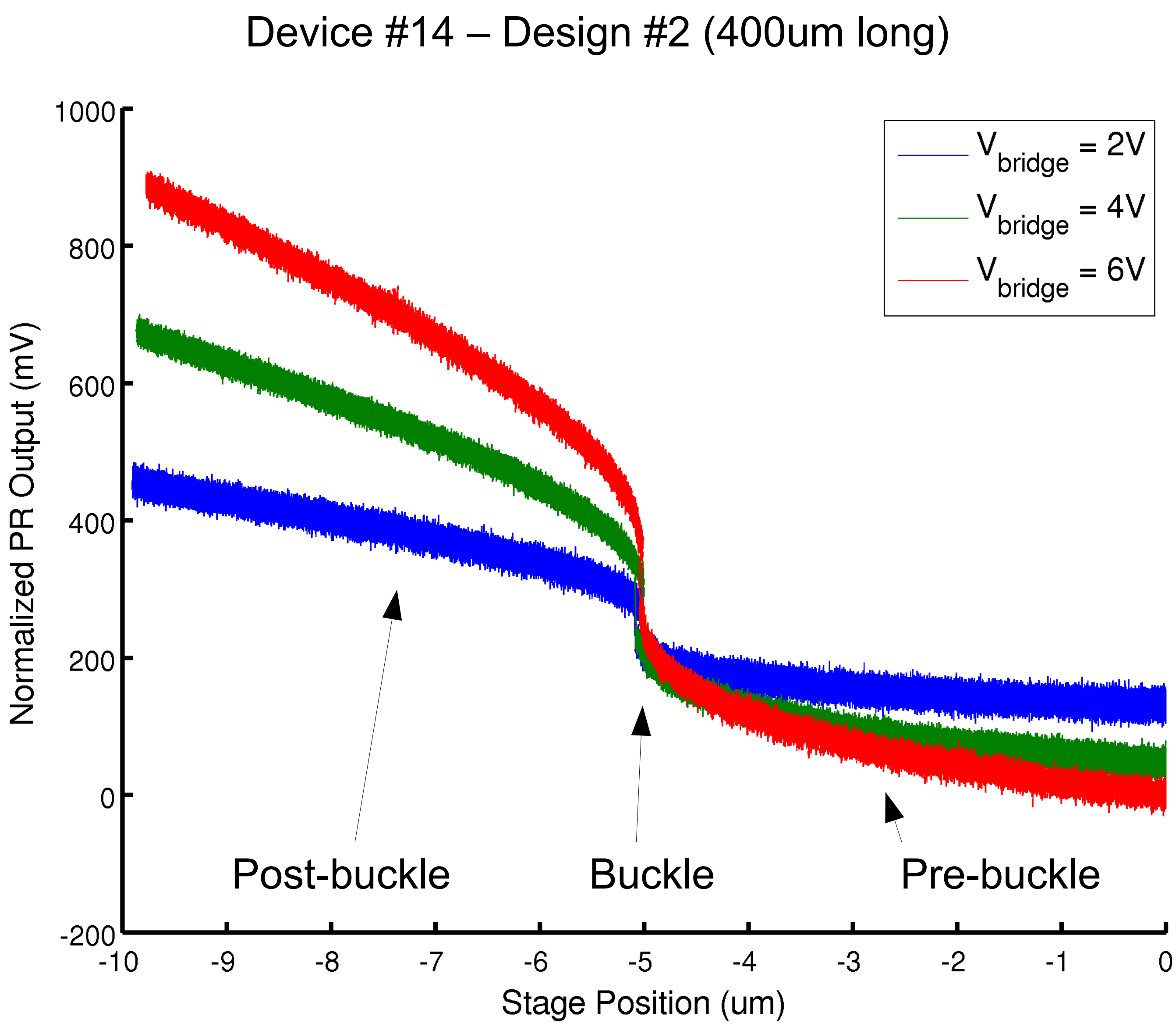
PR+PE Buckling



PR+PE Buckling



PR+PE Sensitivity



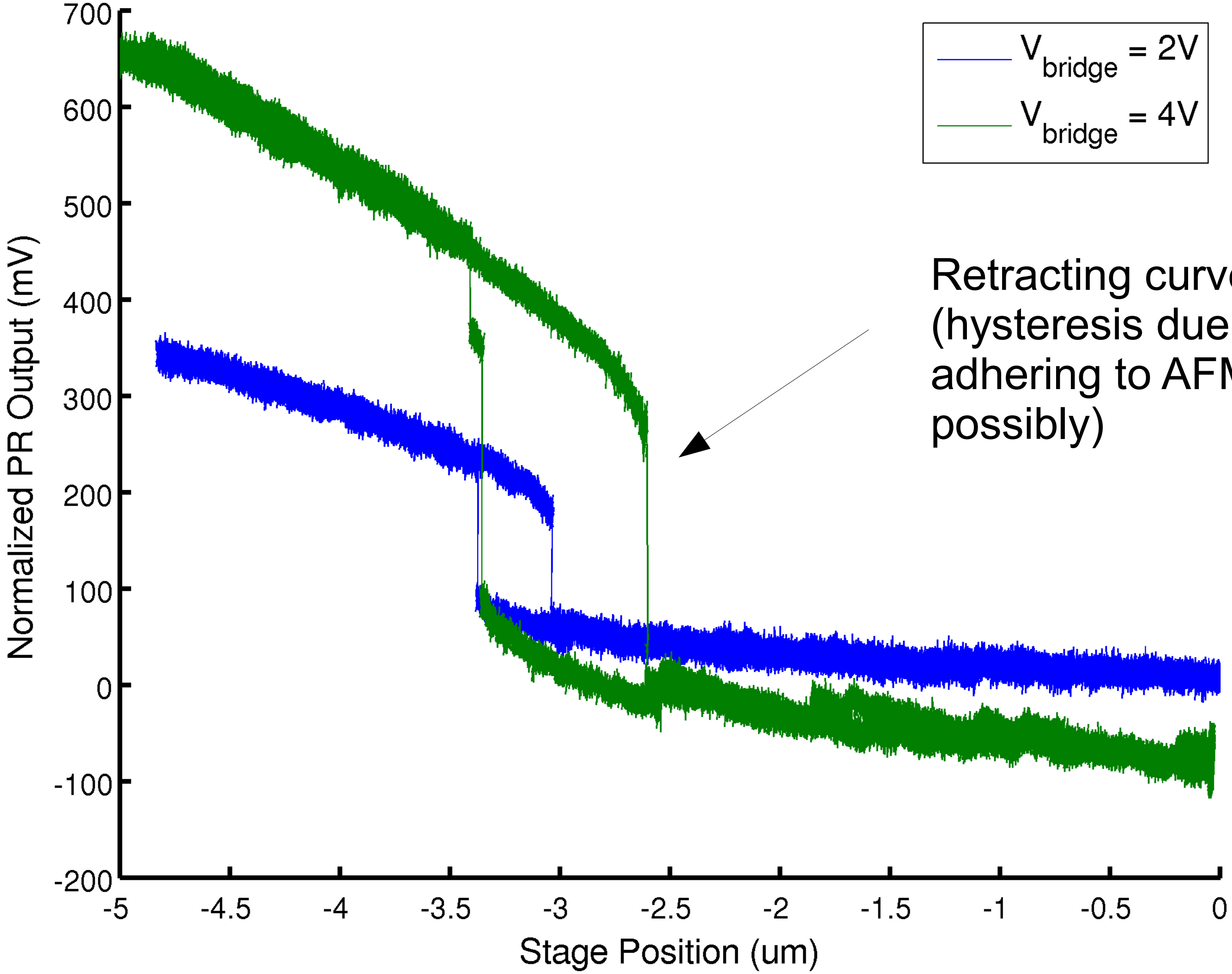
The PR output does not start to change immediately when the AFM cantilever touches the tip.

At first, all of the bending occurs out at the tip of the PR+PE device and not where the PR is located.

Eventually it reaches a threshold point, at which the device appears to controllably buckle (see images on next slide).

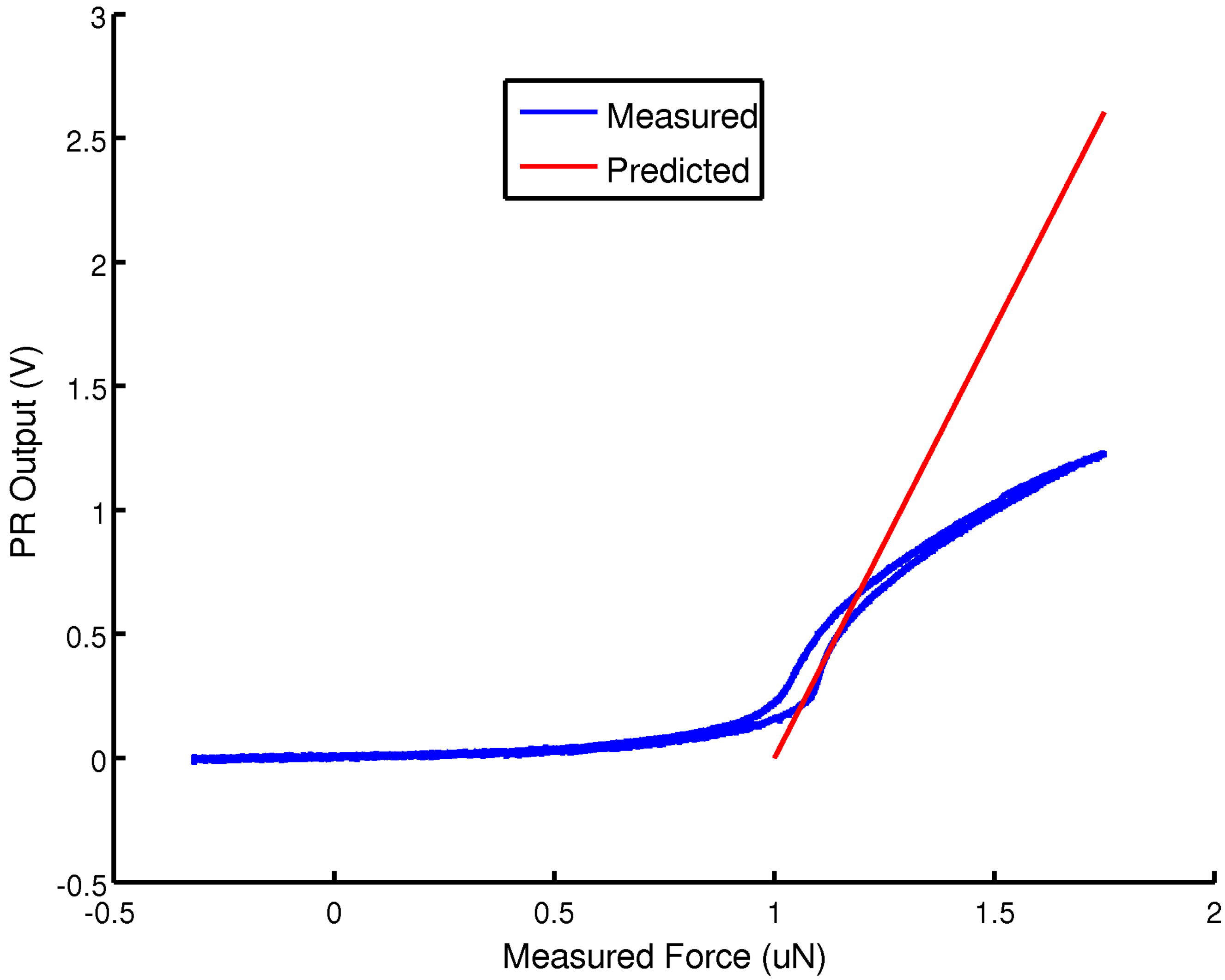
PR+PE Buckling

Device #13 – Design #3 (200um long)

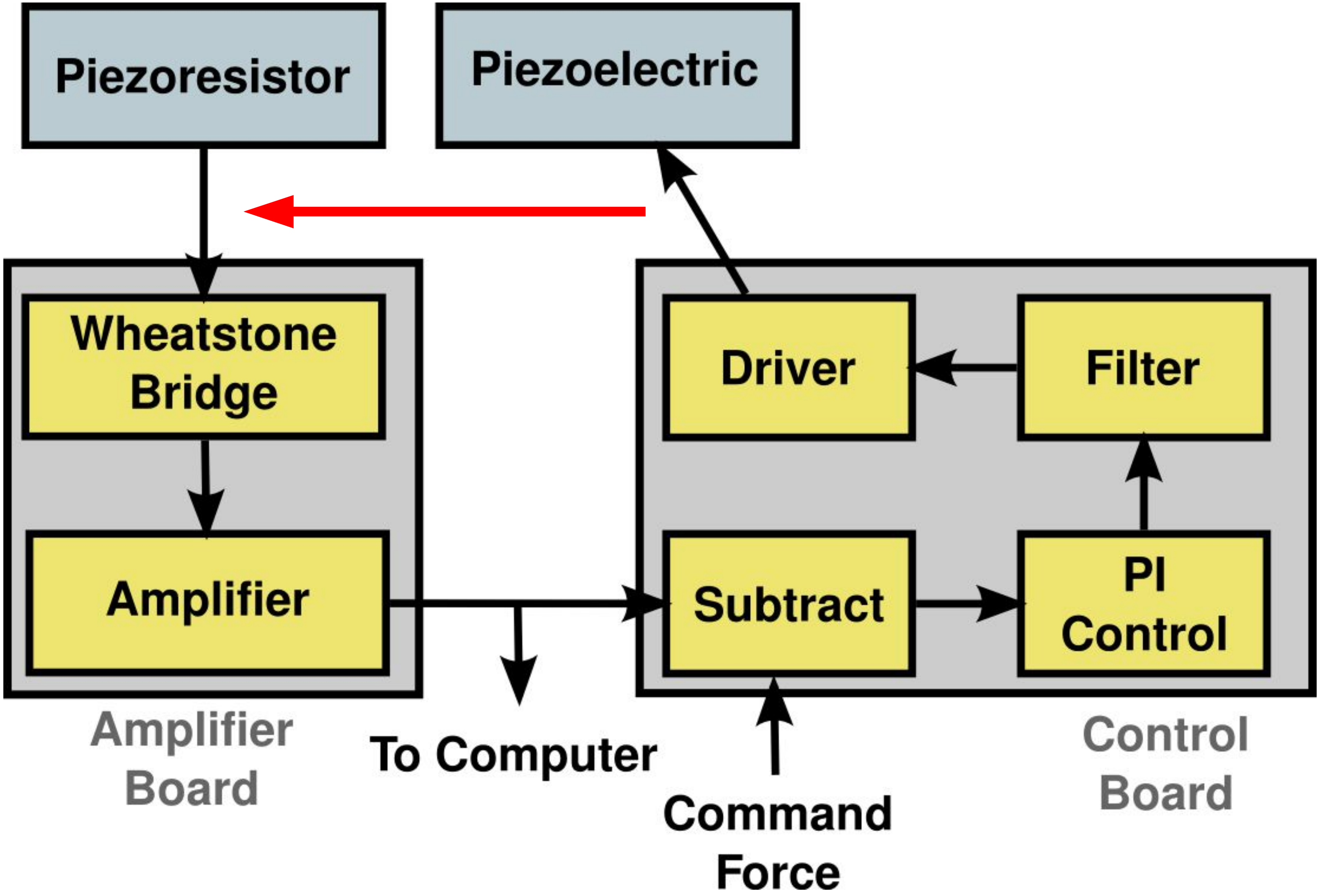


Retracting curve on right (hysteresis due to PR+PE device adhering to AFM cantilever possibly)

Predicted vs. Actual

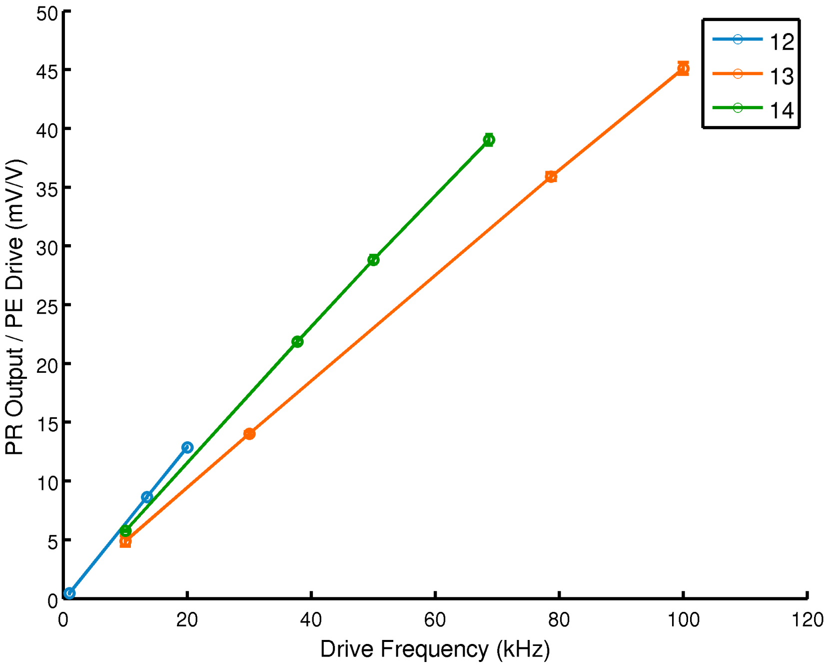


Cross-talk


Piezoresistor
Piezoelectric
Wheatstone Bridge
Amplifier
Driver
Filter
Subtract
PI Control
Amplifier Board
To Computer
Command Force
Control Board

Quick Cross-talk Summary

- Experimental data shown on the right
- Developed a small signal AC model. SPICE results matches within a few orders of magnitude.
- Solution: insert cross-talk signal to both sides of the Wheatstone bridge by putting all four resistors on the die



Conclusions

- PR devices
  - Work as expected
  - Working out bead attachment and functionalization in preparation for biotin-streptavidin force measurements
  - Minor issues: heating, curvature
- PRPE devices
  - Yield issues due to surface concentration reduction, about 30% usable
  - Non-linear voltage response is a show stopper, need new devices in order to be able to measure any forces
  - Cross-talk an issue for highest frequency measurements, will fix in next fab run

Next Steps

- Measure biotin-streptavidin disruption force
- Design v2 round of devices
- Fab in April