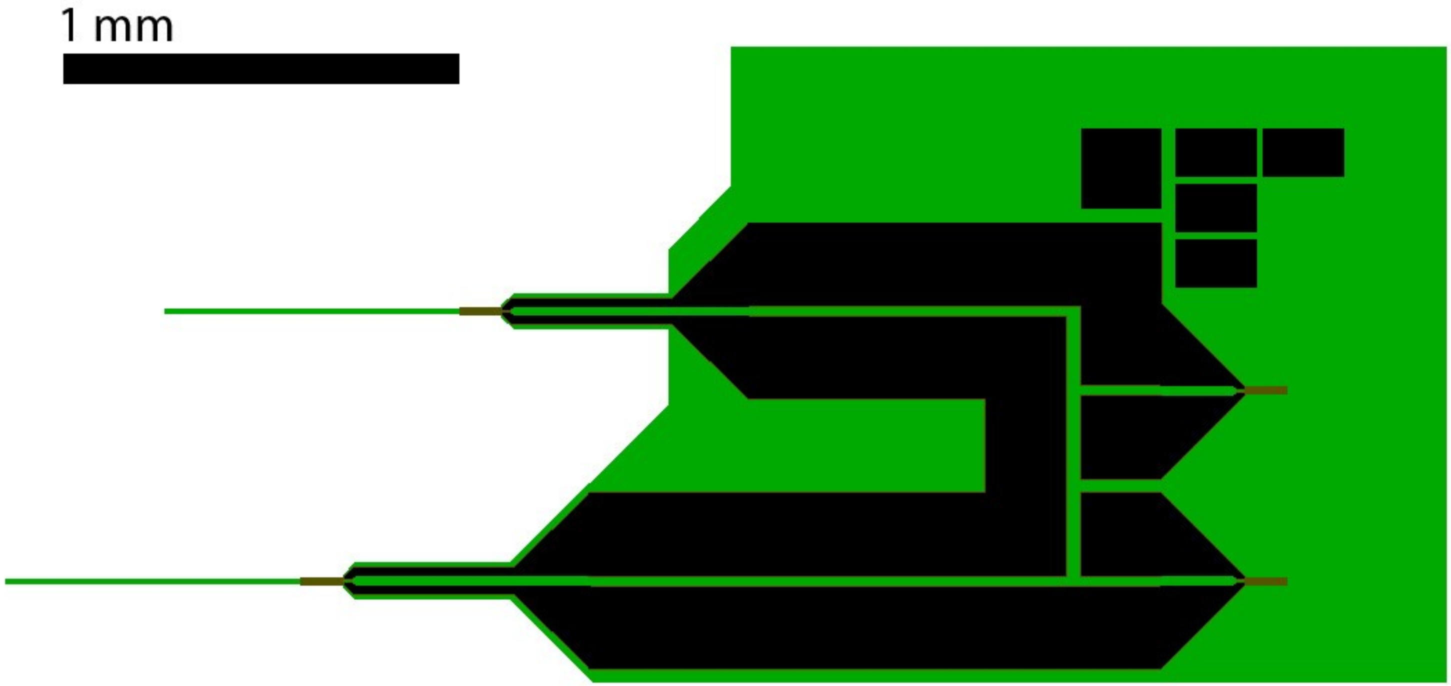



# Worm Club Update

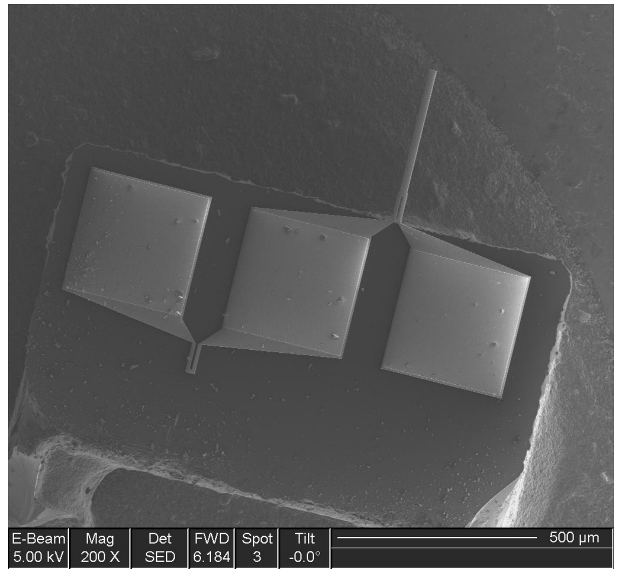
Joey Doll
3/29/10

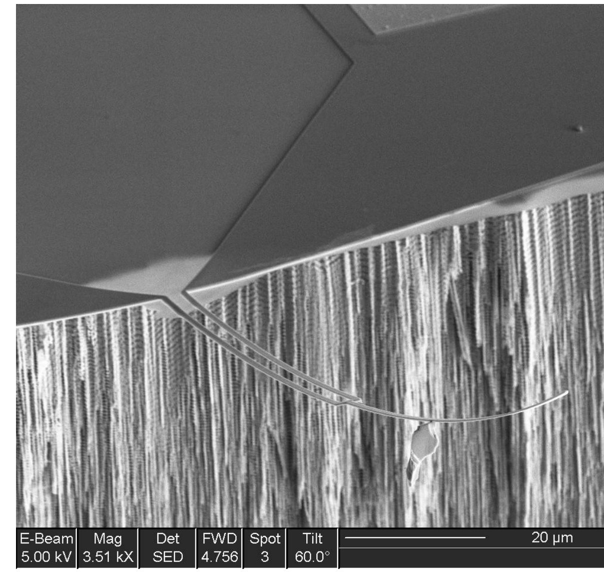
# The Plan

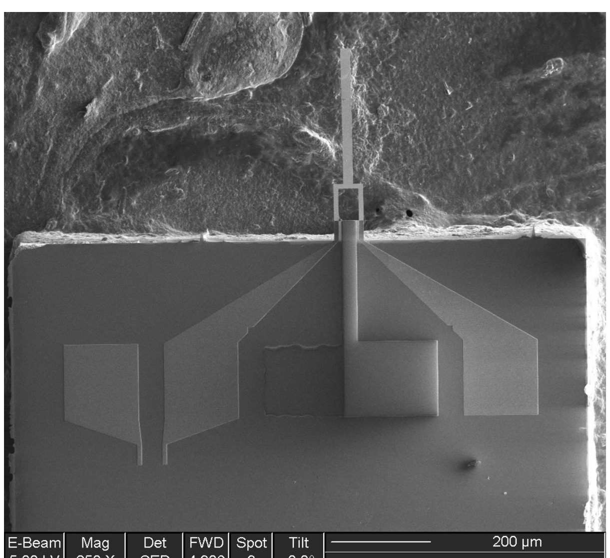
- Introduction
- Problems and solutions
  - Curvature induced stiffening
  - Accidental resistor etching
  - Actuator to sensor crosstalk
  - Experimental issues
- Current work
  - New die layout
  - Design specs
- What's next

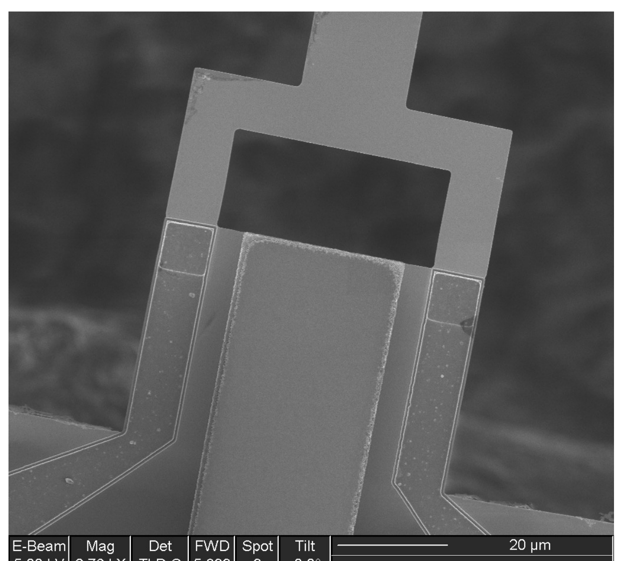
# The Devices

Piezoresistive force sensor (PR)



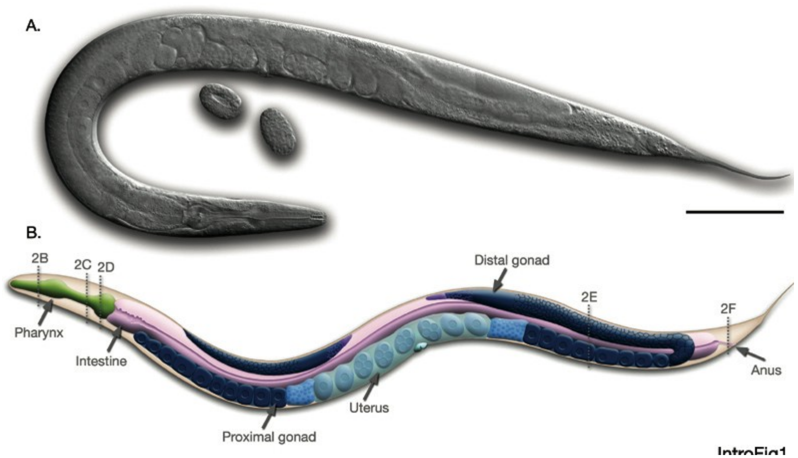



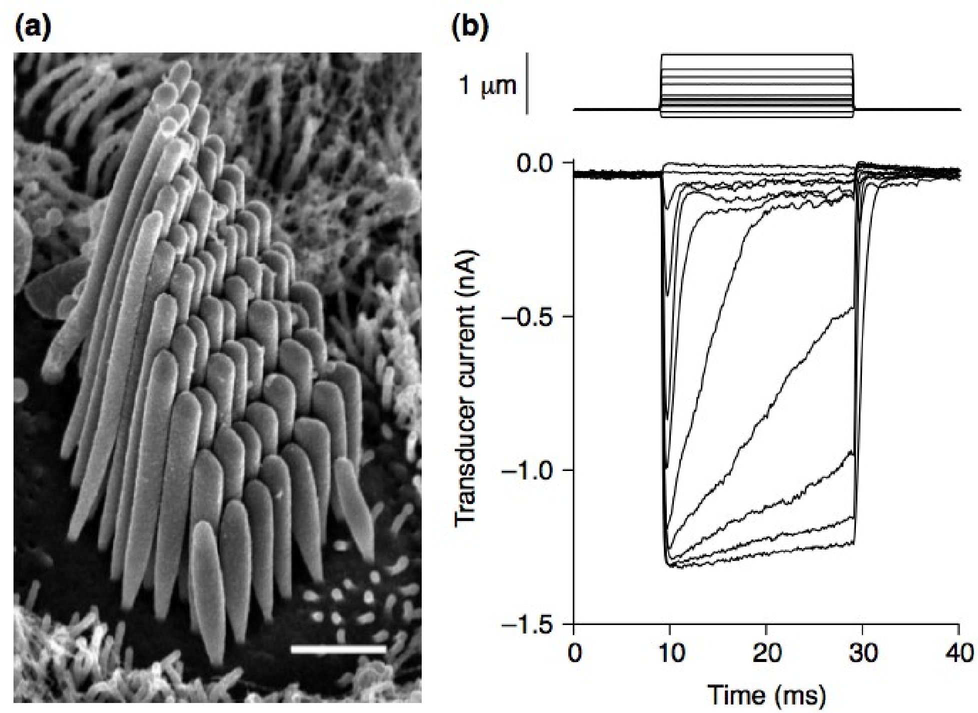




Piezoresistive force sensor with integrated piezoelectric actuation (PR+PE)

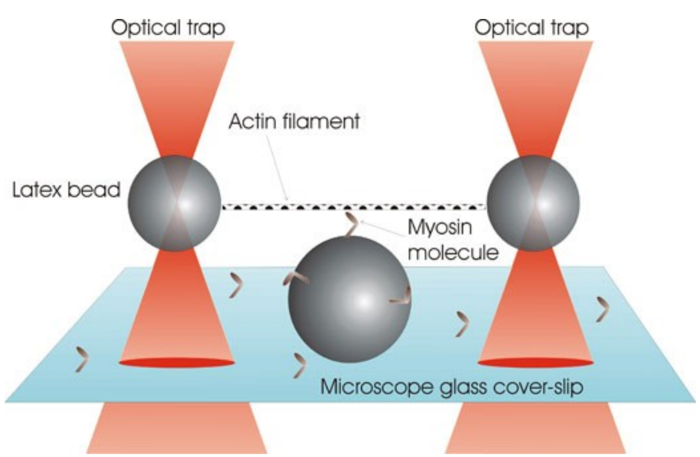
# Applications of a Faster Actuator and Sensor




Sense of touch (TRNs)




Sense of hearing (hair cells)



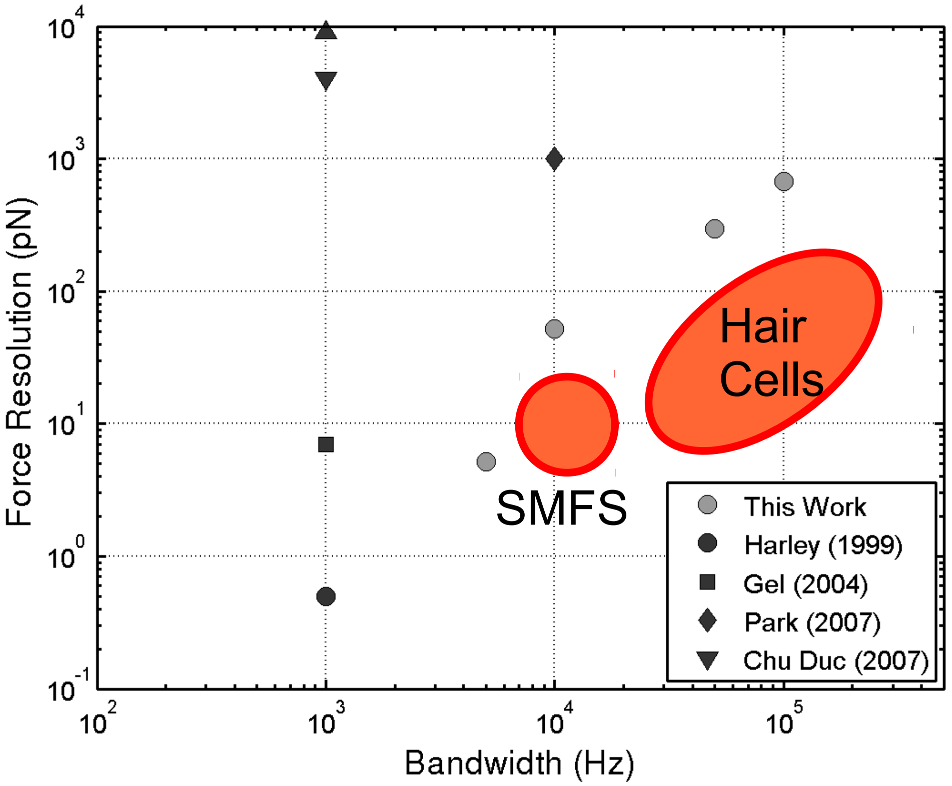

Single Molecule Force Spectroscopy



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

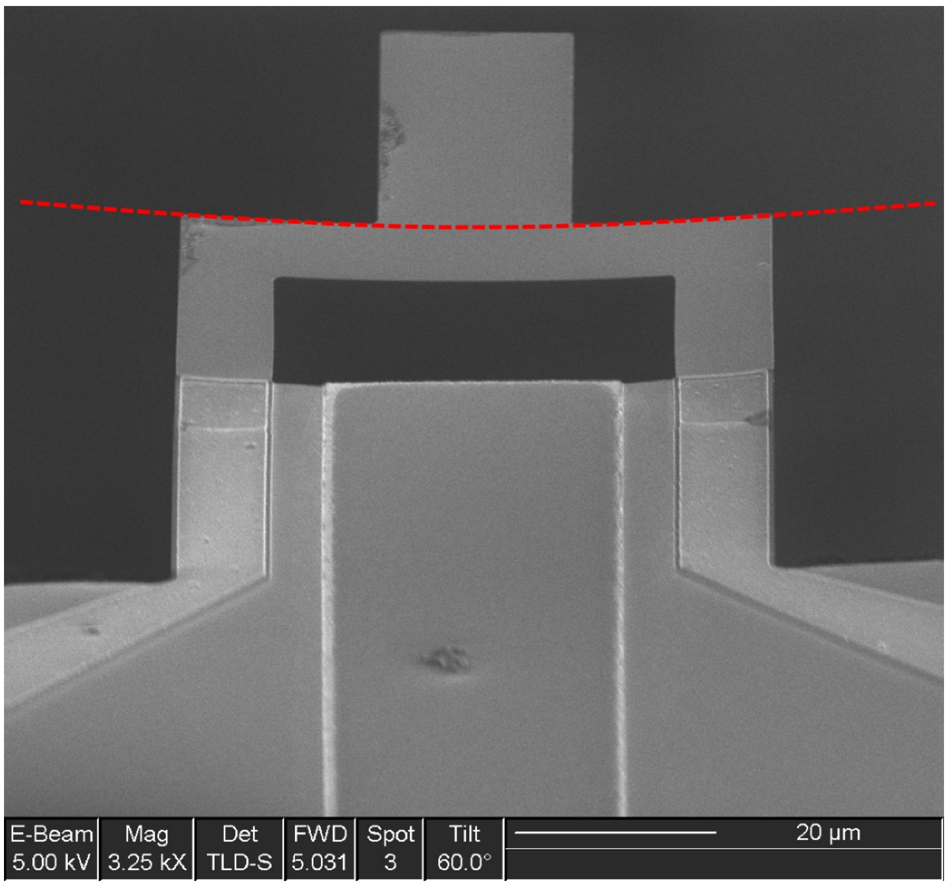
- Actuator
  - Rise time = 1-10 microseconds
  - Tip deflection < 1 micron
- Sensor
- Closed loop control
- Operation in fluid

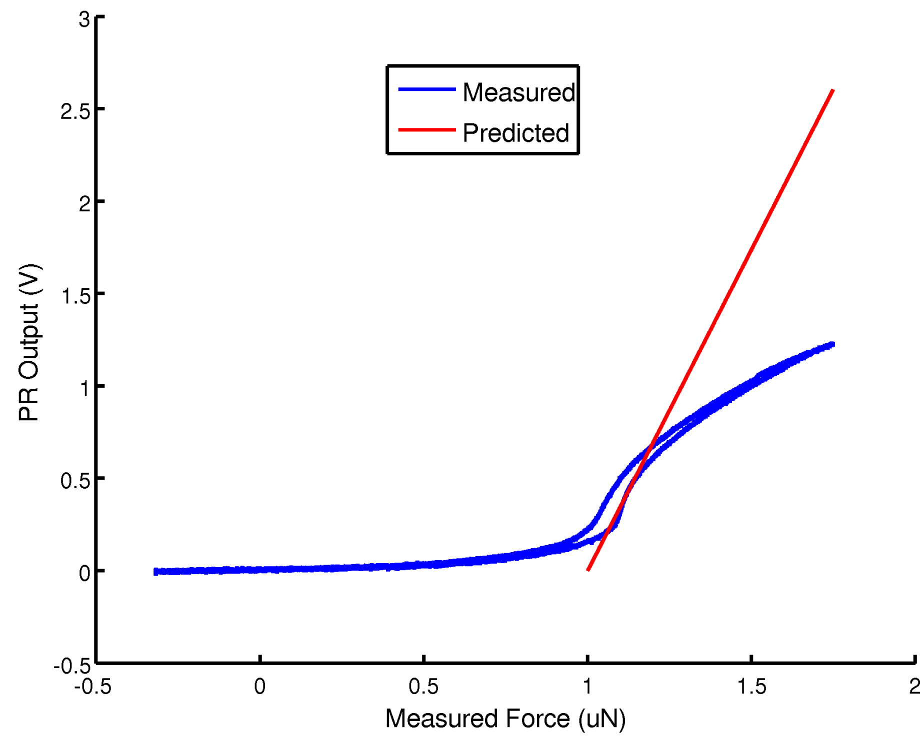


# Where Things Stand

- Made first generation PR and PR+PE devices
- Obtained lots of useful characterization data
- The fabrication process mostly works
- But some issues...
  - Force offsets
  - High resistances
  - Crosstalk
- Designing the next round of devices now

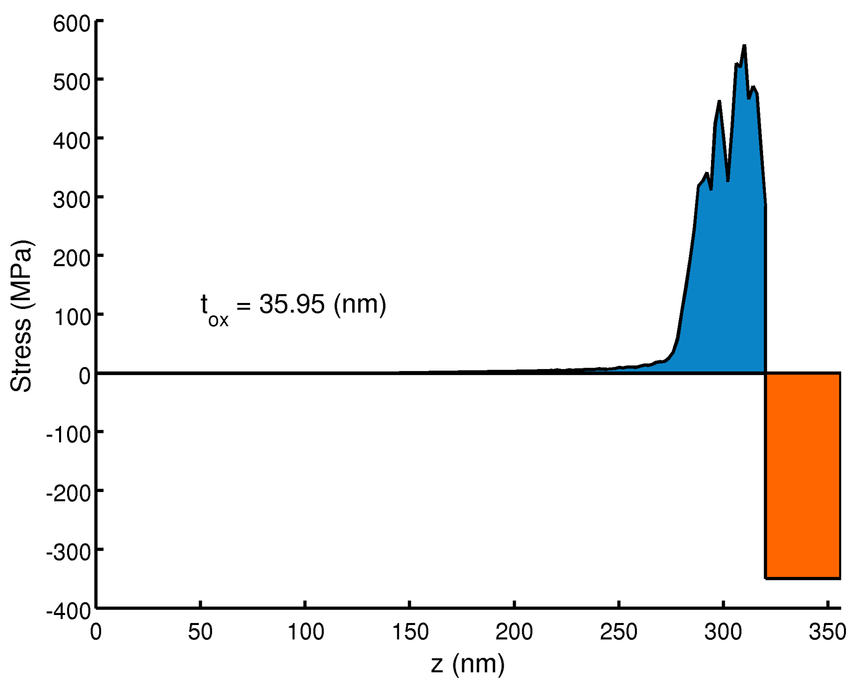
# Curvature Induced Stiffening

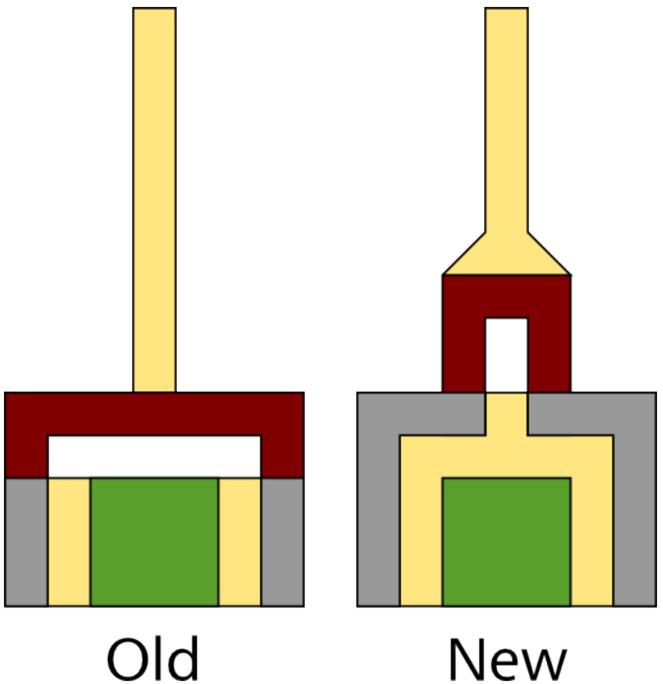



- A large force is required to overcome the "potato chip" effect and start bending the PR
- Due to surface stresses (probably dopants) and the way the cantilever is designed

# Solving the Stiffening Problem



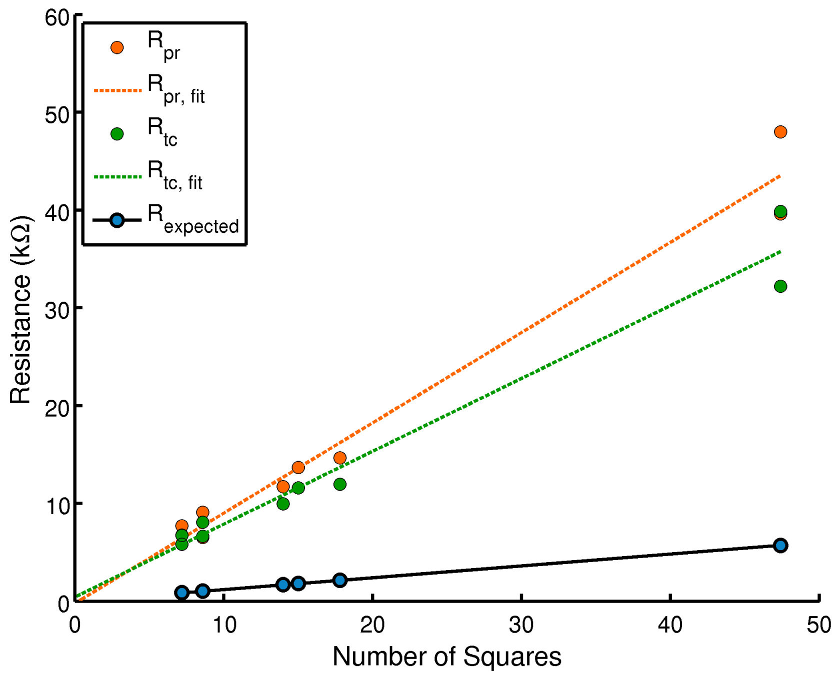

1) Add a stress compensation layer
 Blue = dopants (tensile)
 Orange = surface oxide (compressive)

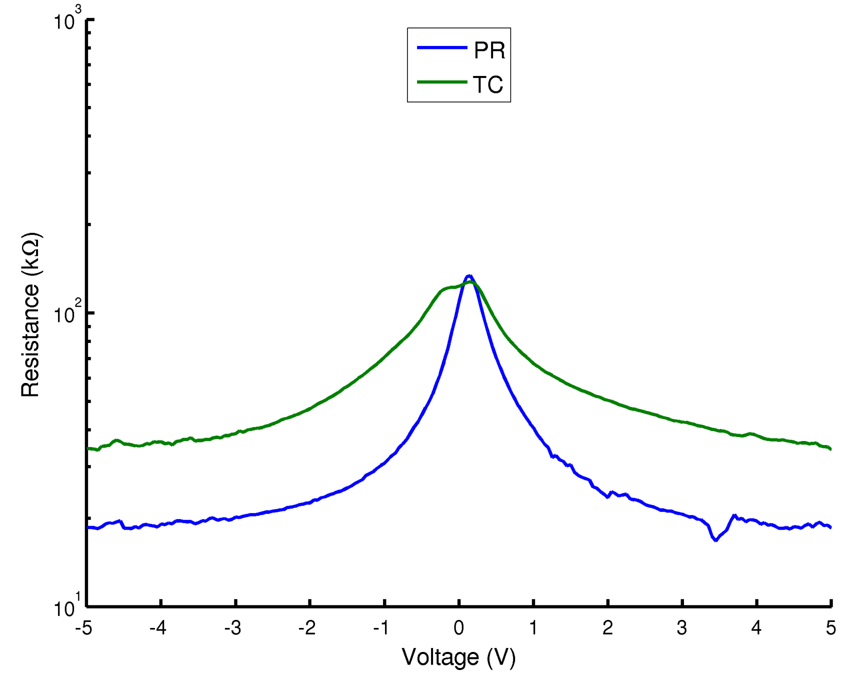
2) Modify the cantilever design to reduce stress sensitivity (eliminate long transverse sections)

3) Measure film stresses whenever possible and choose thicknesses accordingly

Dopant concentration stress model based upon experimental data and modeling

# Accidental Resistor Etching

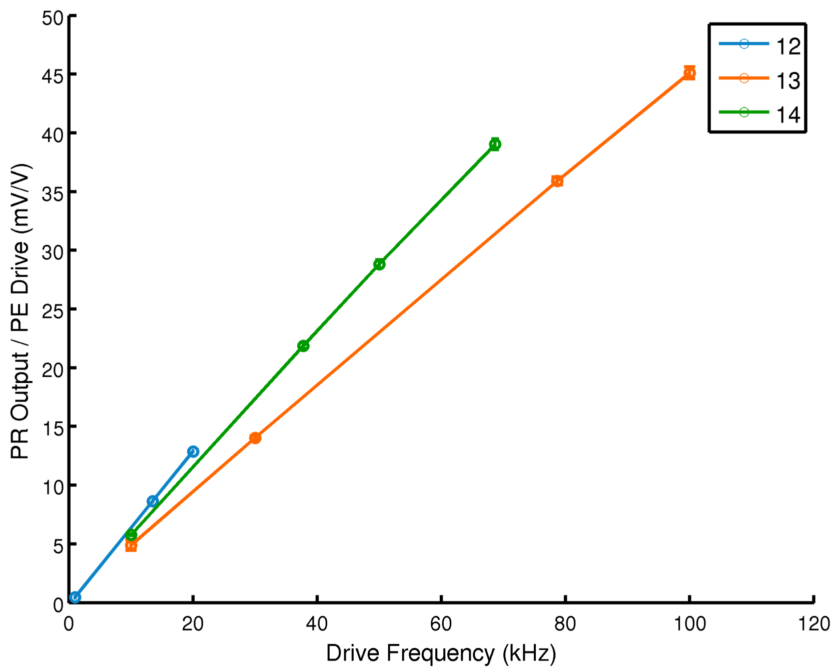


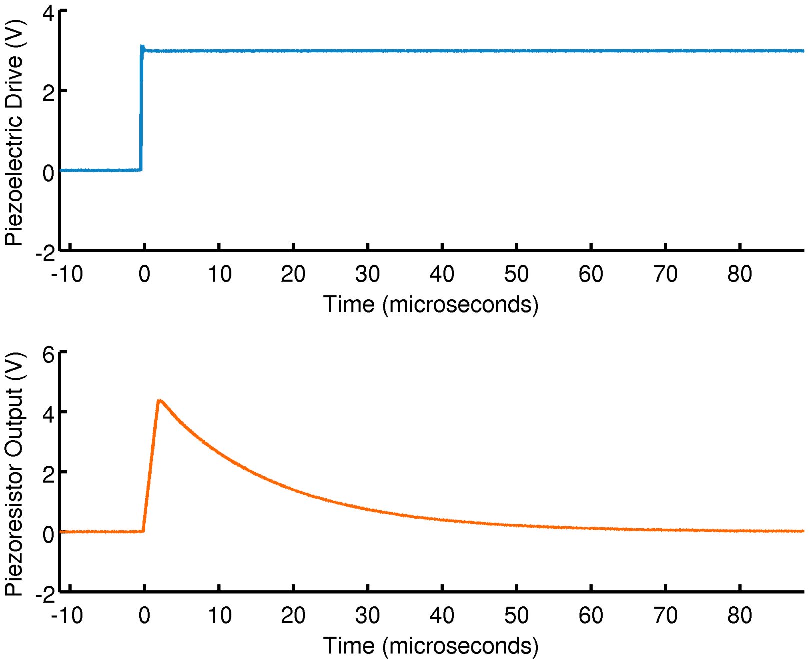




Problem: Resistances were about 10x higher than expected and depended heavily on voltage

Solution: Protect the piezoresistor during AlN deposition. Simple fab solution.

# Experimental Crosstalk Data



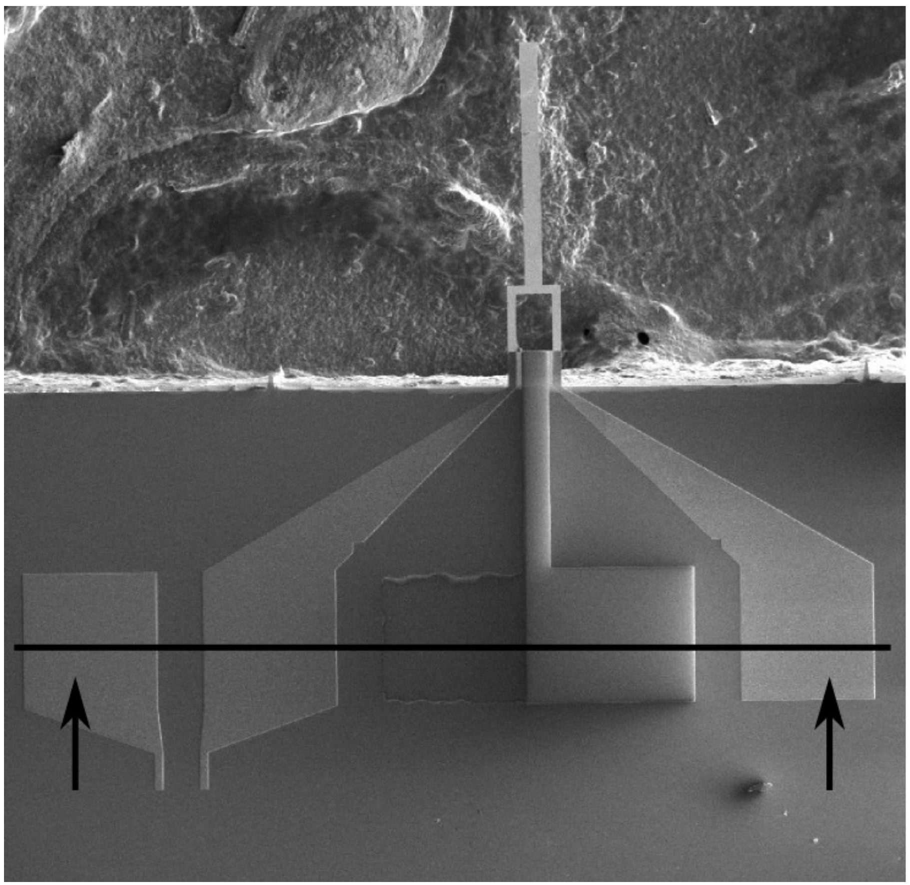

Crosstalk is important due to the signal magnitude difference:

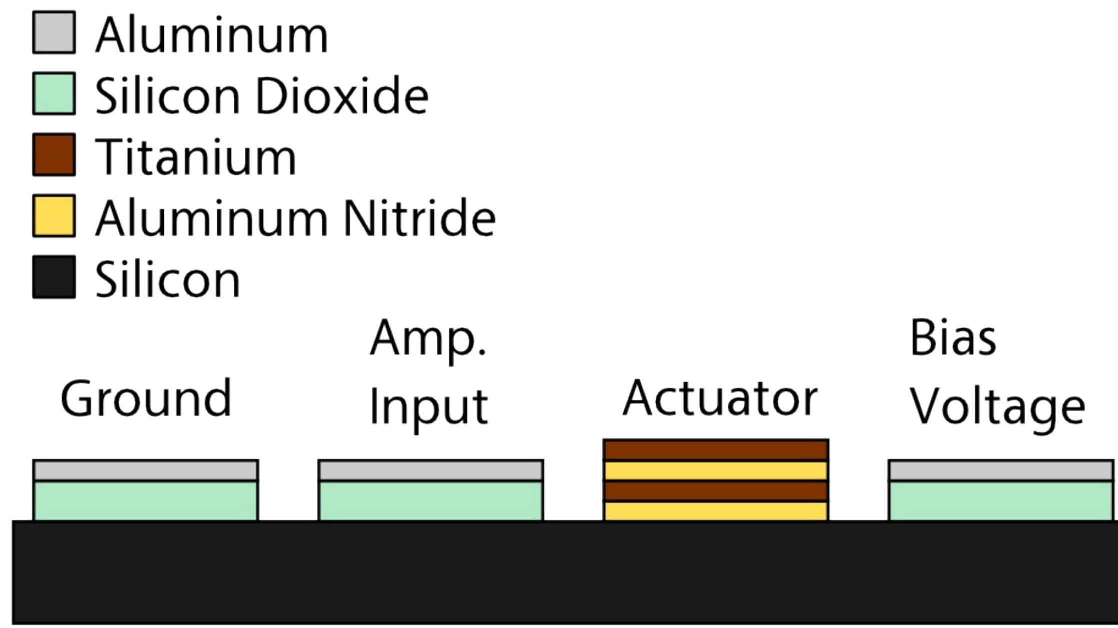
PR output = microvolts before amplification

PE drive = volts

Ideally want < 1 uV/V crosstalk at 100 kHz (40,000x improvement from current)

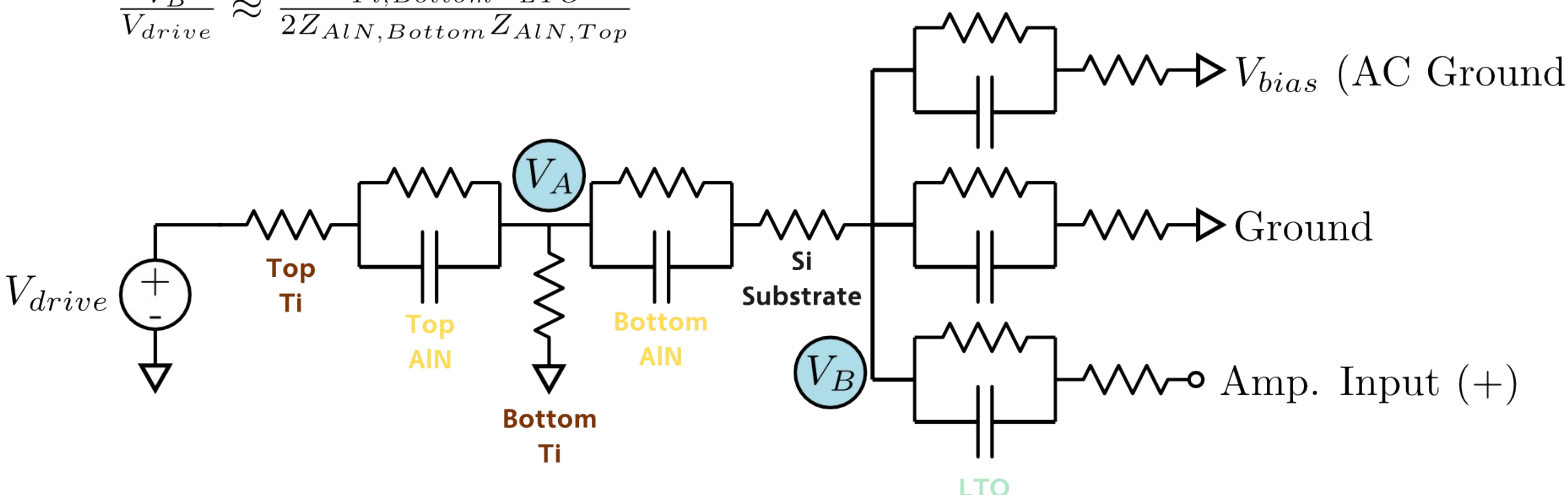
# Crosstalk Schematic





# Crosstalk Model

$$\frac{V_A}{V_{drive}} \approx \frac{Z_{Ti,Bottom}}{Z_{AlN,Top}}$$
$$\frac{V_B}{V_A} \approx \frac{Z_{LTO}}{2Z_{AlN,Bottom}}$$
$$\frac{V_B}{V_{drive}} \approx \frac{Z_{Ti,Bottom}Z_{LTO}}{2Z_{AlN,Bottom}Z_{AlN,Top}}$$



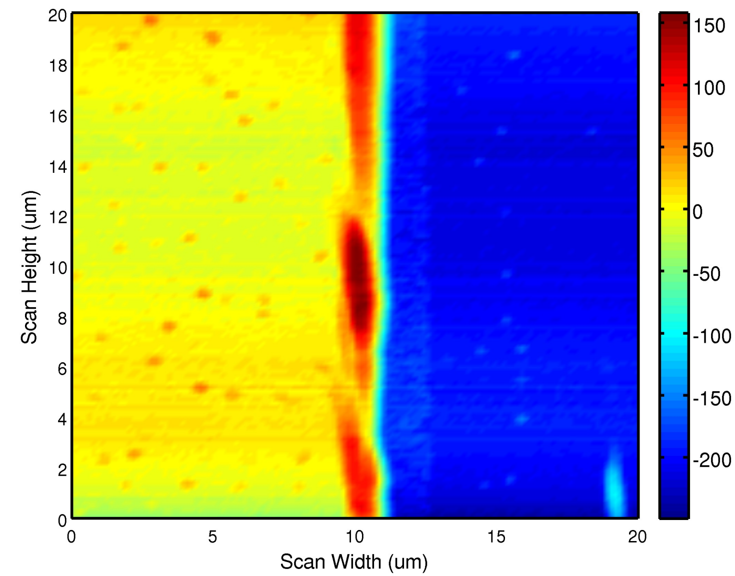

- Model predicts 3 mV/V @ 100 kHz (vs 40 mV/V measured)
- Close enough given the uncertainties involved

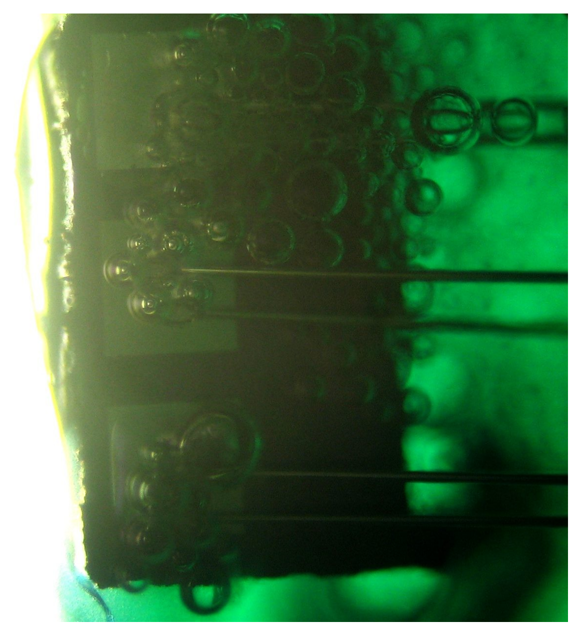
# Crosstalk Solutions

- Substrate ground
  - Removes the LTO from the equation on the last slide → 30,000x improvement
  - Will probably use a p-n junction too for further improvement
- Symmetric device and circuit layout
  - Right now the crosstalk only goes into one input of the instrumentation amplifier
  - Utilize common mode rejection of amplifier to attenuate anything that gets around the isolation well
- >40,000x reduction seems reasonable
  - At least -80 dB from substrate ground
  - -100 dB from CMRR (with perfect device layout)

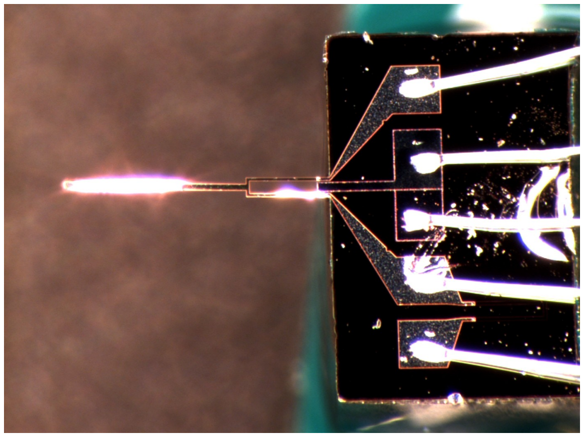
# Some Experimental Issues

- Parylene coating
  - Thin (< 200 nm) coating needed to passivate but not affect mechanics, fixed
- Bead adhesion to parylene
  - Fixed, was just an issue of using the right epoxy + curing
- Wirebond passivation
  - The new, thin parylene doesn't cover the bondpad wires perfectly, will start encasing in epoxy
- Vibrations
  - ~ 100 nm vibrations on current setup
  - Moving to our AFM, want < 1 nm vibration
- Big beads on little cantilevers
  - Need to include bead mass in design optimization



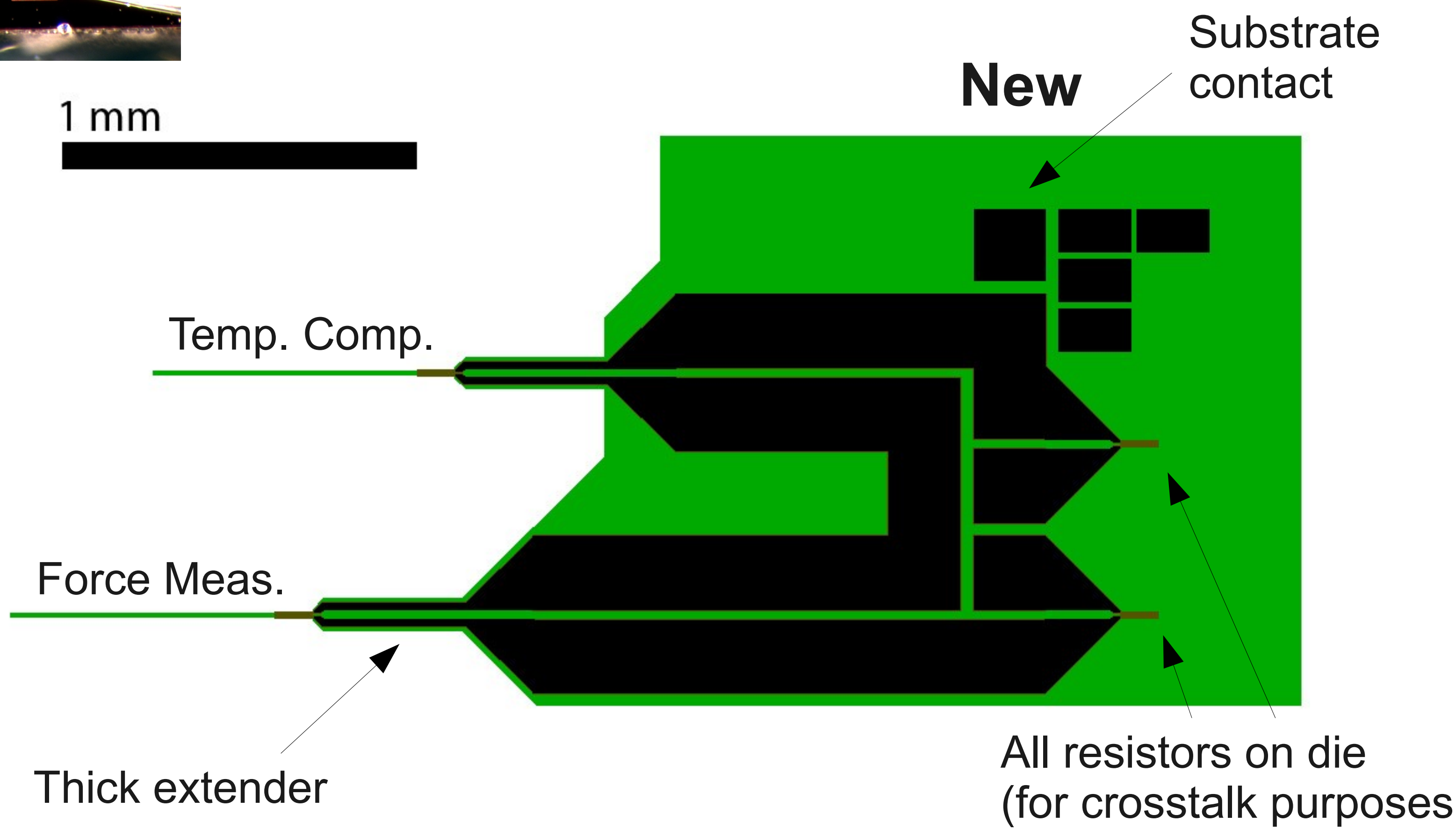
# New Device Layout



**Old**

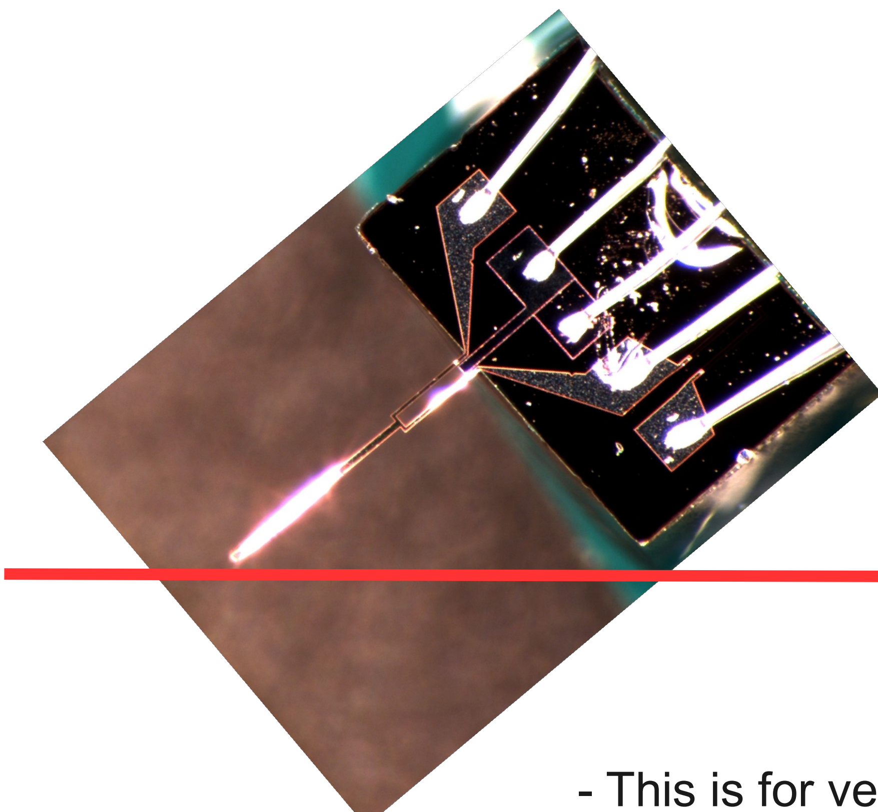
1 mm

**New**

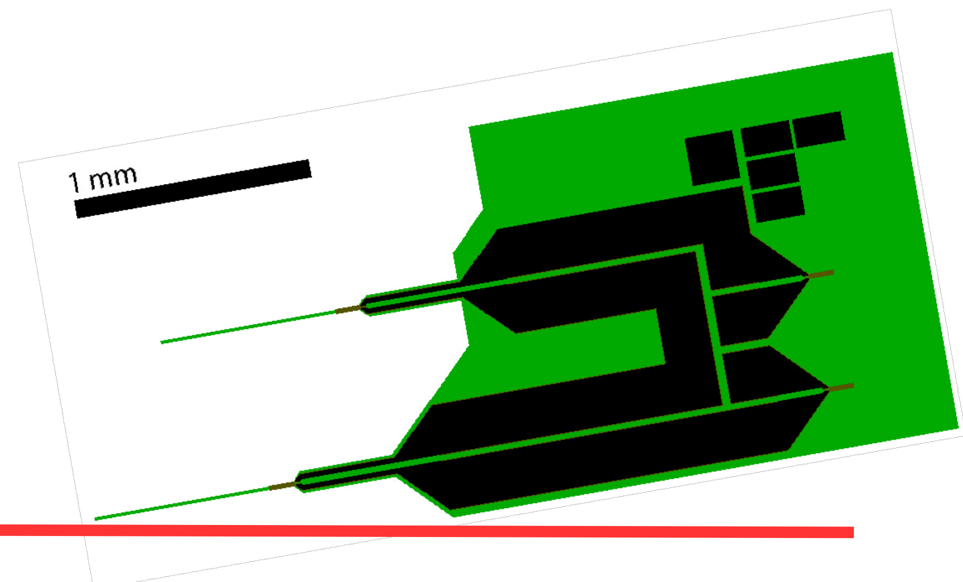


# New Device Layout

**40 degrees**



**10 degrees**




- This is for very, very long cantilevers (800 um)
- The difference is much larger for short (high freq) levers

# The Next Designs

- Combining the PE and PR optimization code is trickier than I thought – no designs ready yet
- General improvements
  - Shift cantilever to one side
  - Make it easy to use at an angle
  - Add die labeling
  - Define cantilever from the frontside
  - Skinnier PCB tip

# Double-Checking the Specs

- Mammalian hair cells
  - 1 microsecond rise time → 300 kHz resonant frequency
    - Current = 10 microseconds (30 kHz)
  - 50 pN force resolution (plausible but hard @ 300 kHz)
  - Max deflection > 1 micron
  - Inner: 7-10 micron diameter bead
  - Outer: 3-5 micron diameter bead
- Turtle hair cells
  - Stiffness = 2-10 mN/m
  - 2-5 micron diameter bead
- General
  - Soft probes (mechanics) → ~1 mN/m
  - Stiff probes (kinetics) → much stiffer than the soft

# What's Next

- Finish characterizing PR devices and finalize models
- Modify AFM for PR measurements and perform demo streptavidin-biotin experiments
- Extend optimization code to PR+PE designs
- Generate + review final designs w/ interested people
- Fab run

Thank You