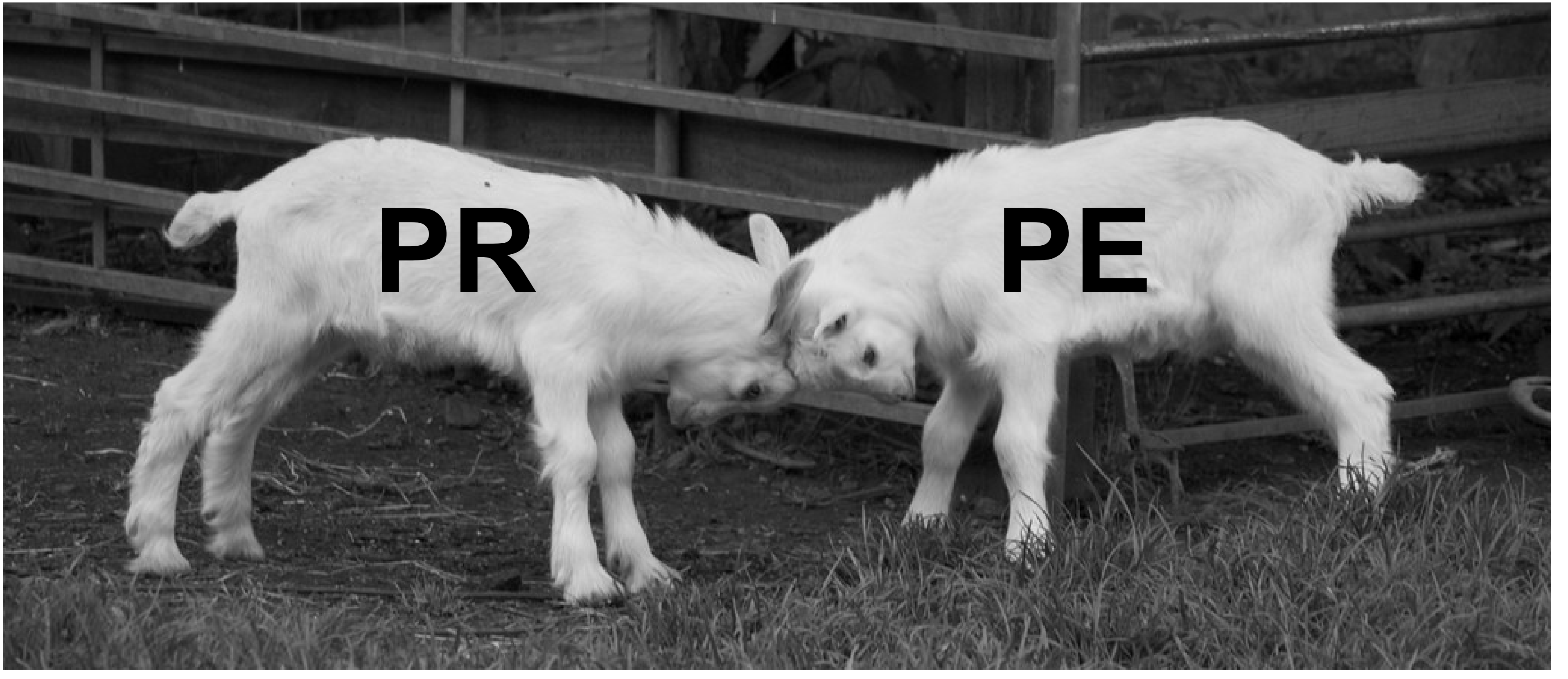
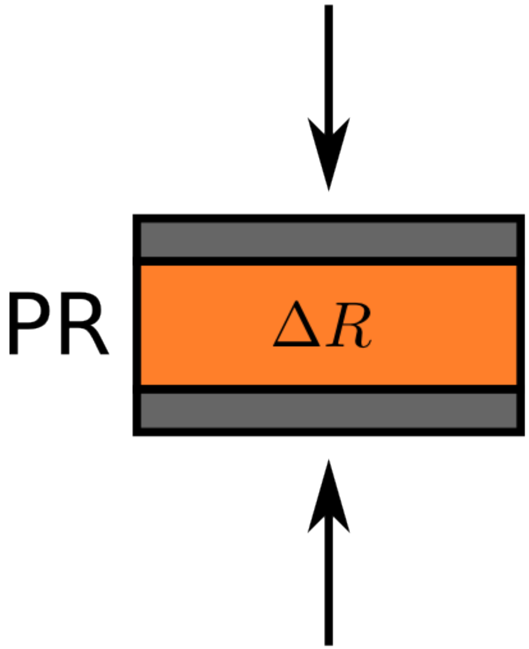


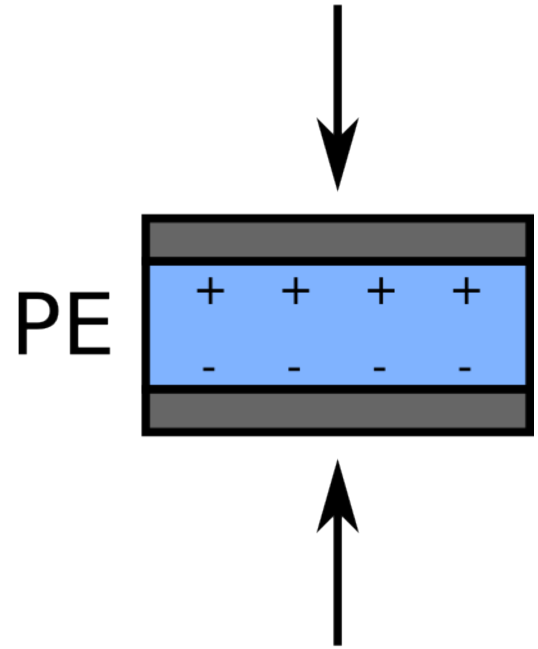
and Cantilever Thermal Design

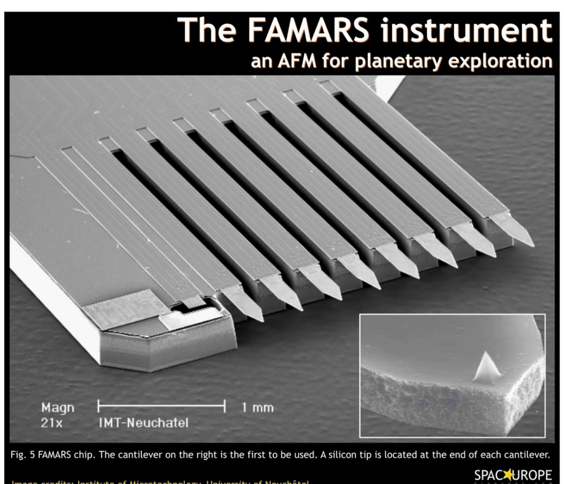
Joey Doll
4/30/2010

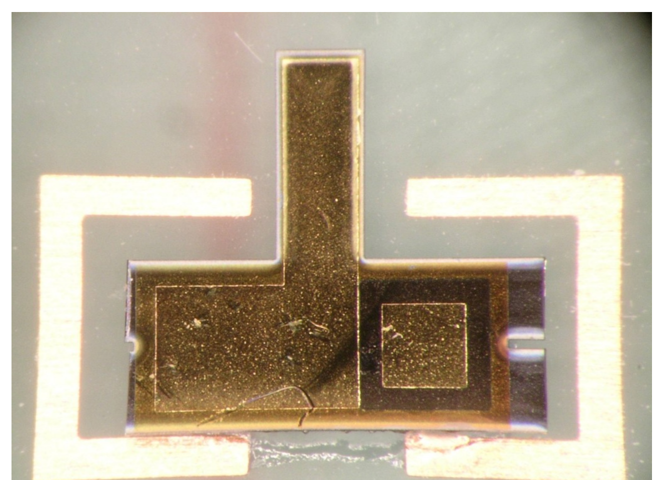
photo source: http://www.flickr.com/photos/pldms/2468668179/

Piezoresistive (PR) vs. Piezoelectric (PE) Sensing



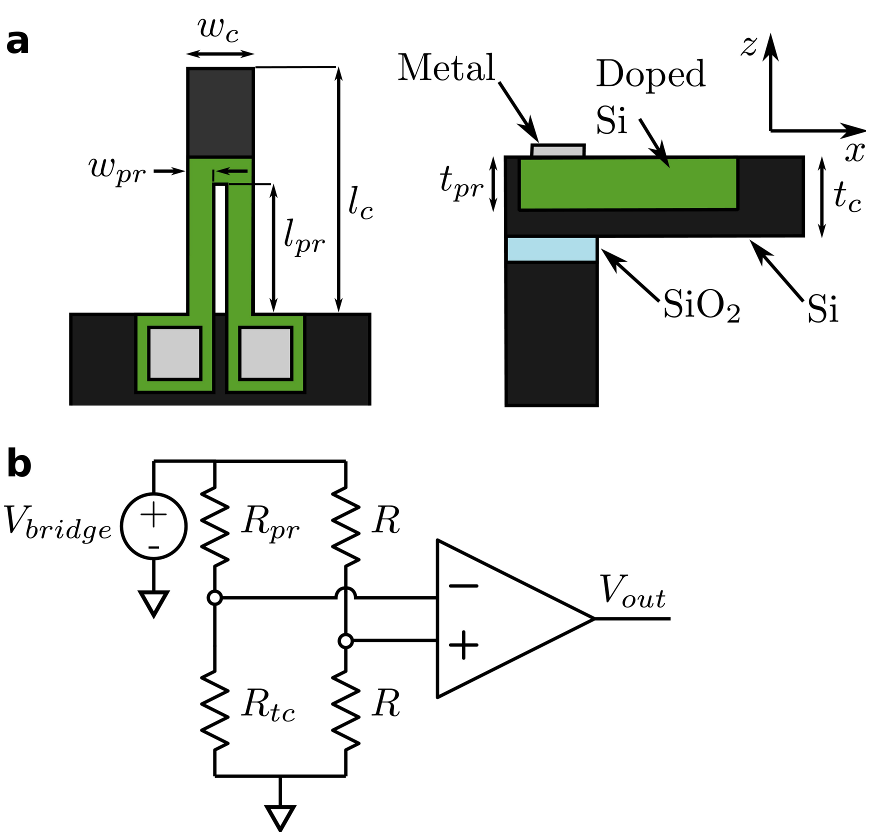


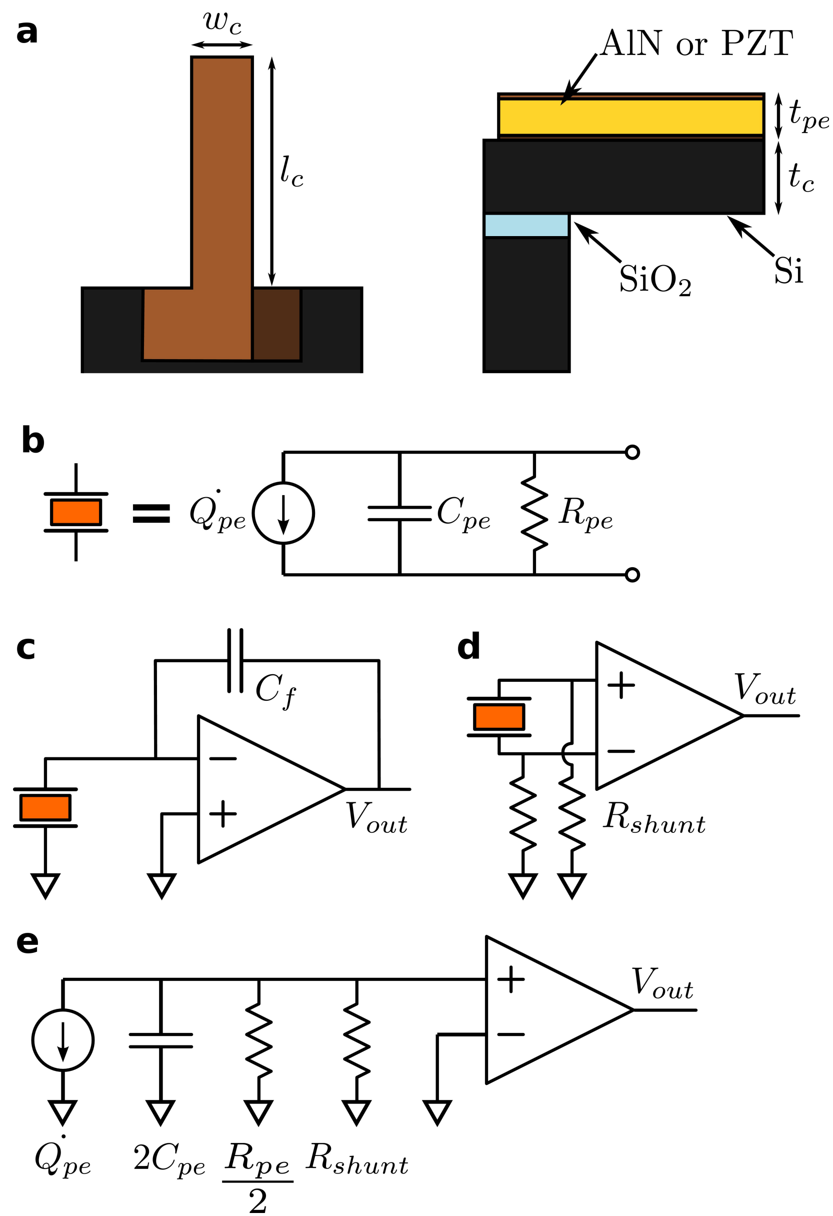




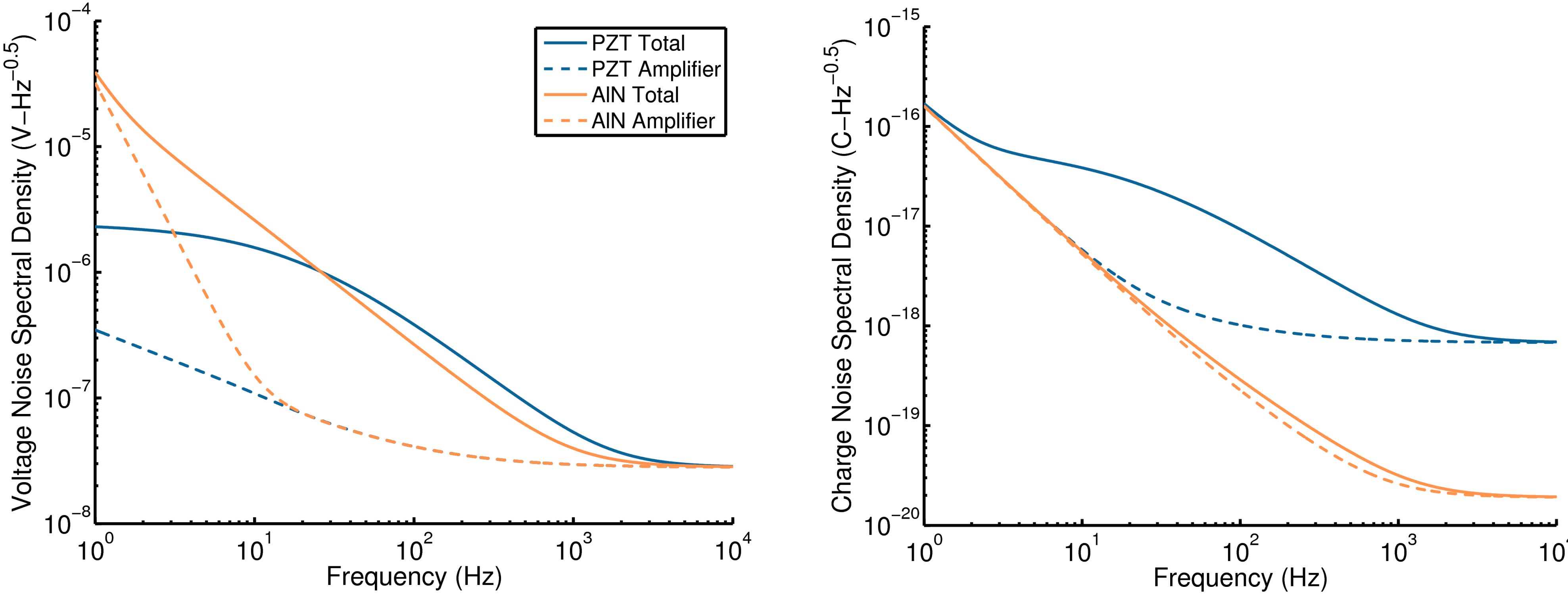
Examples from Univ. Neuchatel – Mars Phoenix Lander AFM and epitaxial PZT cantilever

Comparing PR and PE Sensing



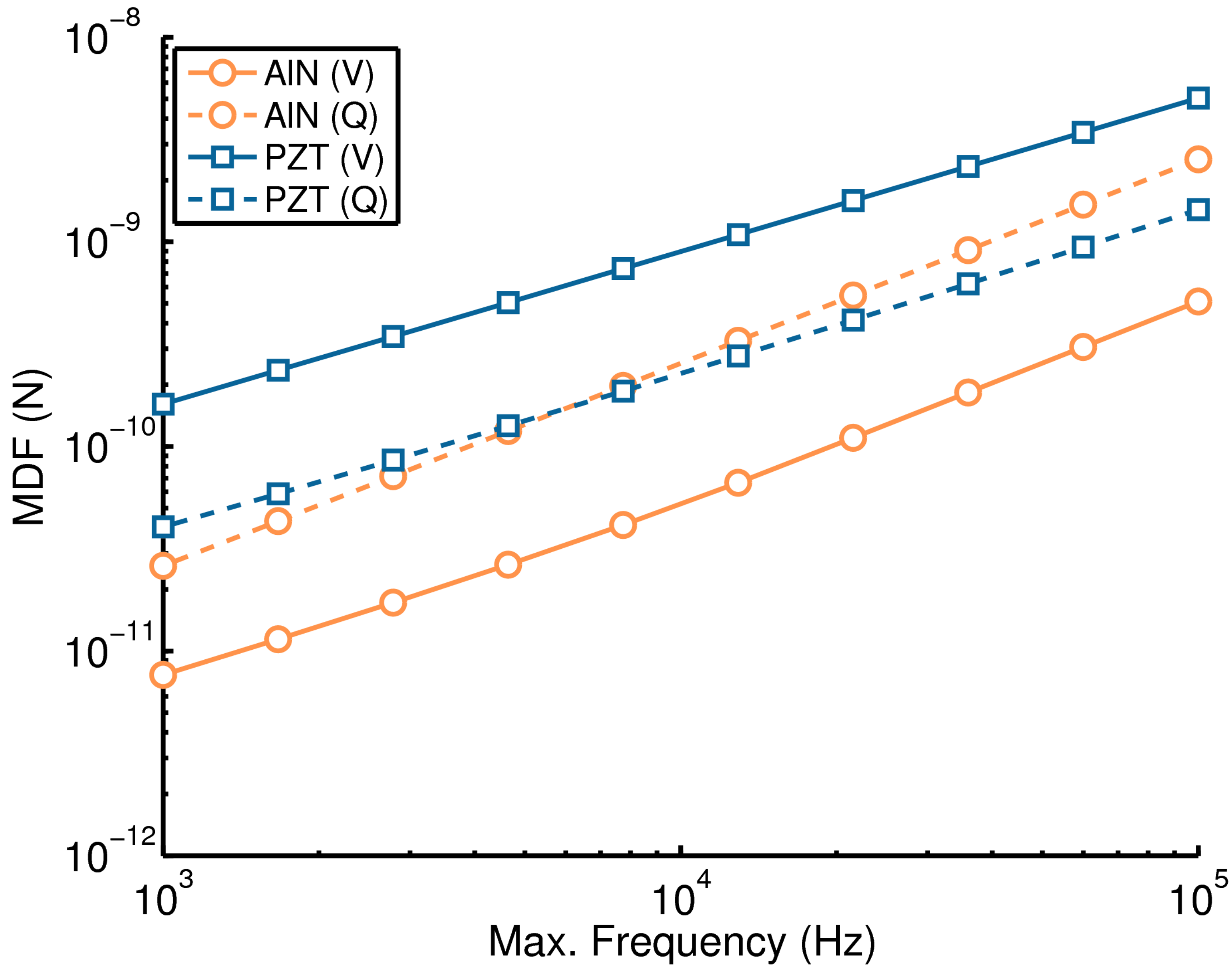


PE Noise

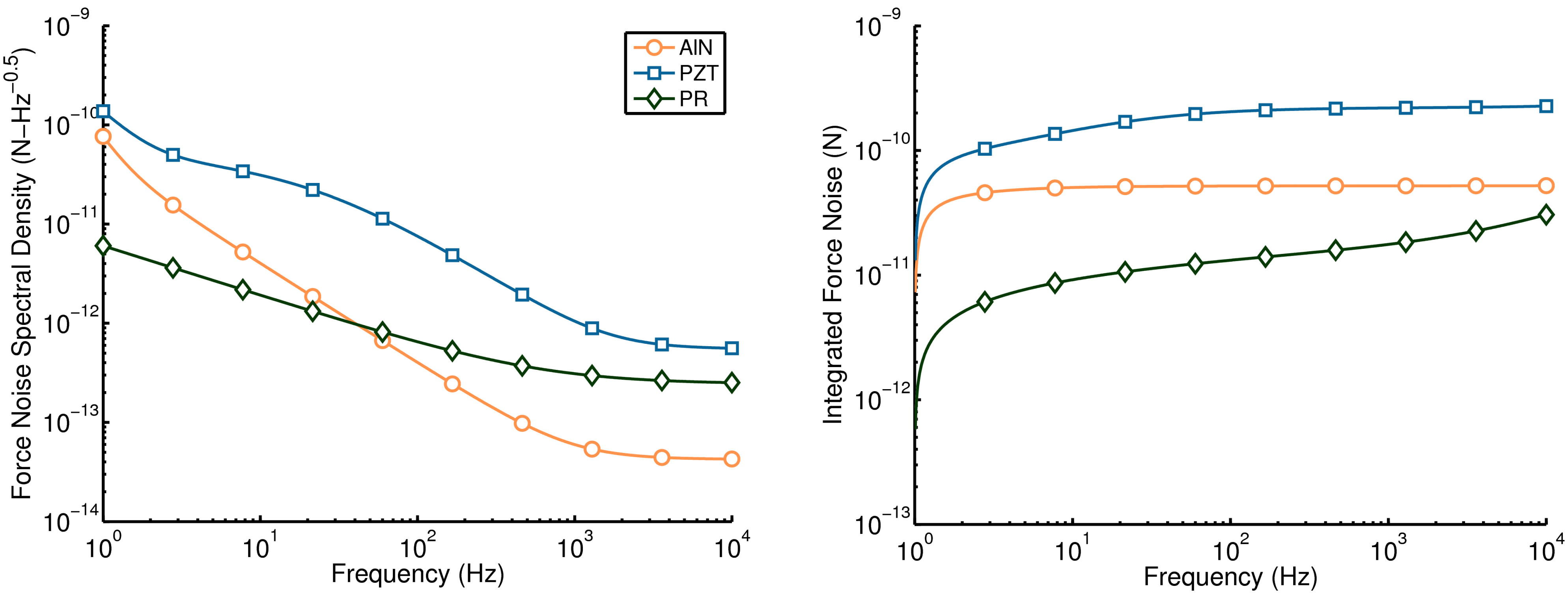


PZT Total
PZT Amplifier
AIN Total
AIN Amplifier
Voltage Noise Spectral Density (V−Hz$^{-0.5}$)
Charge Noise Spectral Density (C−Hz$^{-0.5}$)
Frequency (Hz)
Frequency (Hz)

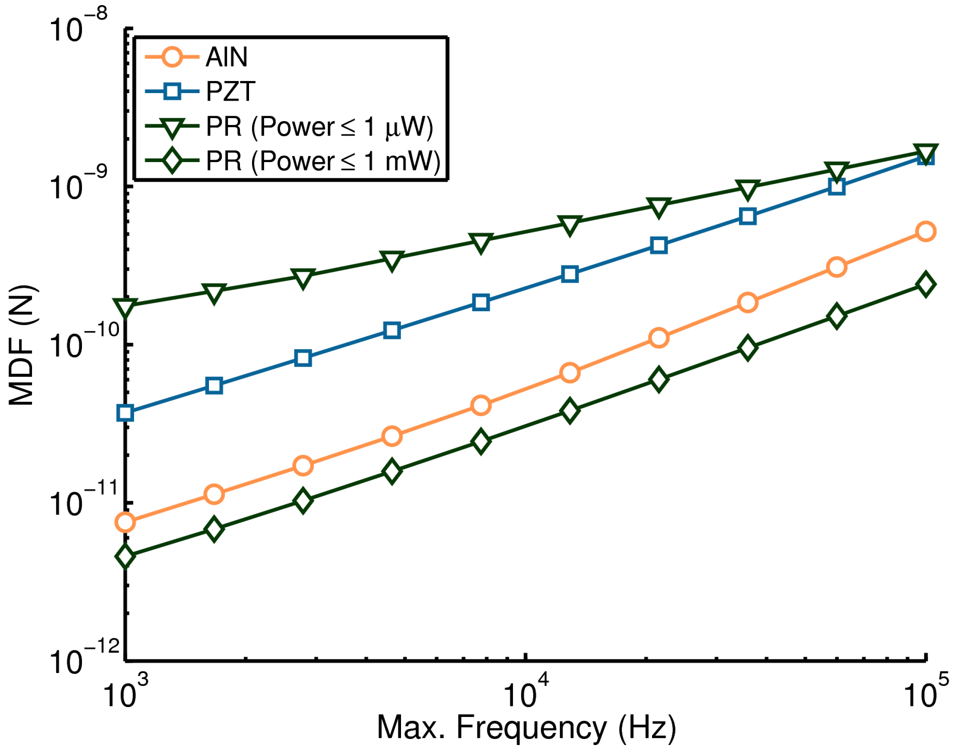
Comparison of PE Sensing Modes

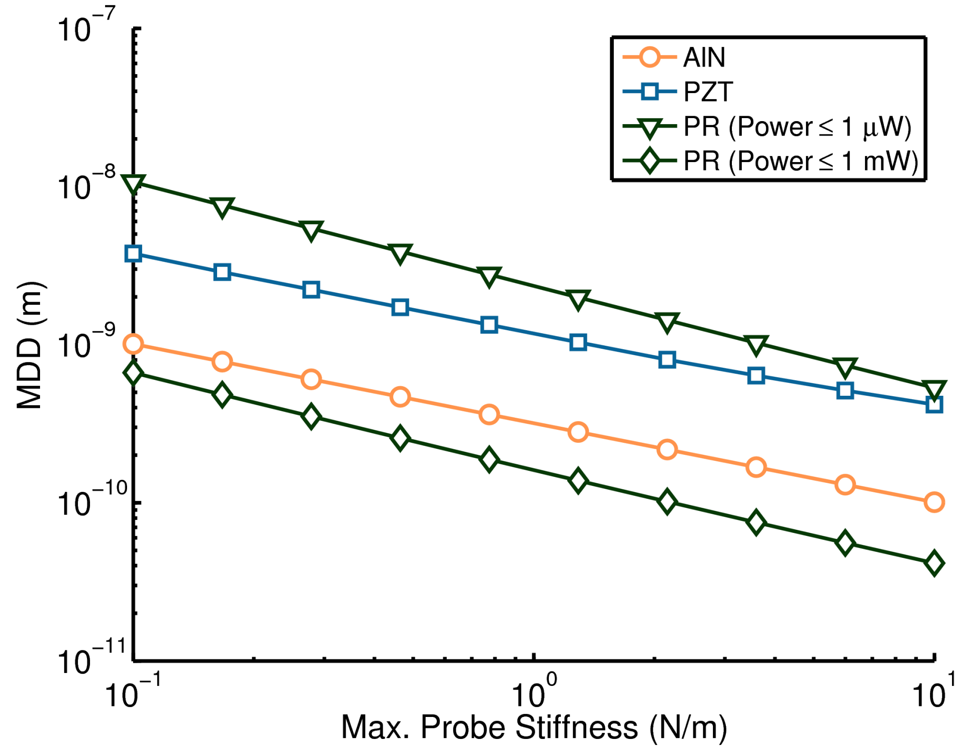


Detailed PR vs. PE Comparison

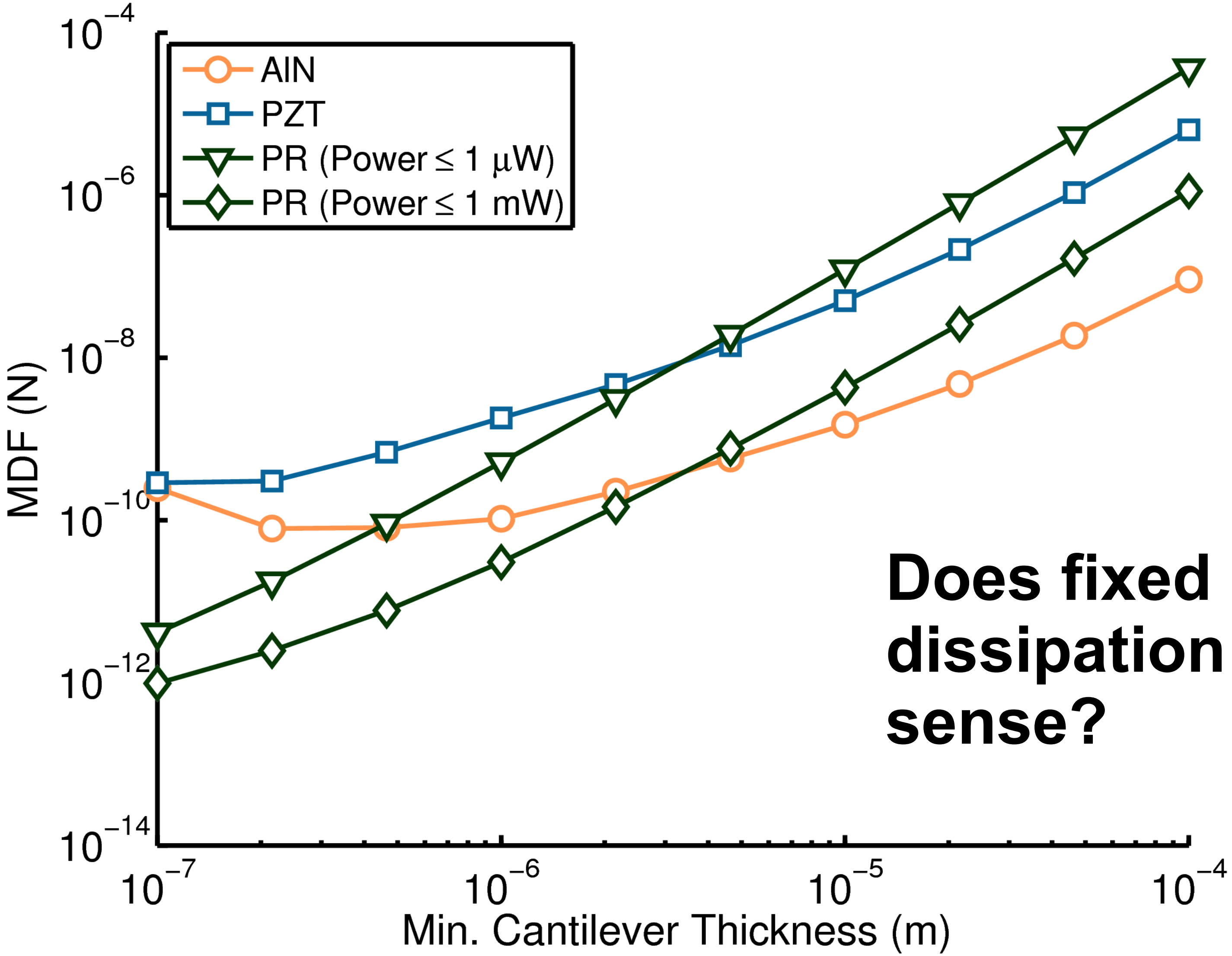


Force and Displacement Sensing



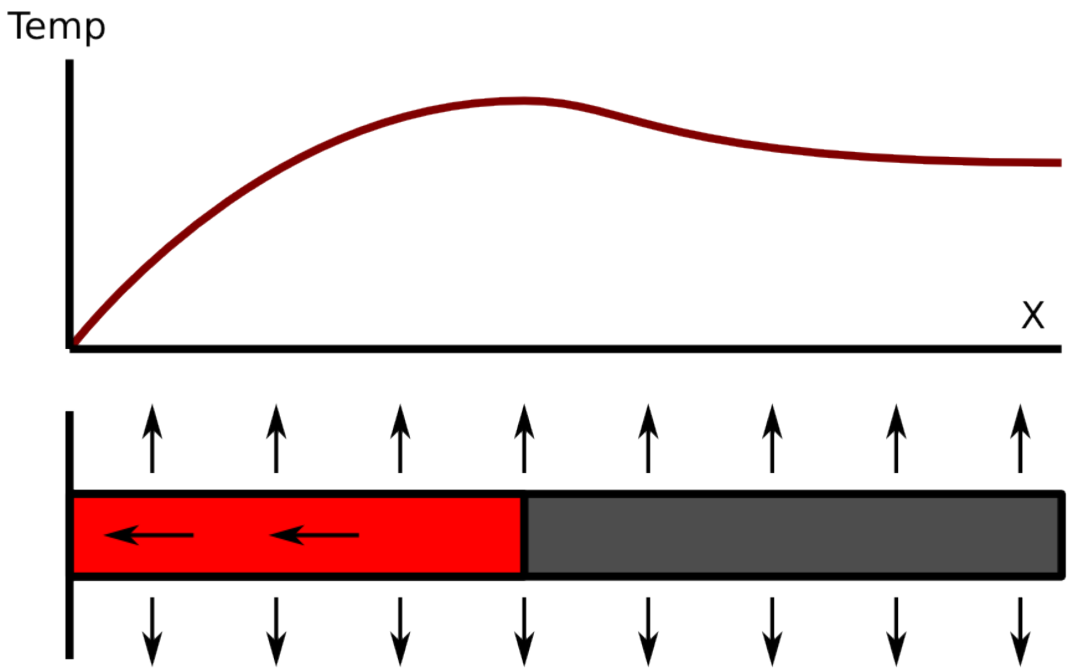


Thickness and Power



Does fixed power dissipation make sense?

Thermal Issues with Cantilever Design



B.C. Fixed Temp — Adiabatic

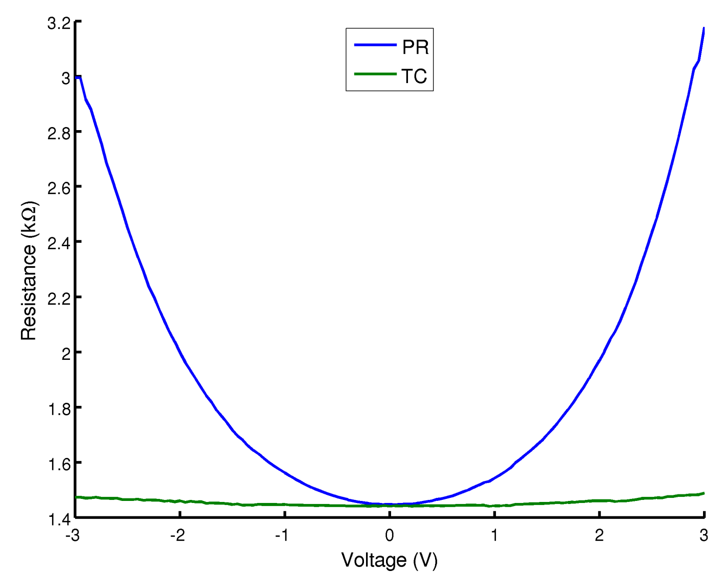
$$-kw_c t_c \frac{\partial^2 T(x)}{\partial x^2} + 2hw_c(T(x) - T_\infty) = Q(x)$$

$$Q(x) = W/l_{pr} \quad x \in [0, l_{pr}]$$

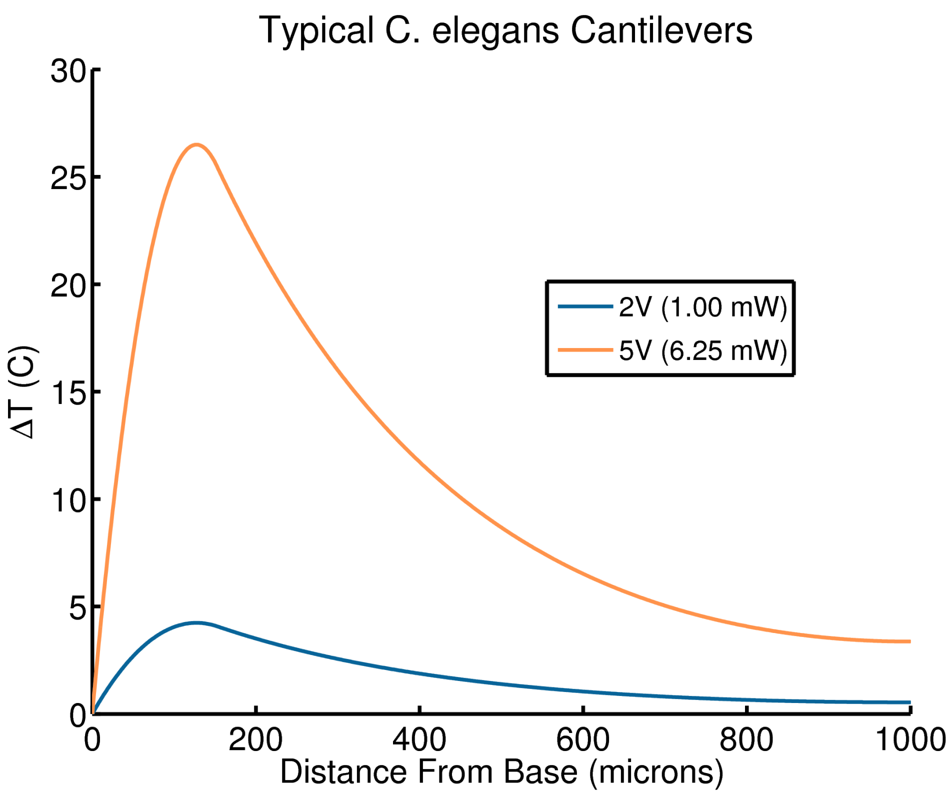
k = 130 W/m-K
h = 2000 W/m^2-K (per K.J. Kim, W.P. King 2009)

Modeling
- Comsol
- 1D numerical

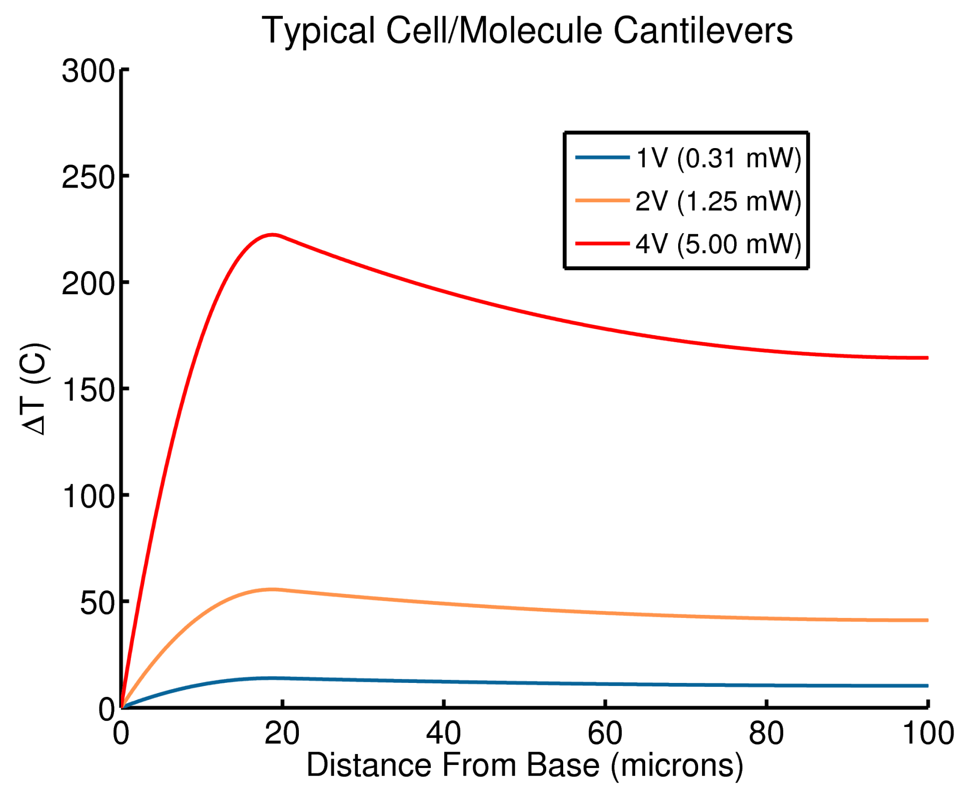
Measuring
- IR microscope
- Raman spectroscopy
- Resistance + temp calib.



Comparing Cantilever Designs

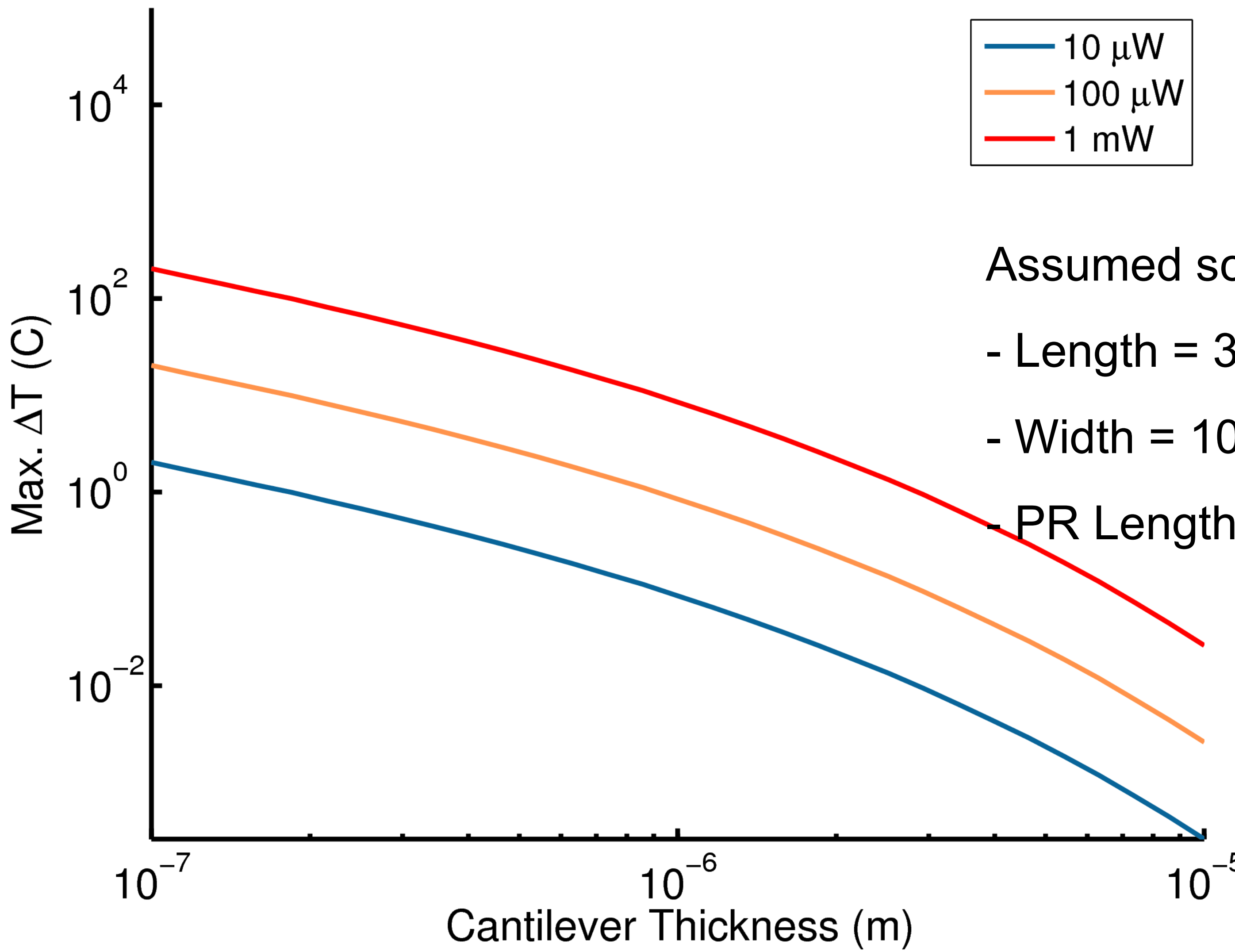


Cantilever = 1000 um x 30 um x 3 um
PR = 153 um long, 1 kOhm



Cantilever = 100 um x 5 um x 300 nm
PR = 20 um long, 2 kOhm

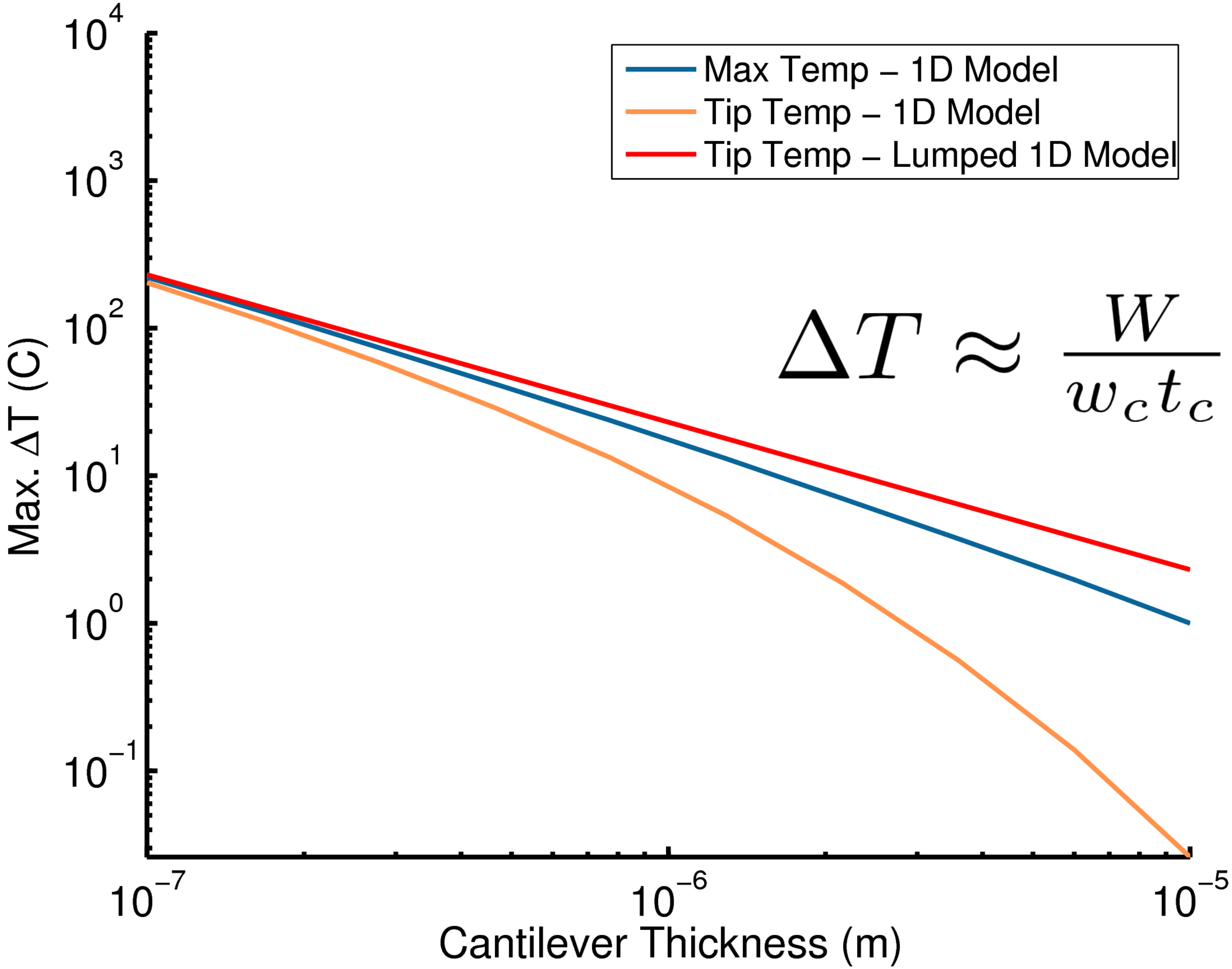
Temp. and Cantilever Size Scaling



Assumed scaling:

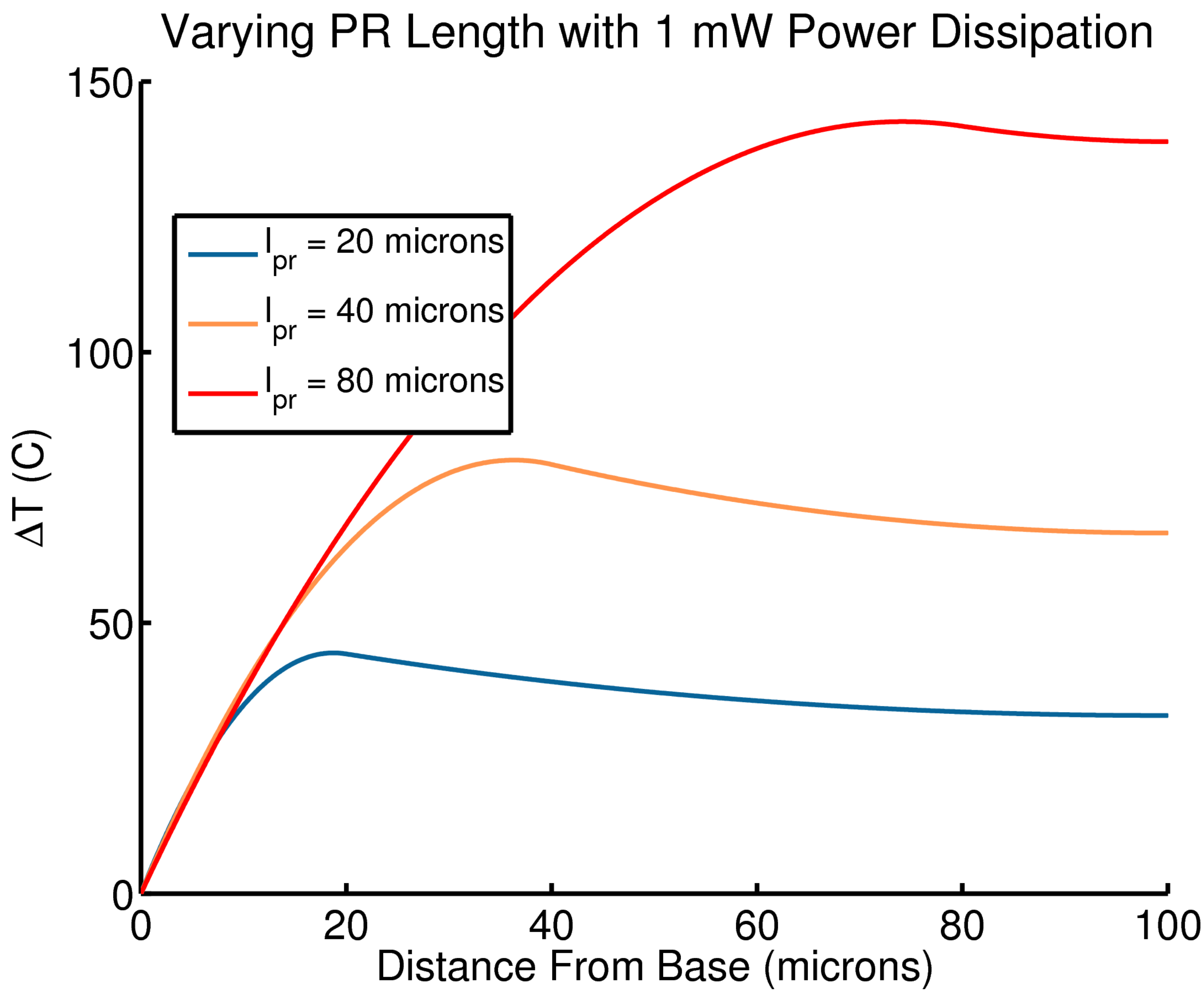
- Length = 300 x Thickness
- Width = 10 x Thickness
- PR Length = 0.2 x Length

Conduction vs. Convection



$$\Delta T \approx \frac{W}{w_c t_c} \frac{l_{pr}}{2}$$

The Effect of PR Length



Tip Temp. vs Power Constraints

- Optimized for 1 Hz – 10 kHz (f_0 = 20 kHz)
- Cantilever = 135 um x 2 um x 300 nm

	Power < 1 mW	Power < 0.1 mW	Temp. < 10K
PR Length (um)	40	18	10
Resistance (kOhm)	5.7	4.4	1.8
Bias (V)	4.8	1.3	1.1
Power (mW)	1	0.1	0.15
Tip Temp Rise (K)	**254**	**11.5**	**10**
MDF (pN)	**3.6**	**6.7**	**6.4**
MDD (nm)	5	9.3	8.8

Conclusions

- PR vs PE sensing
  - PR and PE resolution is limited by device (Johnson, Hooge) and amplifier noise
  - Use PR for thin cantilevers (< 1 micron), low frequencies (< 10 Hz) and moderate power dissipations (> 0.1 mW)
  - Use PE for thick cantilevers, maximizing sensitivity
- PR Thermal Design
  - Power dissipation needs to scale with device dimensions
  - Conduction dominates convection for small devices
  - Tip temp. can be minimized with a small impact on resolution