Reducing Anchor Loss in MEMS Resonators

SUNFEST 2010
NSF REU Site

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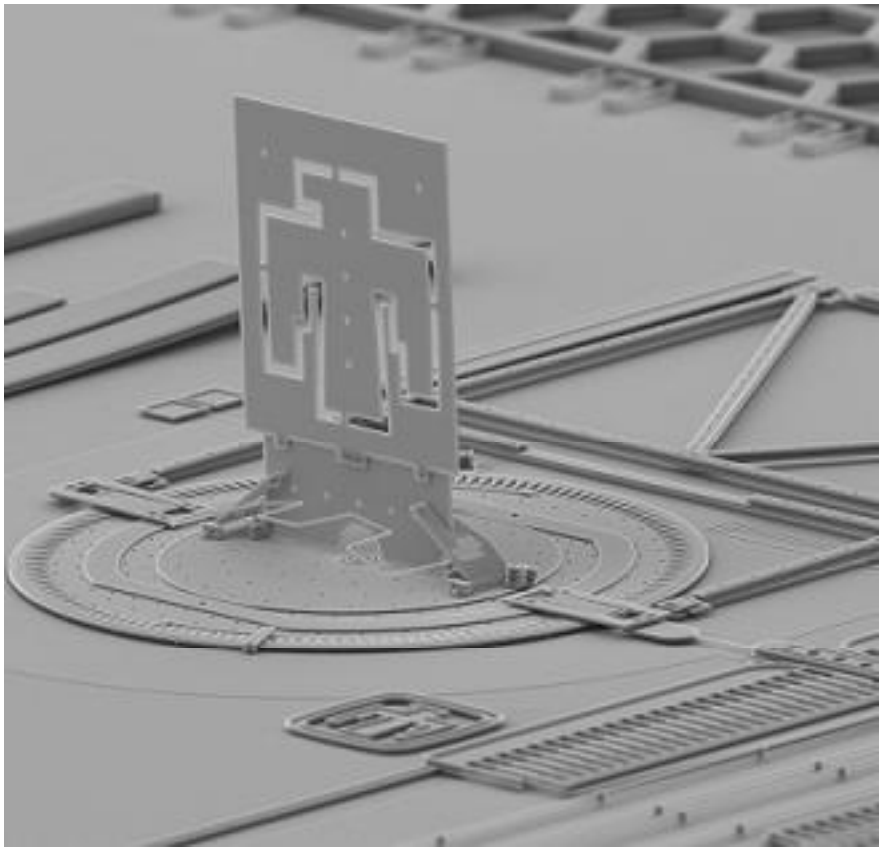
Micro-electro-mechanical Systems (MEMS)

- Uses
  - Mechanical switches
  - Resonators
  - Accelerometers
  - Sensors
- Advantages
  - System-on-a-chip
  - Size
  - Power efficiency

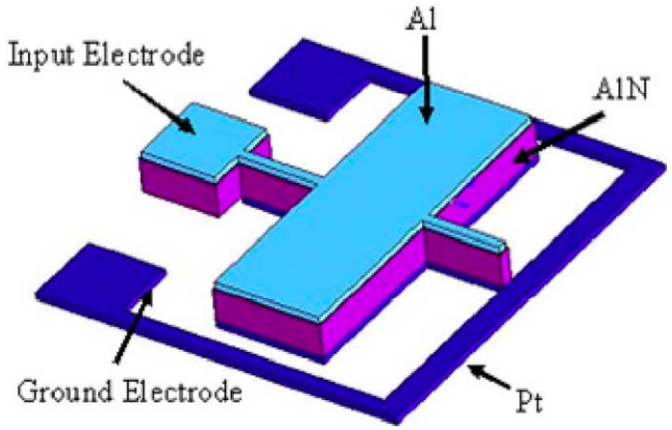


MEMS Resonators as RF Filters

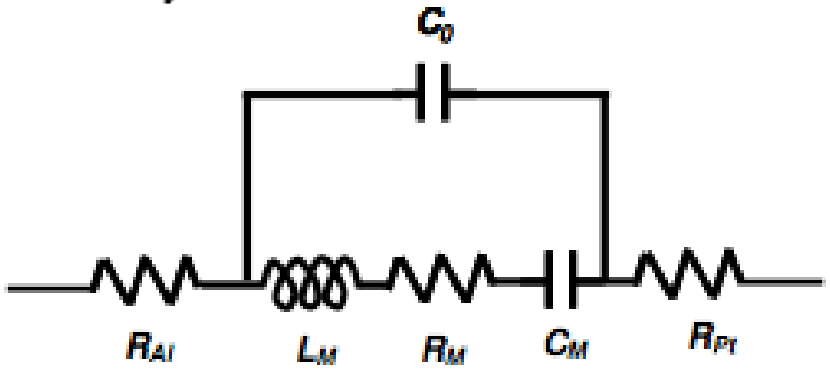
- Piezoelectricity
- Engineered to have a given resonant frequency
  - Act as band pass filter for that frequency
- Vibration at resonant frequency amplified
- Induce the reverse piezoelectric effect
- Electrodes on resonator route signal to external circuitries

AlN Contour-Mode MEMS Resonators

- AlN film sandwiched between metal film
- Utilizes the lateral piezoelectric coefficient (d_{31})
- Resonant frequency is determined by lateral dimensions
- LC circuit
  - Resonant circuit
- Very appealing
  - Easy fabrications
  - Large arrays

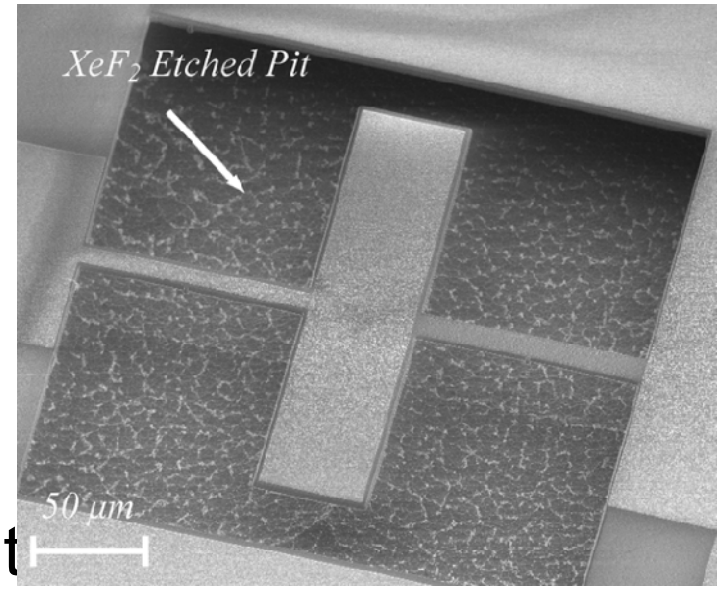


$$\omega_0 = \frac{1}{\sqrt{LC}}$$



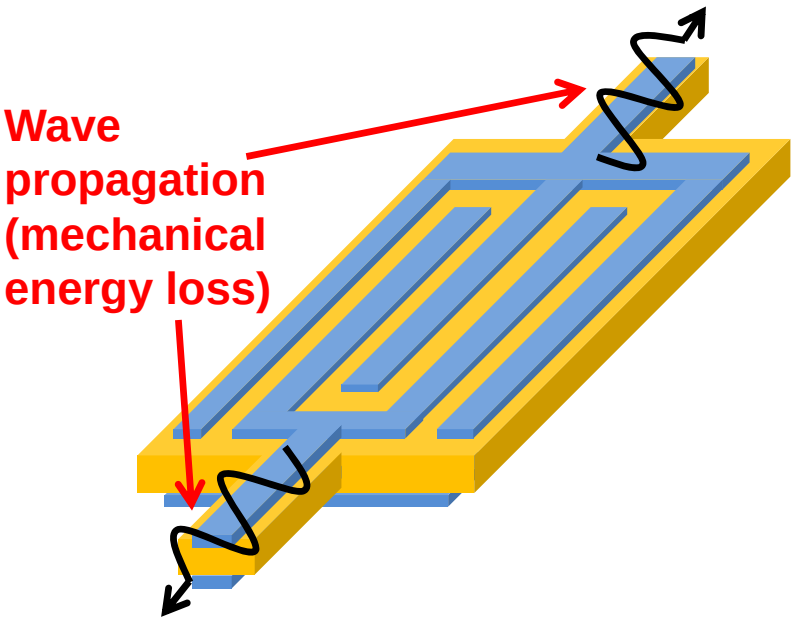
Hurdles

- Quality factor
  - Measure of energy lost by resonator
- Energy Loss
  - Air damping
  - Thermo-elastic dissipation
  - Material loss
  - Phonon-phonon interactions
  - Anchor loss
- Anchor loss is most significant



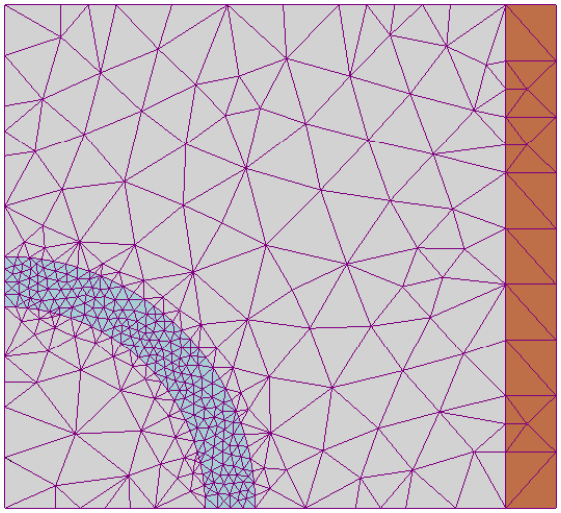
Anchor Loss

- Escape of energy from the resonator to the substrate through the anchor
- Waves that travel to the substrate via the tether are considered lost energy
- Waves must be stopped!



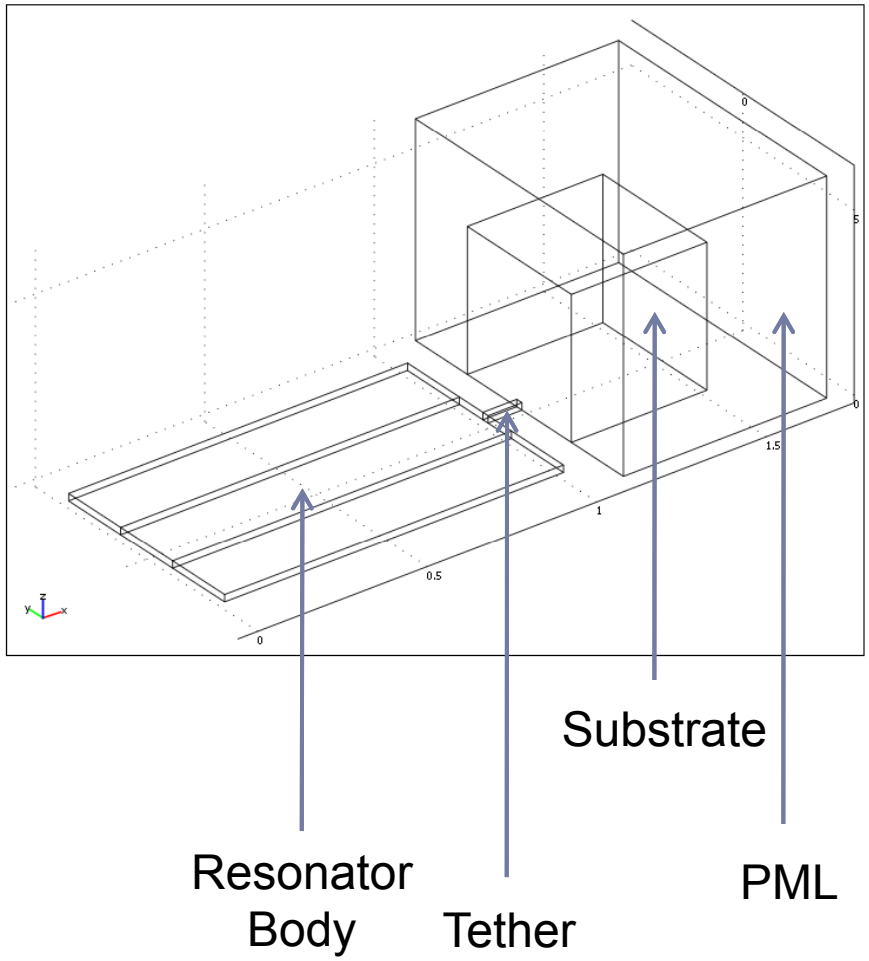
COMSOL FEM Software and PML

- Finite Element Method
- Simulations
- Perfectly matched layer
  - Artificial layer
  - Absorbs all incoming radiation
  - Semi-infinite domain representing silicon substrate
  - Allows for more accurate simulations
- Determine parameters for accurate PML



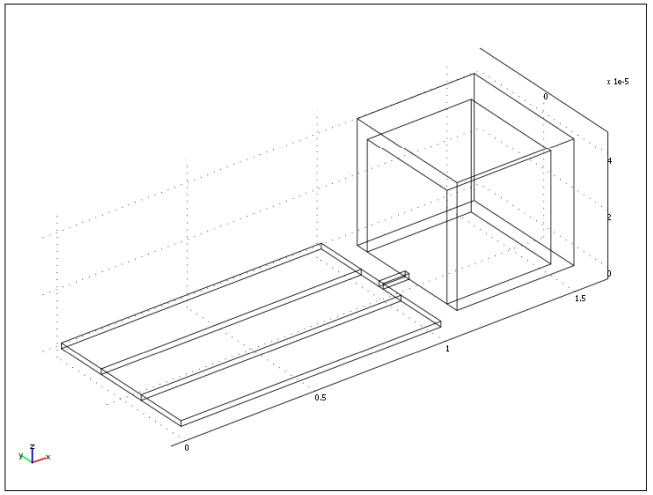
COMSOL Model

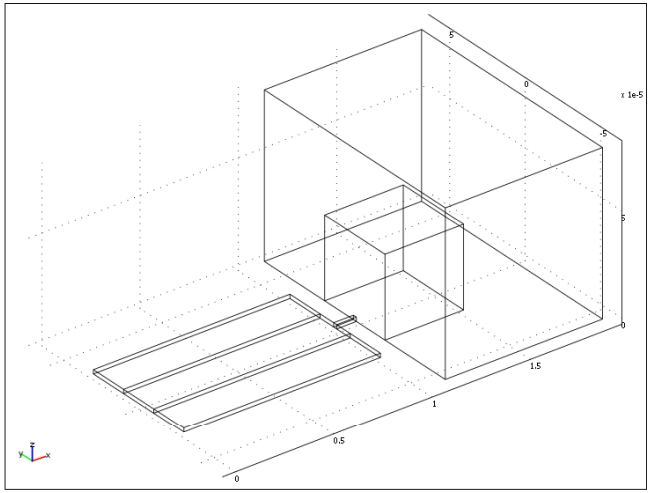
- PML Width
- PML Mesh Density
- Substrate Size
- Substrate Mesh Density
- Base Parameters
  - 2-micron wide tether
  - 10 micron mesh element size
  - 40 micron wavelength



PML Width Simulations

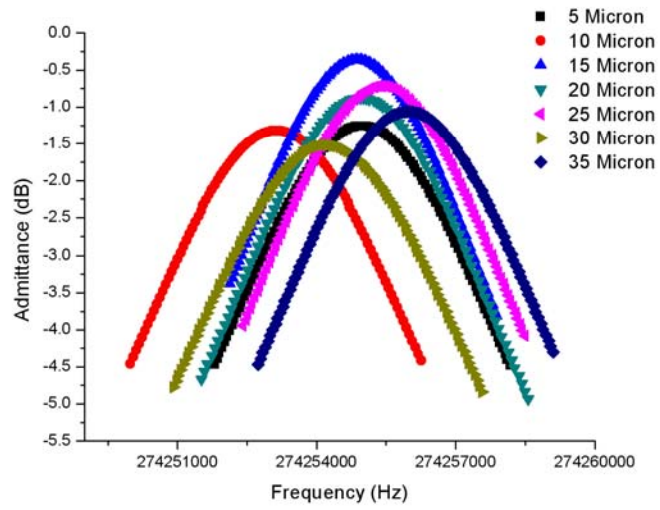
- Vary PML width from 5 microns to 35 microns
- Constant
  - PML Mesh Size
  - Substrate Size
  - Substrate Mesh Density
  - Tether Width
  - Tether Length

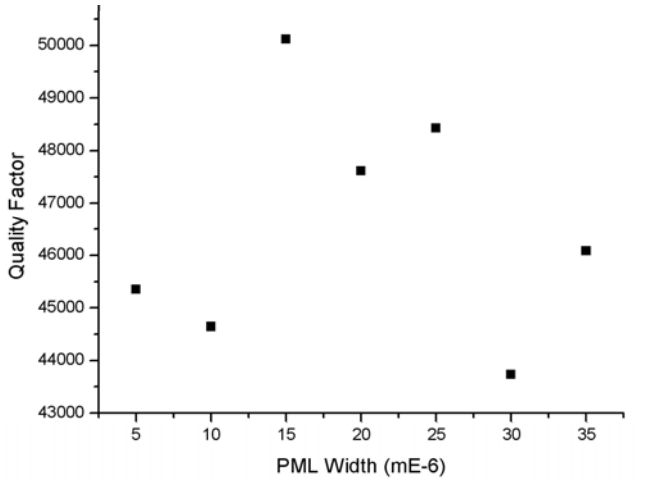




PML Width Simulation Results

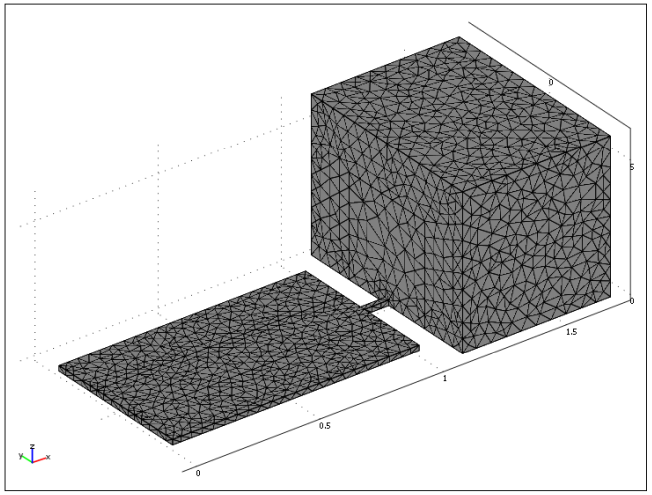
- The average quality factor
  - 46563.2
- Standard deviation
  - 2260.9
  - 5%
- Quality factor has little dependence on PML width

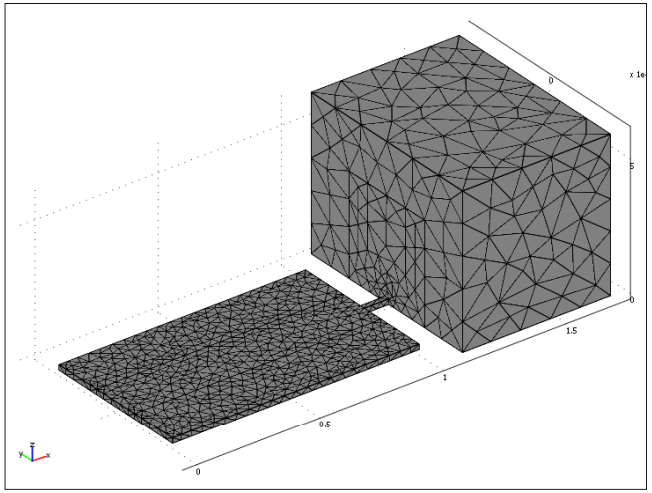




PML Mesh Simulations

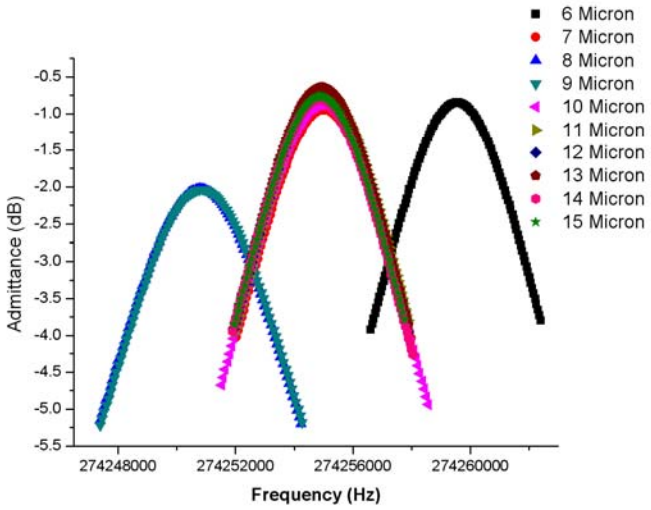
- Vary maximum mesh element size in the PML sub-domain from 6 to 15 microns
- Constant
  - PML width
  - Substrate Size
  - Substrate Mesh Density
  - Tether Width
  - Tether Length

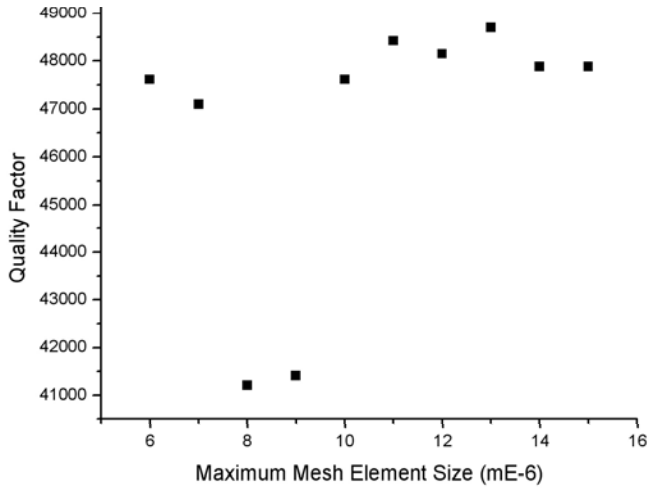




PML Mesh Simulation Results

- The average quality factor
  - 46594.9
- Standard deviation
  - 2824.7
  - 6%
- Quality factor has little dependence on PML mesh density



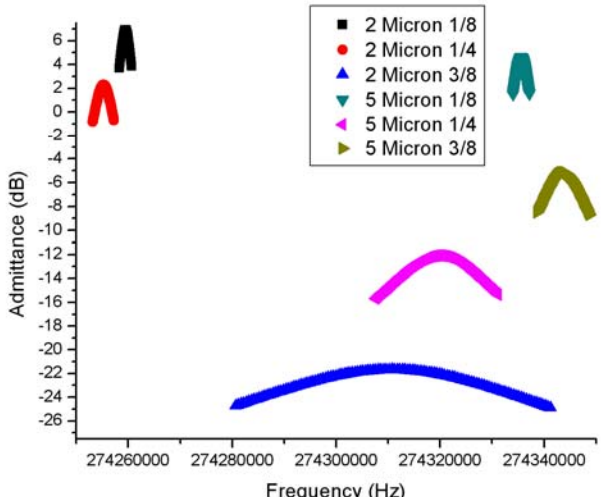


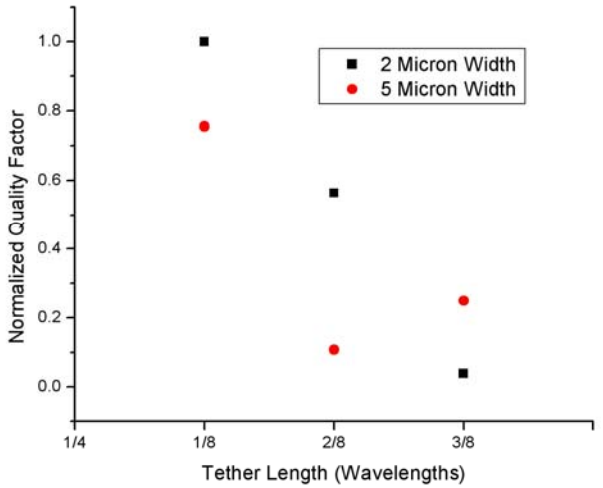
Substrate/Tether Simulations

- Similar simulations done with substrate
  - Vary substrate size
  - Vary substrate mesh density
- Same conclusions: Little affect on quality factor
- Use bade model to examine the effect of the tether on the quality factor.
- Tether lengths
  - 1/8 λ
  - 1/4 λ
  - 3/8 λ
- Tether widths
  - 2 and 5 microns

Tether Results

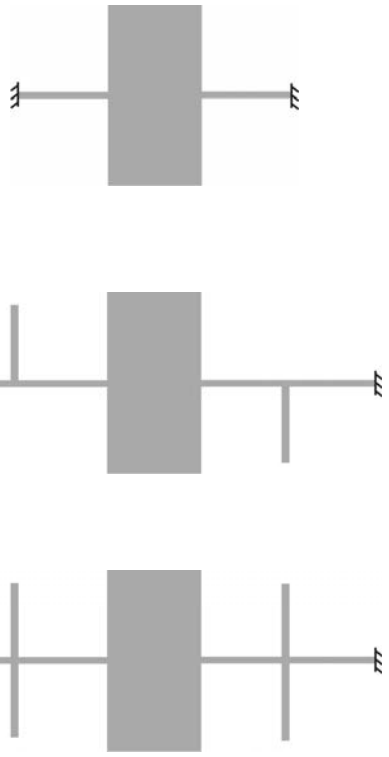
- Wider and thinner tether is better
- 1/8
  - 20% drop form 2 to 5 micron
- 1/4
  - 25% drop form 2 to 5 micron
- 3/8
  - Increase form 2 to 5 micron
    - Explored in future





Further Work

- Explore length, width, and number of branches
- No branches
  - Lengths ofλ/8, λ/4, and 3λ/8
  - Width of 2 and 5 microns
- 1 branch
  - Lengths λ/4
  - Width of 2 and 5 microns
- 2 branches
  - Lengthsλ/4
  - Width of 2 and 5 microns



Conclusion

- Created a base model
  - Not affected by PML
  - Can be modified to simulate novel resonators designs
  - Save time and money
- Shorter and thinner tethers
  - Higher quality factor

Acknowledgements

- Dr. Gianluca Piazza
  - Assistant Professor, Advisor
- Dr. Songbing Gong
  - Post-Doc PMaNS lab
- Nick Kuo
  - PhD Student PMaNS lab
- Dr. Jan Van Der Spiegel
  - Director, SUNFEST
- National Science Foundation

Thanks for Listening!

- Questions?