Composite mirror suspensions development status and directions

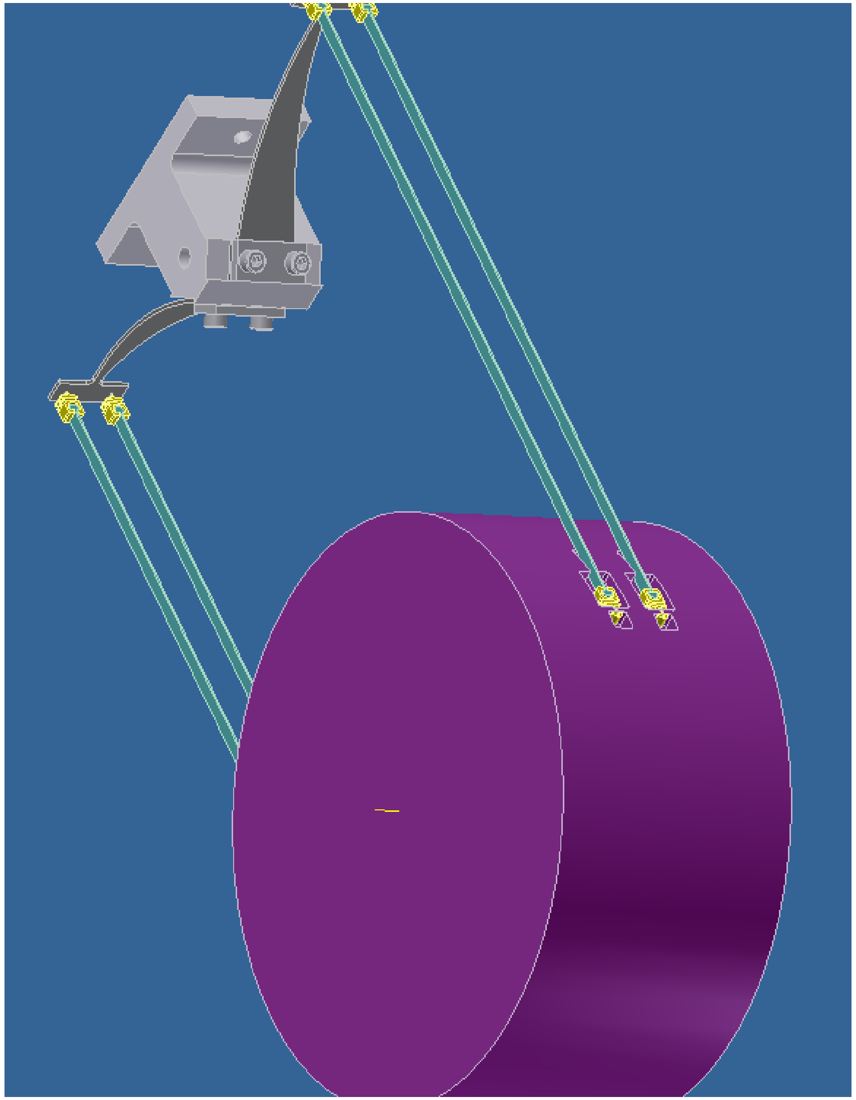
ELiTES activity

interim report

JGW-G1201174

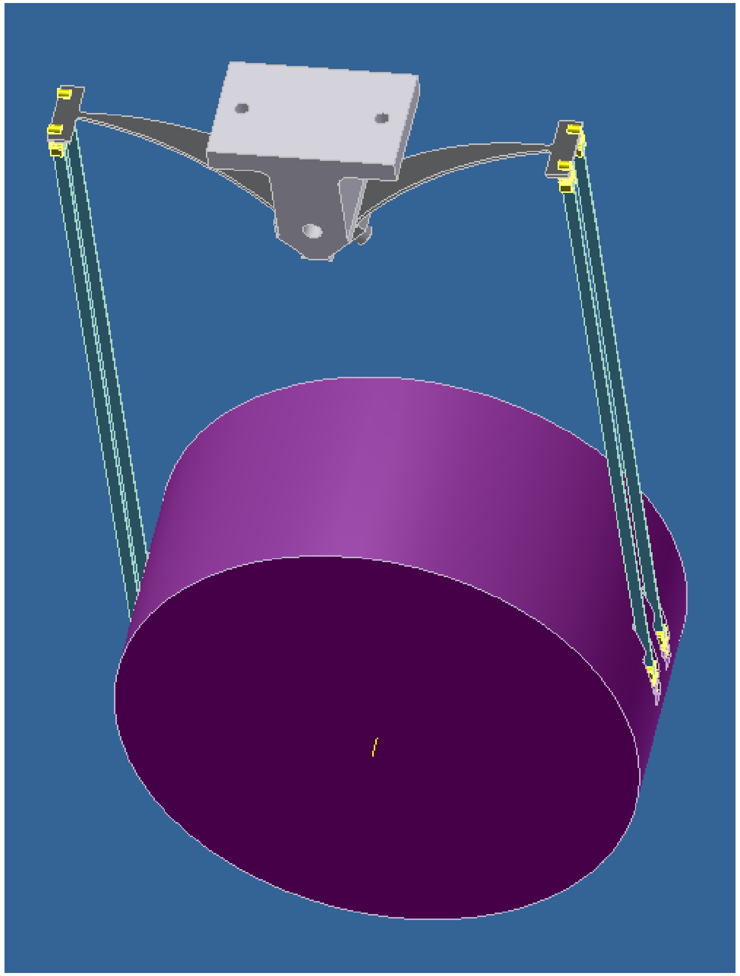
The idea

- A fresh approach to the design of
  low thermal noise mirror suspensions for KAGRA and ET



Key features:

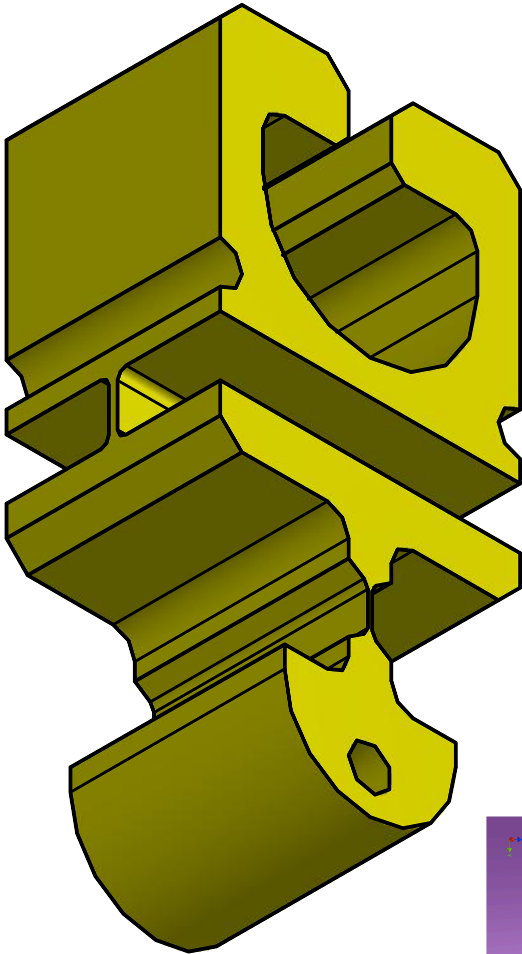
- Composite structure
- Purely Compressive joints
- No shear noise
- No need for bonding
- Easy replacements
- Easily scalable to larger masses

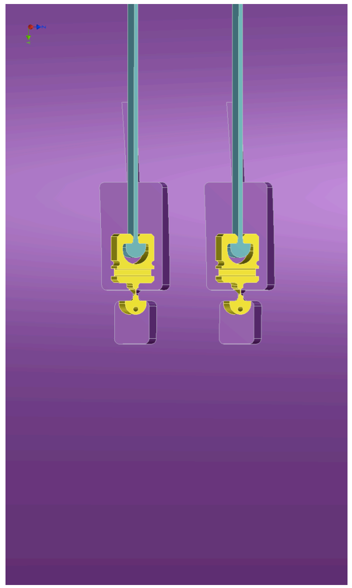


Flexure
Key features:

- Silicon flexures
- Intrinsic Q-factor >10^8
- Thermo-elastic >10^6
- Diluted Q-factor >10^9
- Before cryo gain !

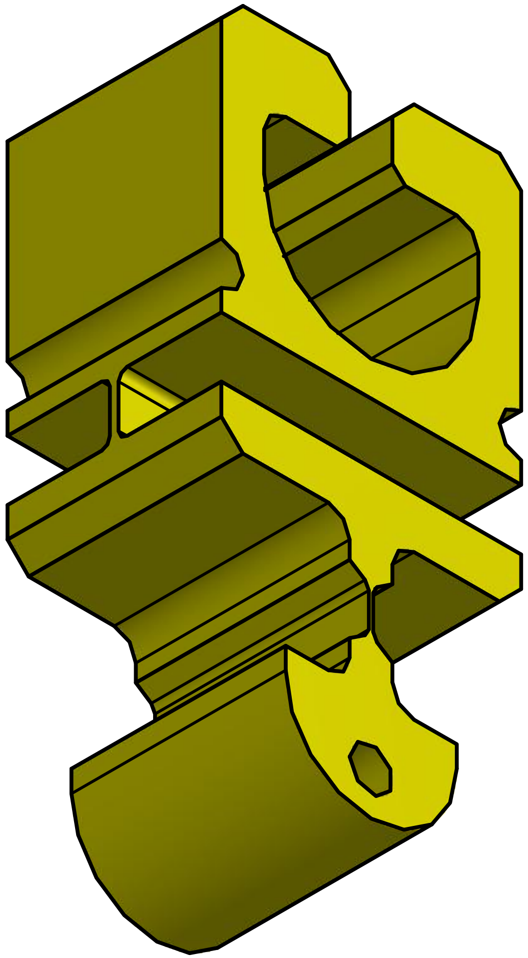
- Many Machining options available





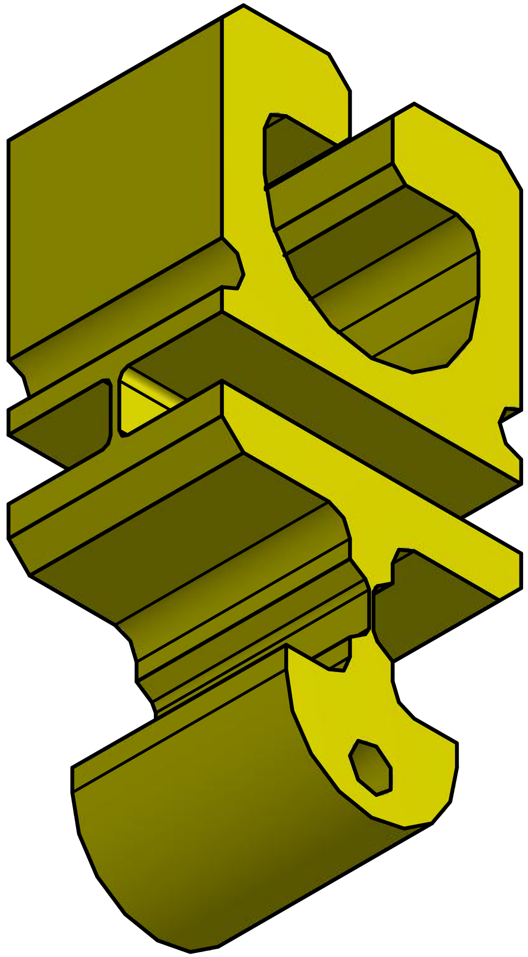
Flexure structure

- Ultra-Sound Machined structure
- Etching of the flexure surface
- Expected to increase the break point >1GPa



Flexure structure

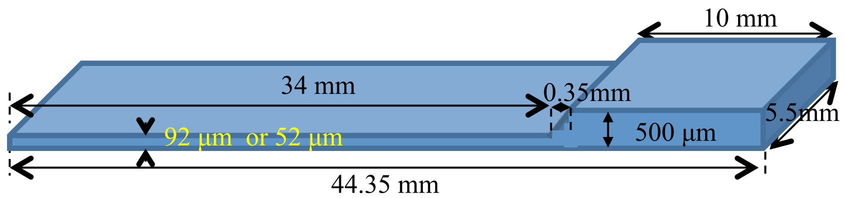
- Thin, short, etched flexure
- smallflexure aspect ratio
- Large thermal conductance

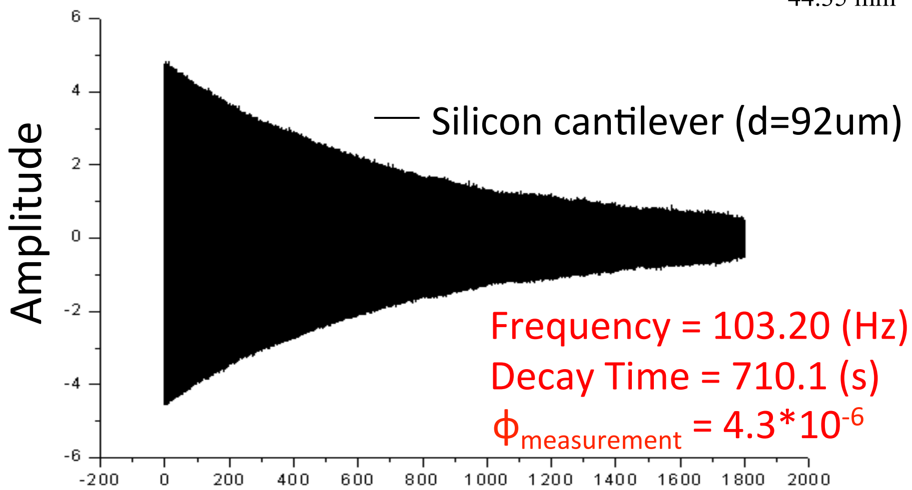


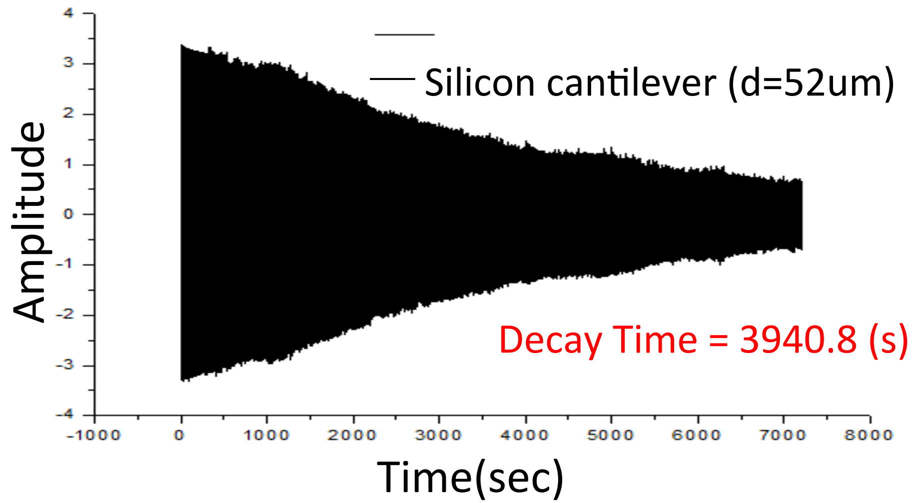
Chao Shiu laboratory, Taiwan

Silicon cantilever with KOH wet etching

4” un-doped double-side polished (001) silicon wafer,
500um thickness etched down to 92 and 52 µm



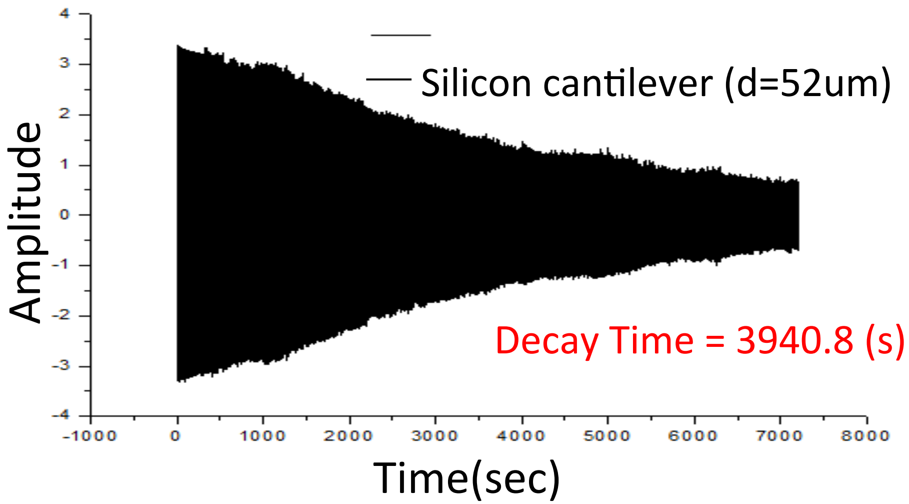


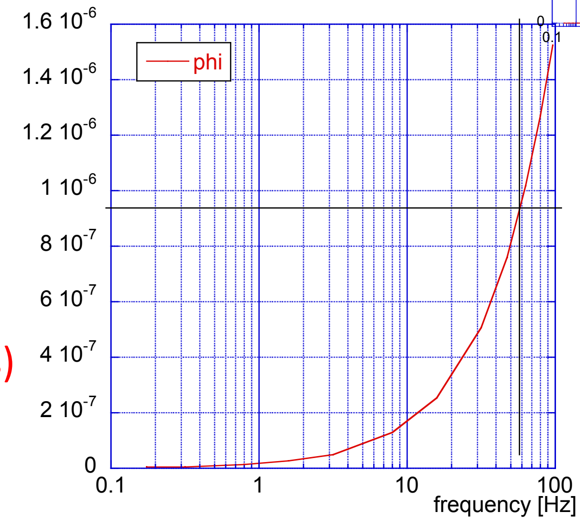


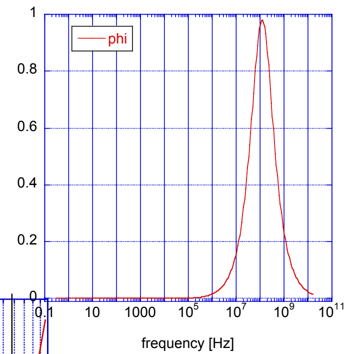
0.3 10^{-6} loss measured from residual gas

Thermo-elastic limit

- **@ 59 Hz 0.945 10^{-6} loss angle predicted (T.E.)**
- **1.3 10^{-6} measured** (-) **0.3 10^{-6} residual gas**
- **1. 10^{-6} loss angle measured**
- => 100% Thermoelastic limited ! ! !

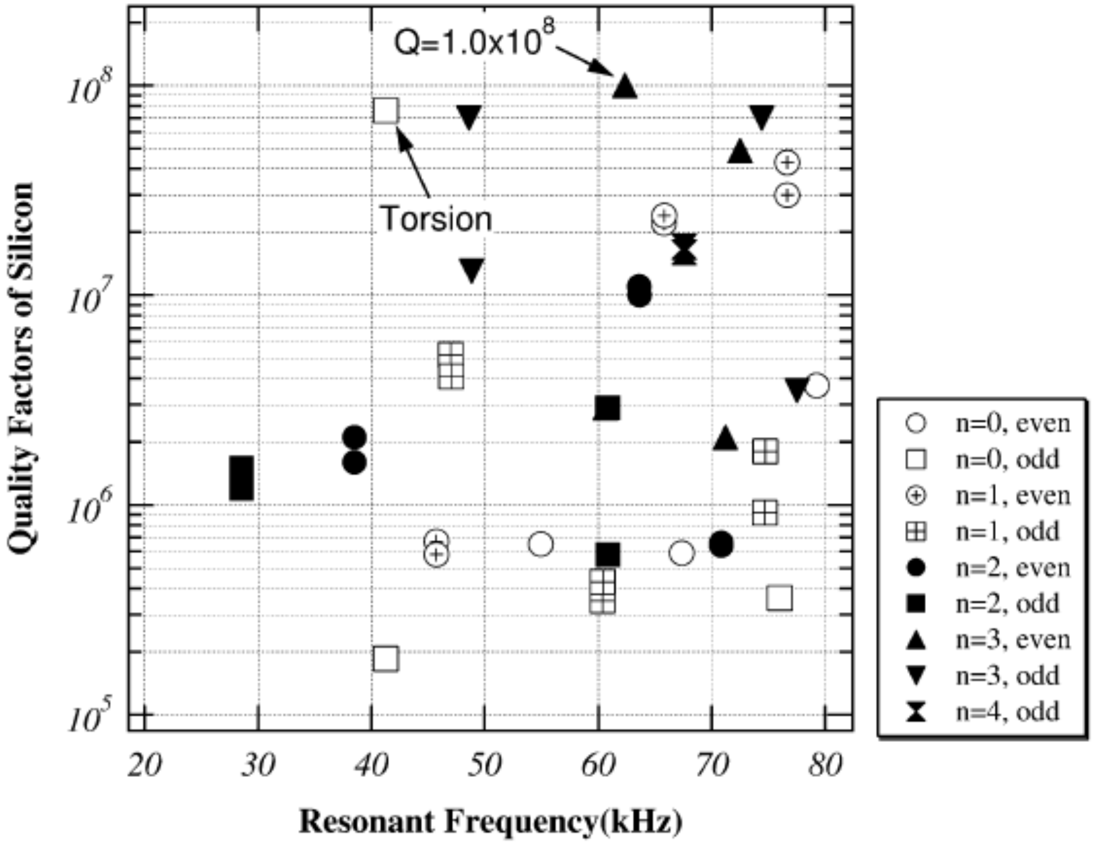






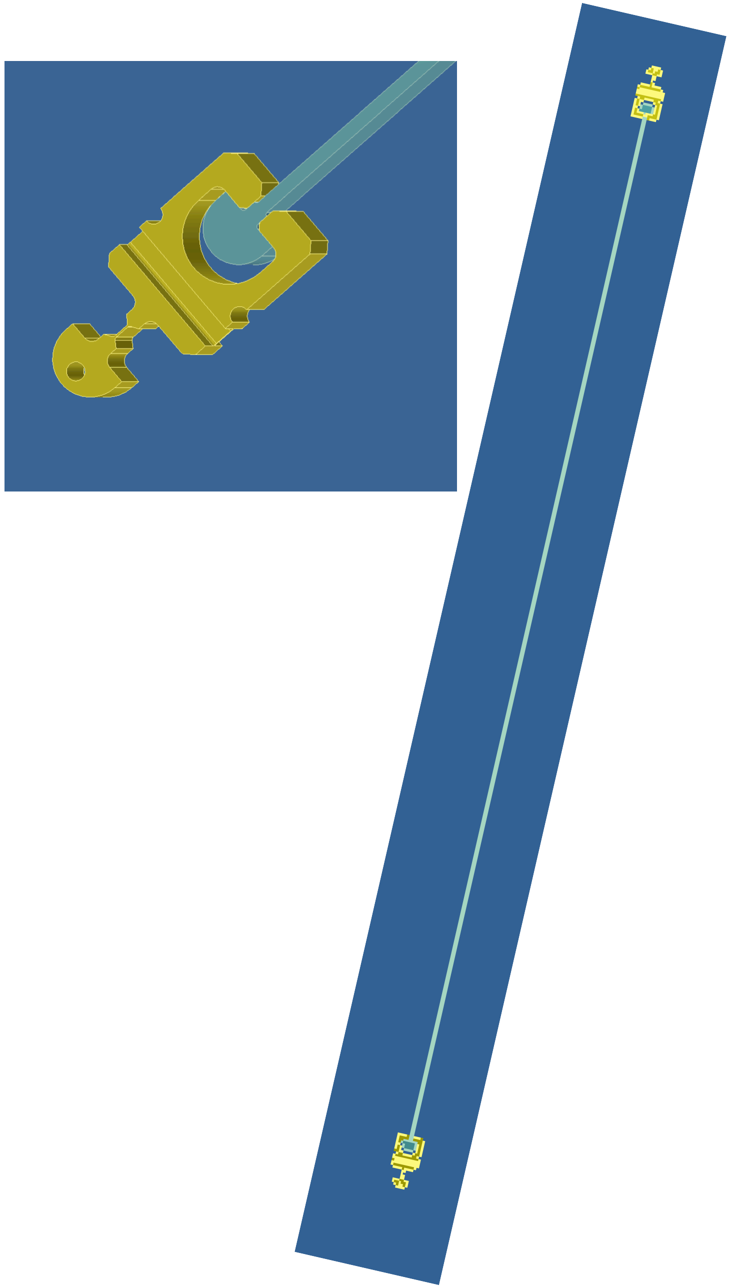
Kenji's Q-factor measurements

- Measurement on a mirror substrate
- 10^8 lower limit



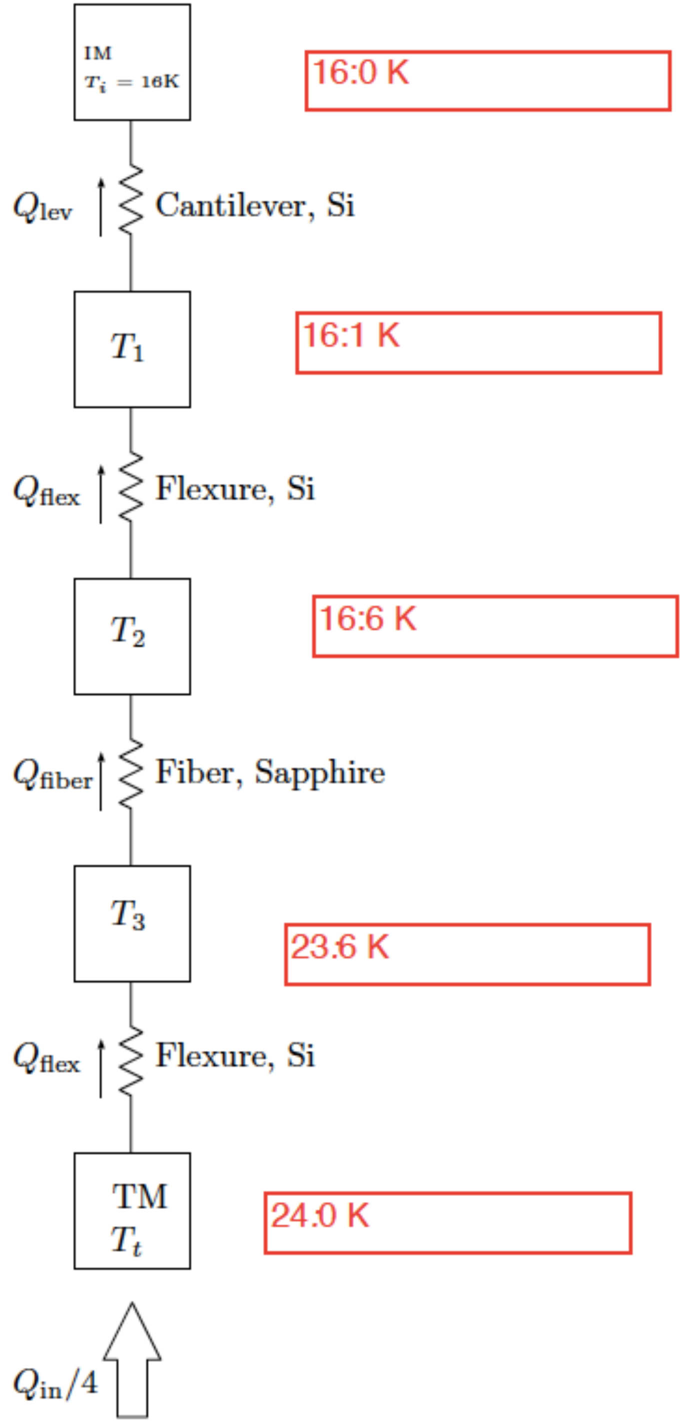
Ribbons
Key features:

- Compression joint attachment
- Machined-polished Sapphire ribbons
- High quality sapphire
- High quality surface finish (sub-phonon defect size)
- = > High thermal conductivity !



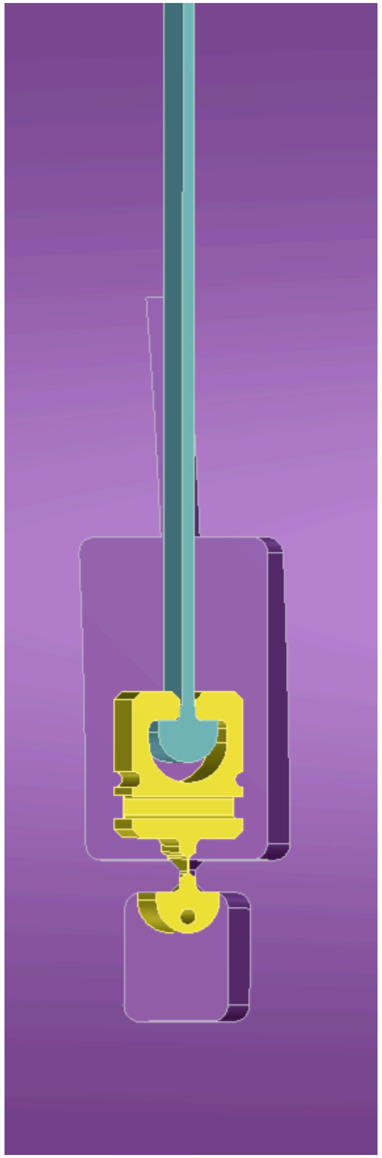
Conductance budget

- Preliminary conductance budget from Sakakibara with 1 W load
- Thin ribbon responsible for bulk of loss ! ! !
- Plenty of space for parametric optimization



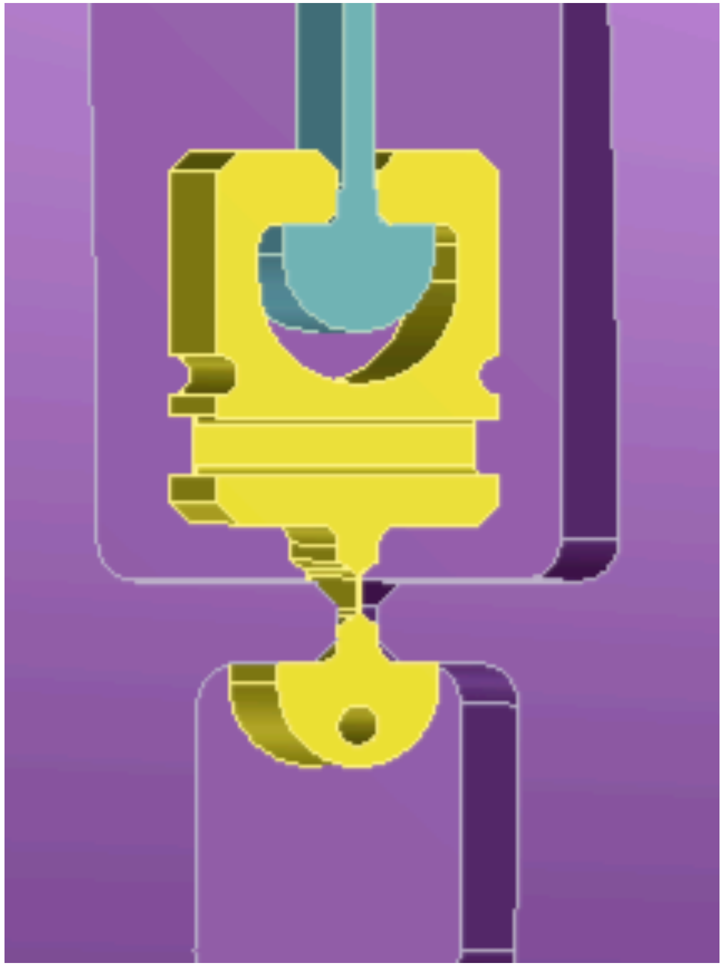
Mirror attachment
Key features:

- Mini-alcoves (low volume machining)
- Machining before coating deposition
- Minimize substrate induced stress
- Recessed attachment, Low vulnerability
- No bonding shear noise
- No flats, 100% of mirror surfaceavailable

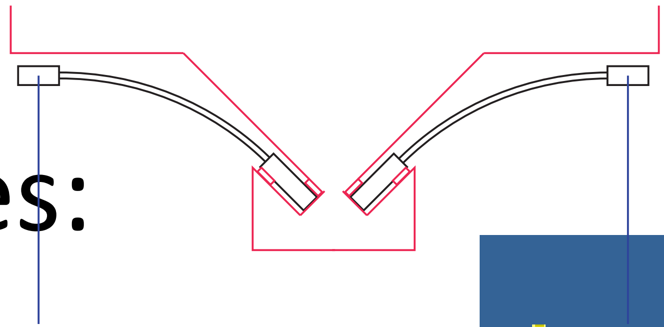


Connections
Key features:

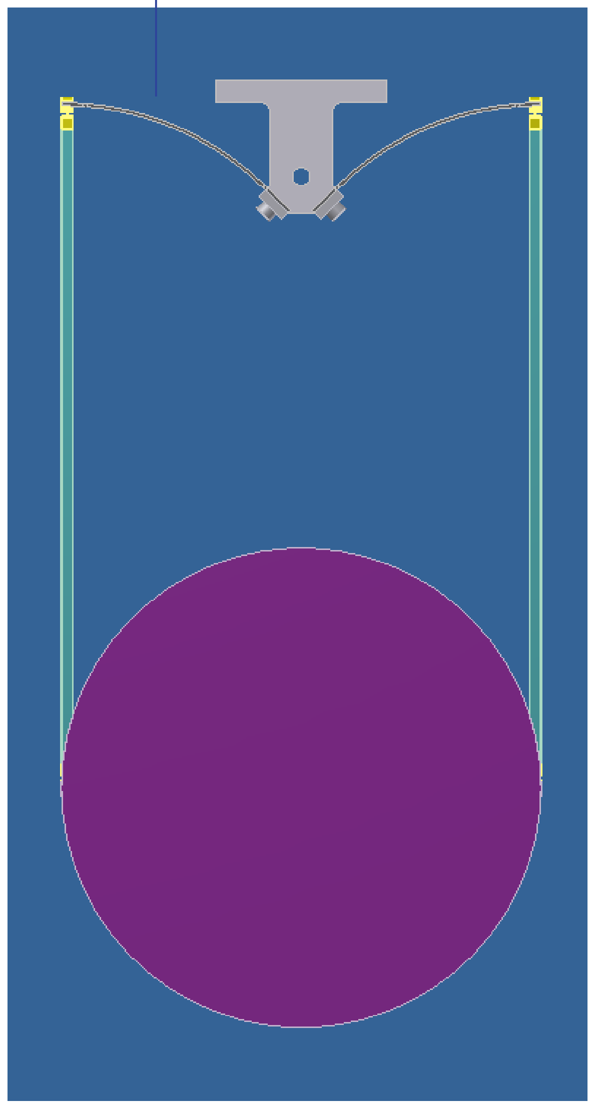
- Purely compressive joints
- Sub-μm, Gallium gaskets + direct contact
- Complete elimination of stick and slip noise
- Perfect heat conductivity
- Easy replaceability



Springs
Key features:

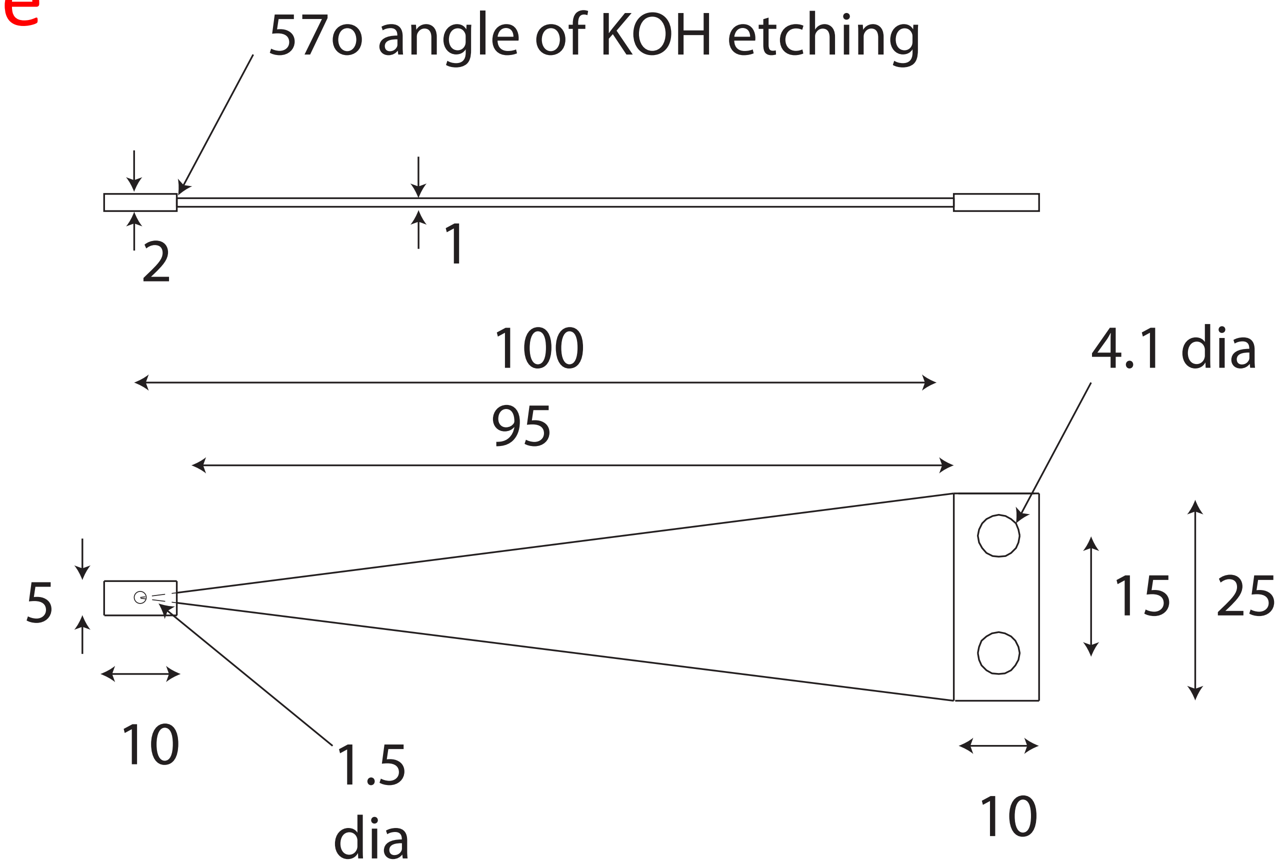


- Silicon springs
- Defects etched away
- Allowable surface stress < 1 GPa (to be confirmed)
- Elimination of vertical suspension thermal noise (necessary due to KAGRA’s tunnel tilt)



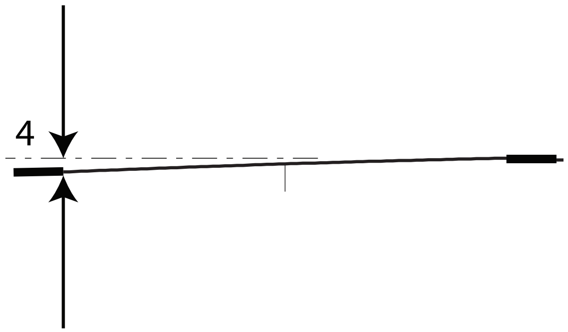
NIKHEF test

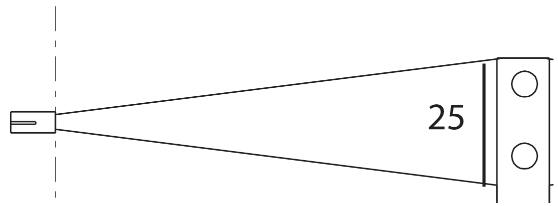
- Produce a number od samples
- Test and see



Etched Silicon cantilever blades

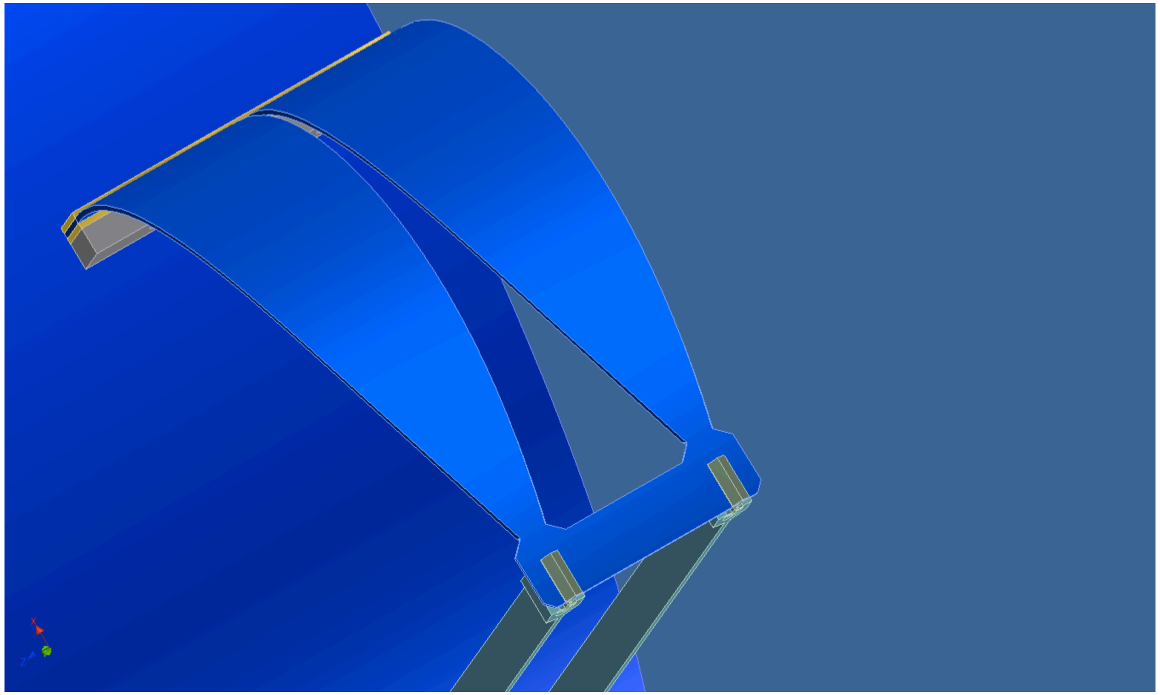
- Etch the bending area
- Leave thick section for clamping and for fiber connection
- With 0.15 Gpa Only limited flexure possible
- With >1GPa large deflection



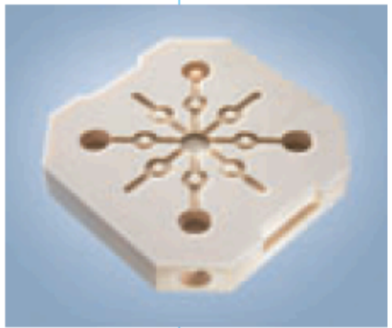


Larger stresses possible?

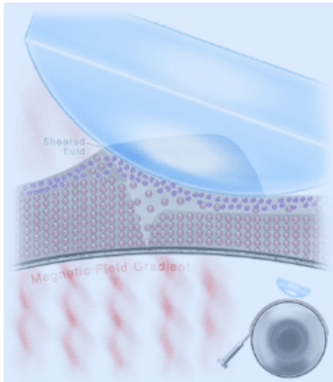
- MEM sensors operating at 1.4 GPa, ~ 10 times higher limit!
- Is etching eliminating surface defect and therefore causing the larger strength?
- if YES, large bends possible!
- Lower frequency bounce modes

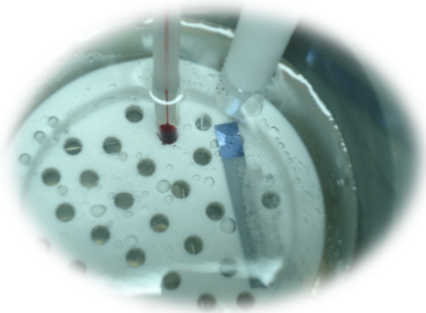


Key technologies:



- Ultrasound machining of sapphire and silicon
- Magneto-rheological Finishing (QED)
- Silicon etching to eliminate defects





Why Gallium

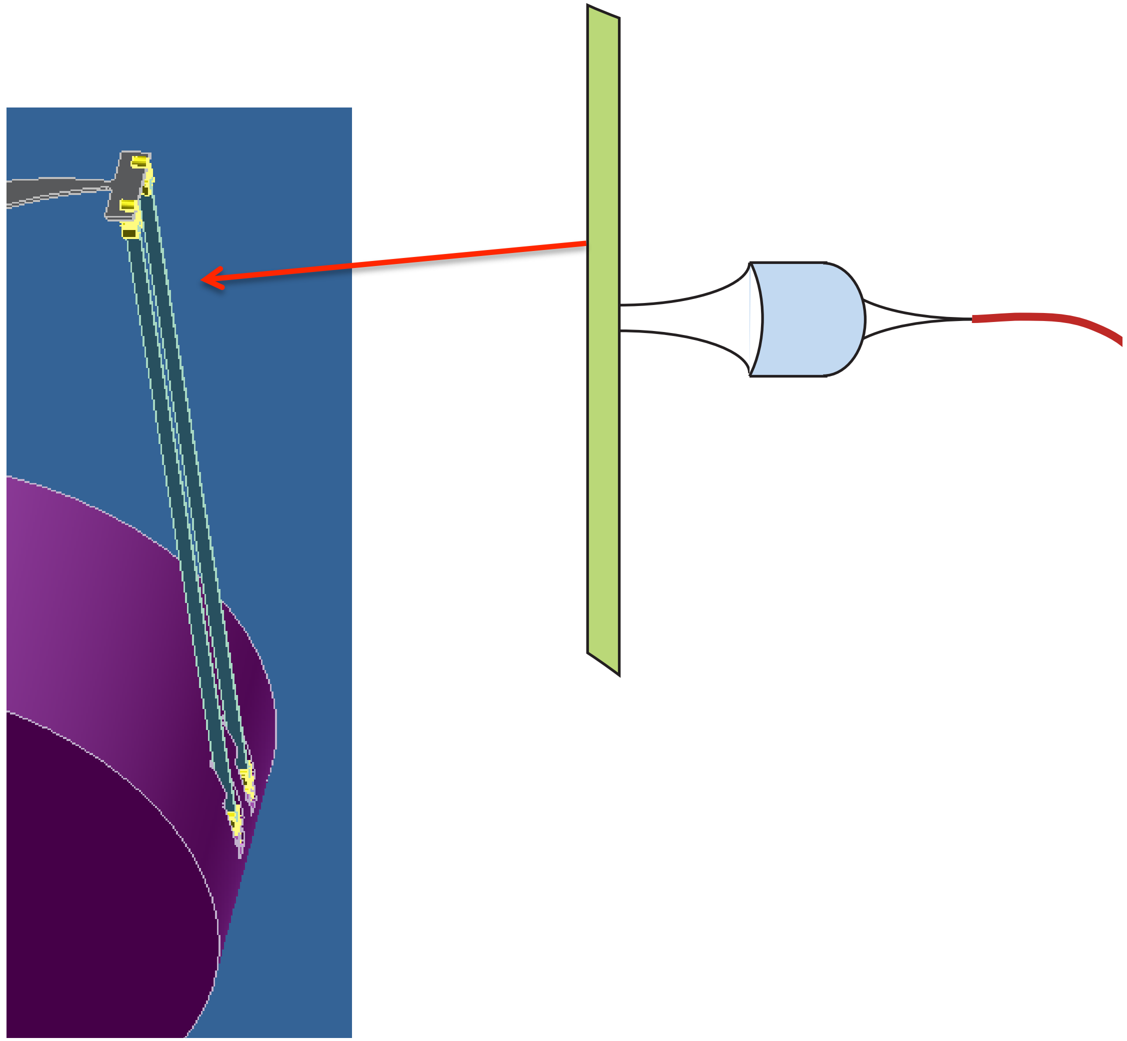
- Indium proved extremely effective to eliminate friction noise in compression joints (Vladimir Braginsky)
- Melts at relatively high temperature
- May need heating mirror to more than 160^{o}C for disassembly

Indium vs. Gallium

Property	Unit	**Indium**	**Gallium**	**score**
Solid density (near r.t.)	g·cm^{-3}	7.31	5.91	
Liquid density @ m.p.	g·cm^{-3}	7.02	6.095	
Expansion at melting		1.041	0.9696	G
Melting point	°K	429.7485	302.9146	G
Melting point	°C	156.60	29.77	G
Wetting silicates		Yes	Yes	X
Boiling point	K	2345	2477	G
Vapor pressure	Pa	1 @ 1196°K	1 @ 1310°K	G
Vapor pressure	Pa	10@1325°K	10@1448°K	G
Elec. resistivity (20 °C)	nΩ·m	83.7	270	
Thermal conductivity	W·m^{-1}·K^{-1}	81.8	40.6	I
Therm. expansion (25 °C)	µm·m^{-1}·K^{-1}	23.1	18.0	G
Young's modulus	GPa	11	9.8	X
Poisson ratio			0.47	
Brinell hardness	MPa	8.83	60	G
Atomic radius	pm	167	135	
Magnetic ordering		diamagnetic	diamagnetic	X

Violin mode elimination

- Fiber-fed Red-shifted Fabry-Perot
- Can cool violin modes to mK level
- Same for Parametric Instabilities)

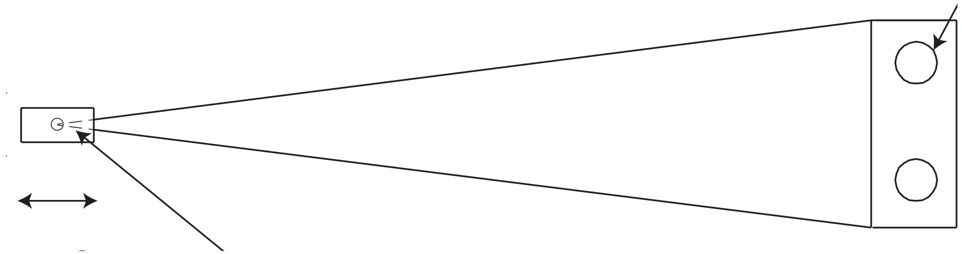


What was done

- Discussed Ultra-Sound Machining technology capabilities and limitation with Mack
- Interactively advanced design
- Optimized machining procedures to physics requirements
- Design optimization ongoing

To do list

- Test effective break point
  - Etched not etched
  - doped-not doped
  - Different axis orientation
  - tension



- FE simulation
- GWINC simulations
- Test machining
- Test assembly
- Conductivity
- Q-factors
- Gallium
- . . . . .

Development target

- Going from strawman to final design of cryo suspensions for KAGRA mirrors
- NIKHEF volunteered to lead, provide most of parts for this R&D stage, perform tests
- Alessandro Bertolini co-ordinating this R&D
- But of course many contributions are needed
  - Fracture measurements
  - Q-measurements
  - Thermal measurements (UTB?)
  - . . .