Low Thermal Noise Suspensions for Future Detectors

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Overview

- Suspension R&D for ET-HF
  - Upgrade to the aLIGO fibre puller
  - Further characterisation of fused silica
- Suspension R&D for ET-LF
  - Crystal growth machine for sapphire and silicon
  - Bonding experiments
  - Modelling of crystalline suspensions
- Summary

Motivation for Suspension Upgrades

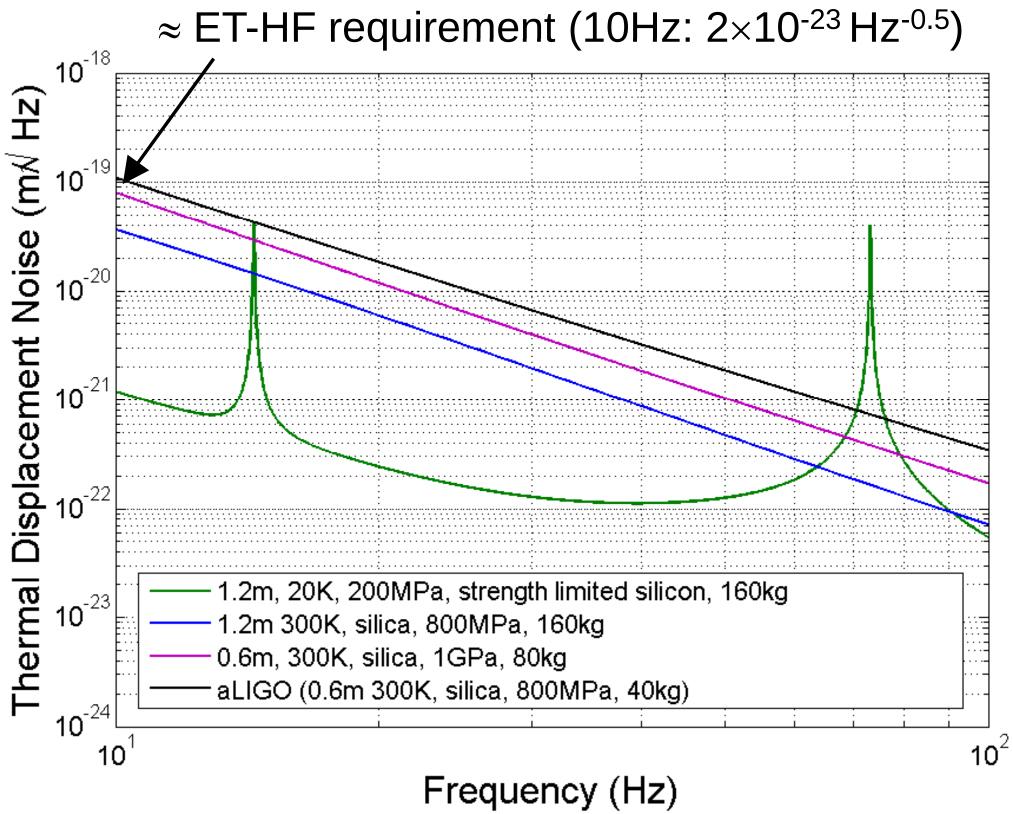
- Currently looking at two upgrade scenarios in Glasgow

Warm upgrades

- Fused silica
- 80 kg - 160kg test masses
- 60 cm - 120 cm suspension lengths
- 800MPa - 1GPa stress in fibres

Cold upgrades

- Silicon at 20 K - 120K
- up to 160kg test masses
- 100 cm suspension lengths



- These are well aligned to ET-HF and ET-LF

Temperature	290 K	10 K
Mirror material	fused silica	silicon
Mirror diameter	62 cm	>45 cm
Mirror thickness	30 cm	about 50 cm
Mirror mass	200 kg	211 kg

R&D for ET-HF

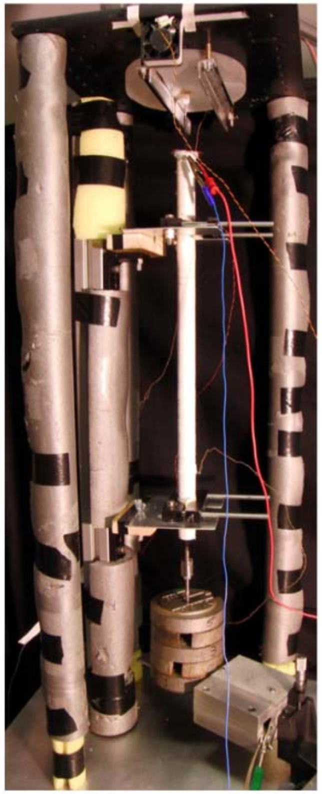
Upgrade to the aLIGO Puller

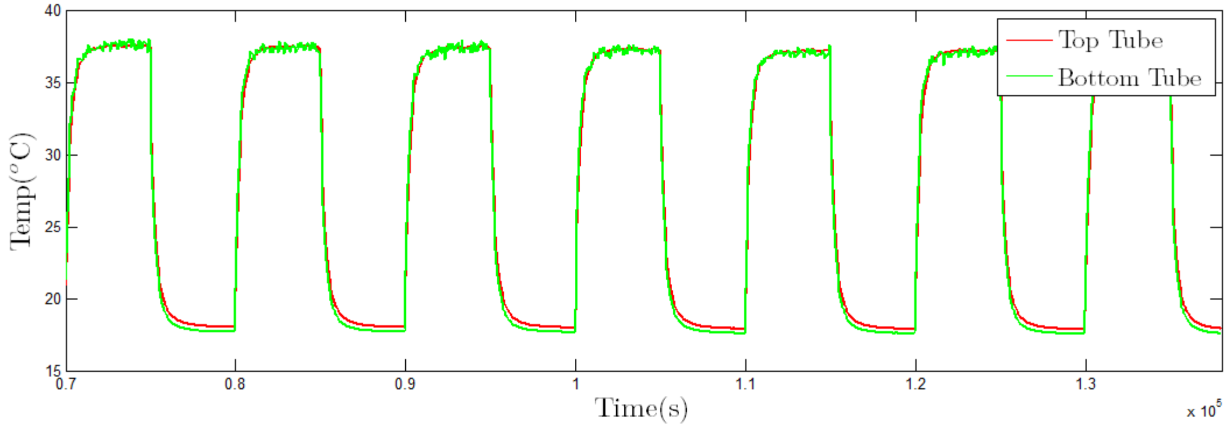
- ET-HF technology requires room temperature silica suspensions
- Upgrade Glasgow fibre pulling machine to allow:
  - fibre lengths up to 2m
  - fibre stock diameter up to 5mm (requires 400W laser)
- Building up new suspension test structure which can be varied from 90kg-160kg

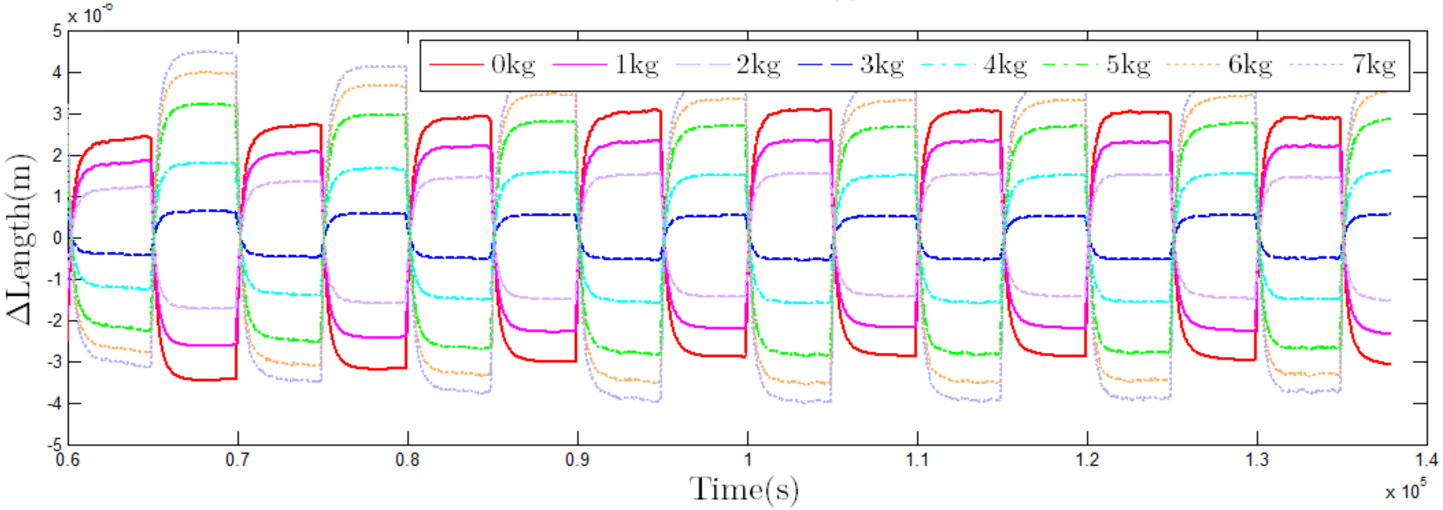
Laser power control via camera video feed

Characterisation of Fused Silica

- Risk reduction for aLIGO includes:
  - – Modelling / analysis of violin mode Q's (aLIGO show Q's of up to ≈1 billion @ 500Hz)
  - –Thermoelastic cancellation in fused silica suspensions (e.g. nulling the effective thermal expansion coefficient)

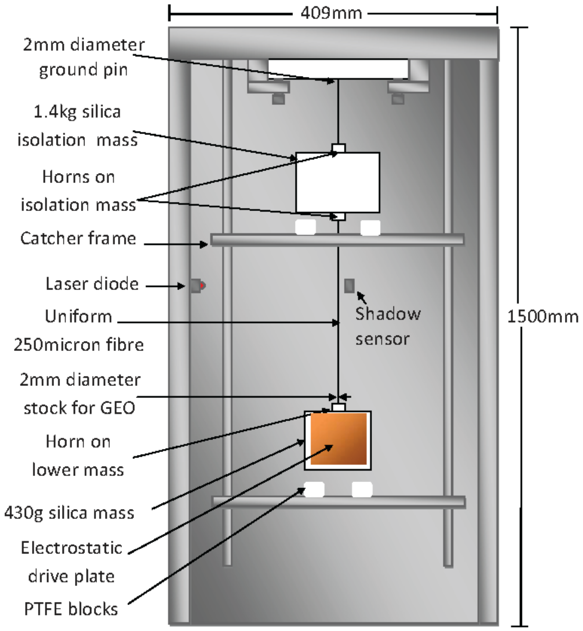




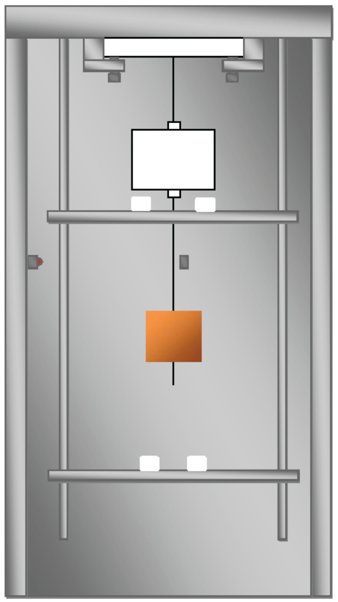


Thermoelastic Cancellation

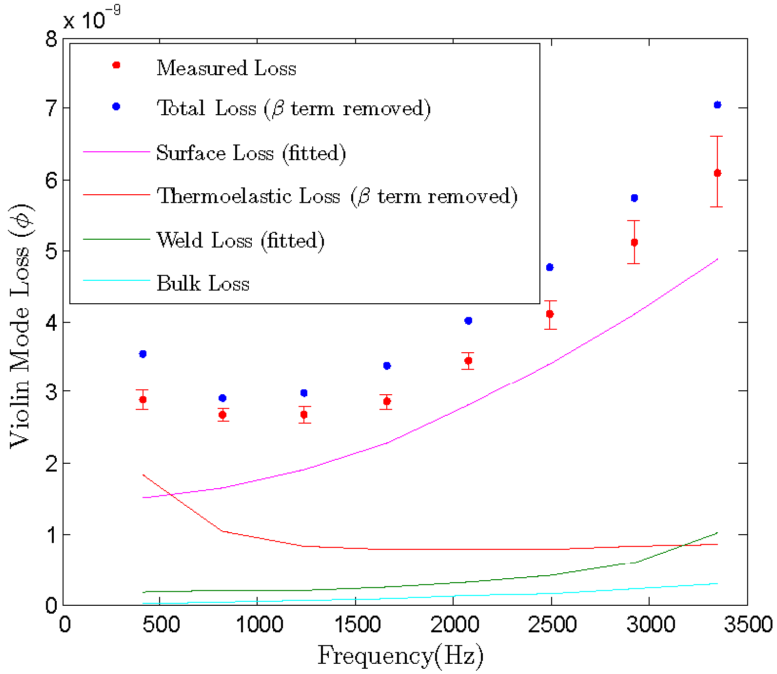
- Ringing up multiple modes in uniform fibres to directly test thermoelastic cancellation => understand thermal noise performance (aLIGO upgrades & ET-HF)



Stage 1: with mass



Stage 2: free fibre



- Fit with β=0 K^{-1}

- Stage 2: allows fitting to surface loss and thermoleastic α
- Stage 1: allows fitting to surface loss and thermoleastic $(\alpha - \sigma_o \beta / Y)$

Thermoelastic Cancellation

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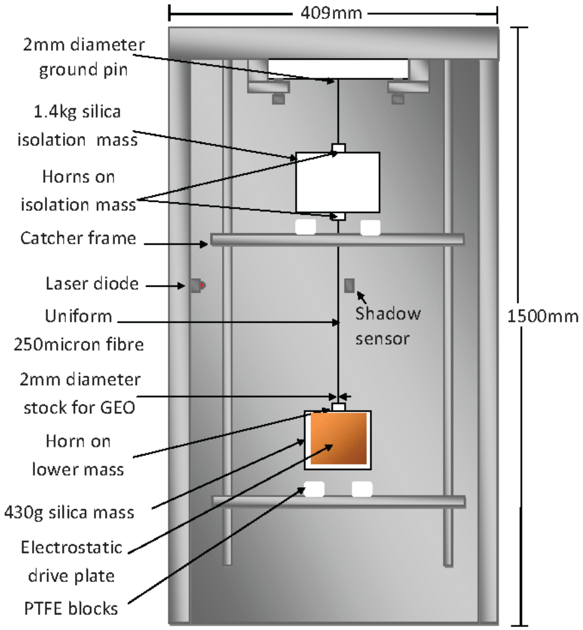
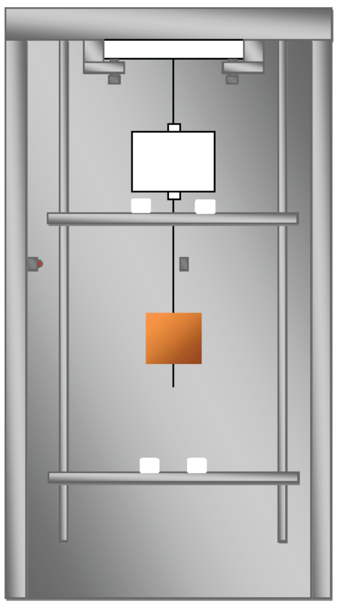
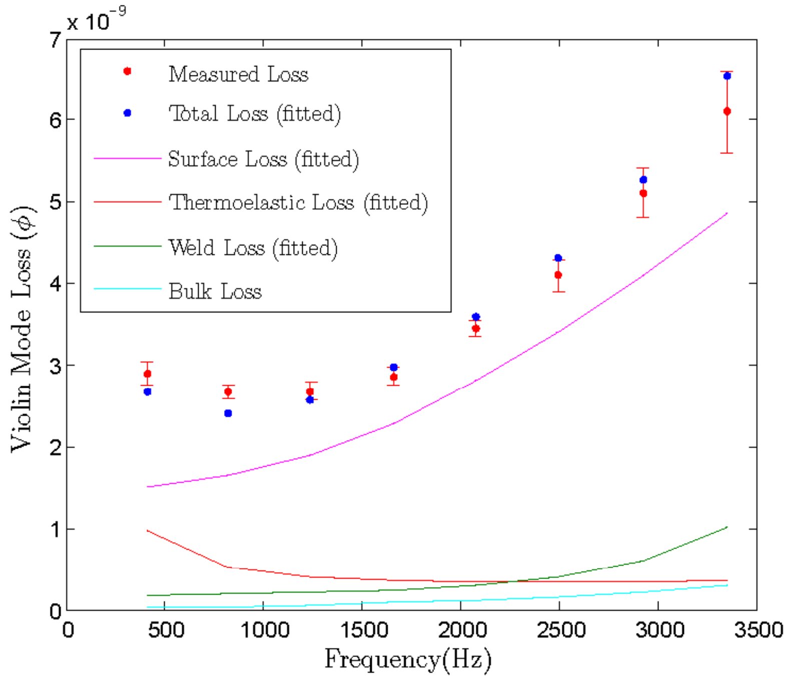


Stage 1: with mass



Stage 2: free fibre



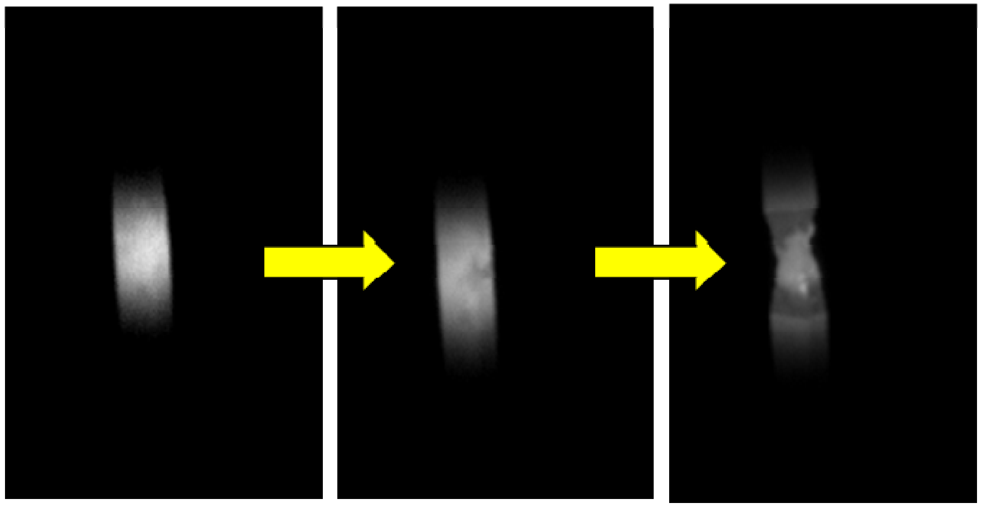
- Fit with $\beta=1.5\times10^{-4}K^{-1}$

- Stage 2: allows fitting to surface loss and thermoleastic α
- Stage 1: allows fitting to surface loss and thermoleastic $(\alpha - \sigma_o \beta / Y)$

R&D for ET-LF

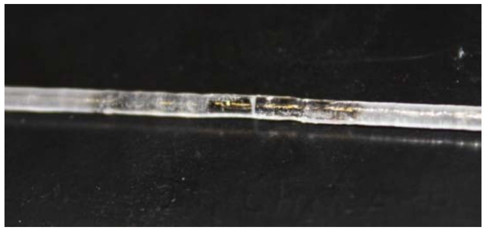
Crystal Growth Machine

- There is significant interest for growing fibres of sapphire and silicon
- The original aLIGO fibre puller with shorter stage is currently being upgraded to grow crystalline fibres via Laser Heated Pedestal Growth

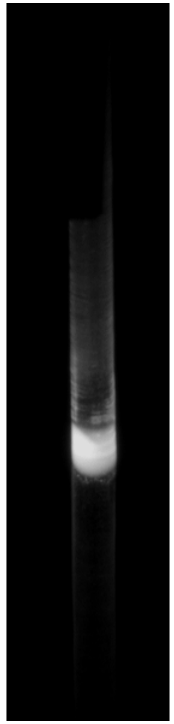


Silicon heating at 10.6 um (in air)

Silicon melted at 90W in air



Sapphire jointed at 80W

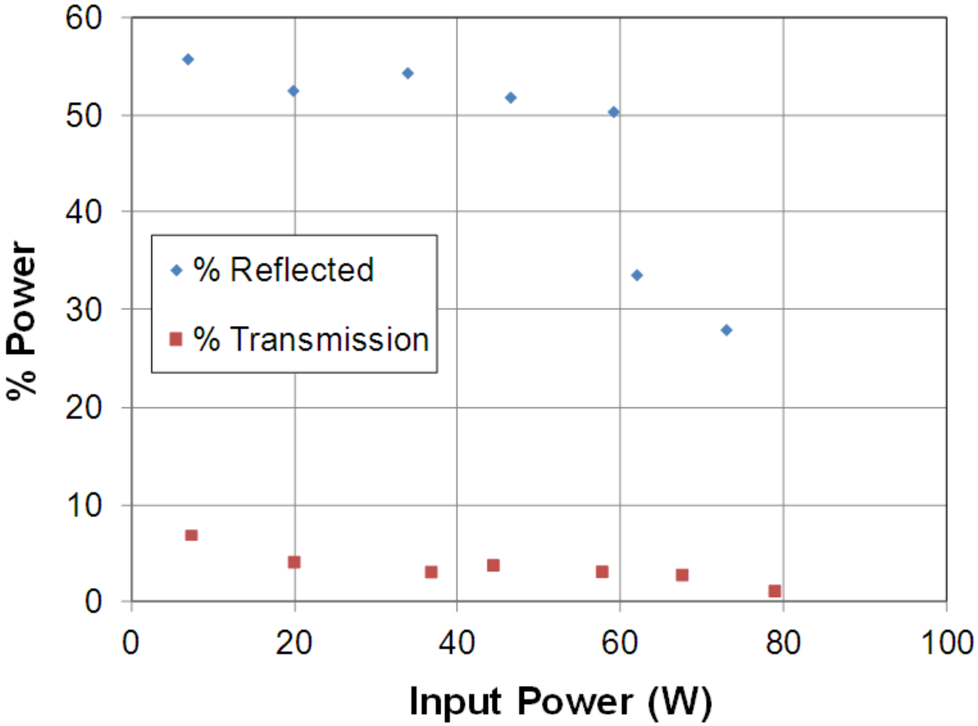


M.M. Fejer et al., Rev. Sci. Instrum, 55 (11), 1994

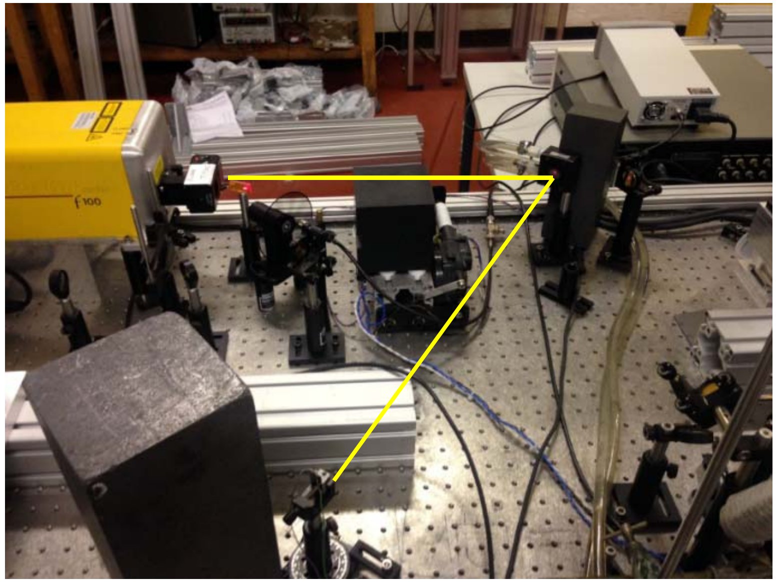
M. Alshourbagy, Development of Single Crystal Fibers for Optical, Scintillation and Mechanical Applications, PhD Thesis,

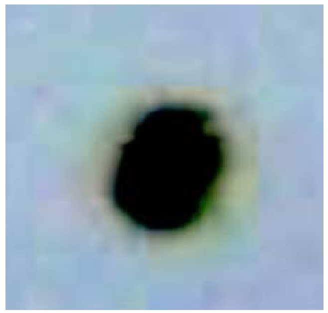
Measurement of Silicon at 10.6μm

- The emissivity of silicon varies significantly as a function of temperature
- At the melting point there is ≈2× change of reflectivity



- Reflectance/Transmission at 10.6μm



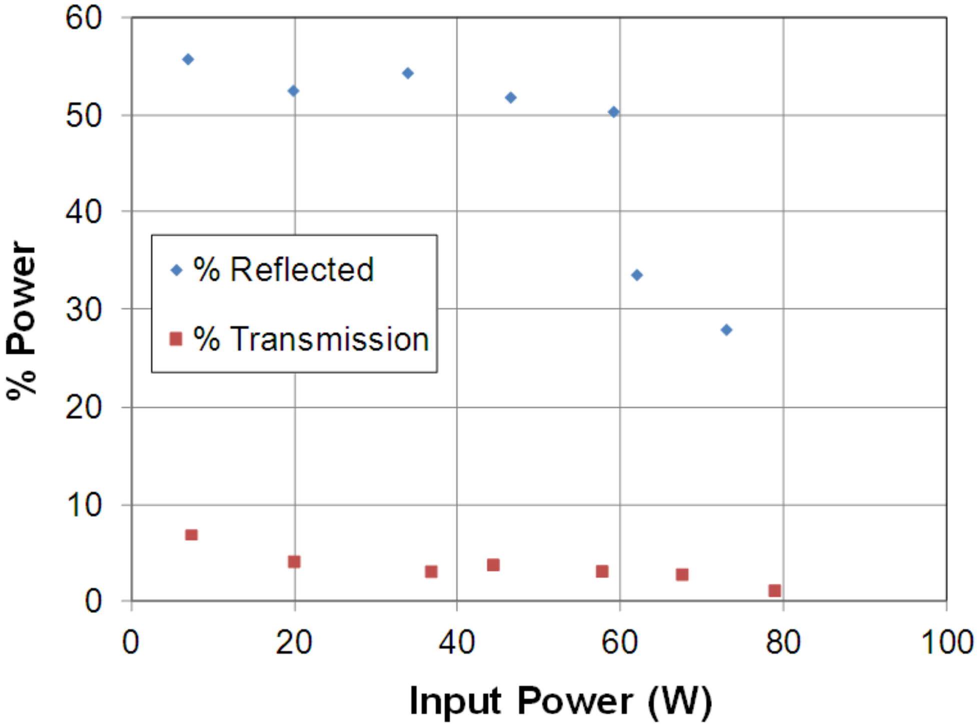


- CO_2 test setup and transmitted beam quality

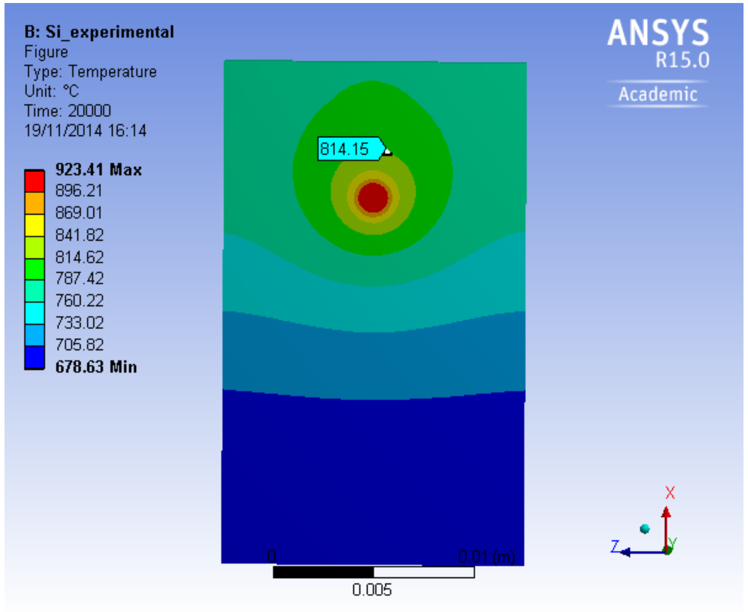
Thermal Modelling of Silicon

• It is important to model the thermal effects in laser heated silicon to understand and optimise the growth process (reflectivity, absorption, viscosity etc…)

• Using ANSYS Workbench/FLUENT with user defined functions for the thermo-mechanical properties

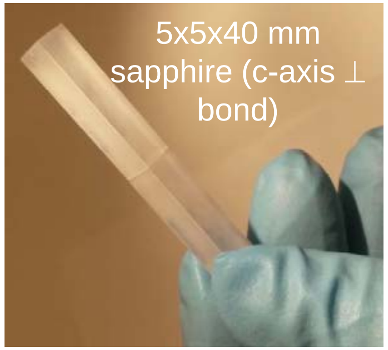


• Reflectance/Transmission at 10.6μm

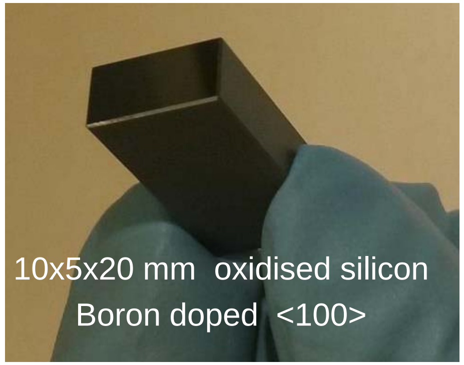


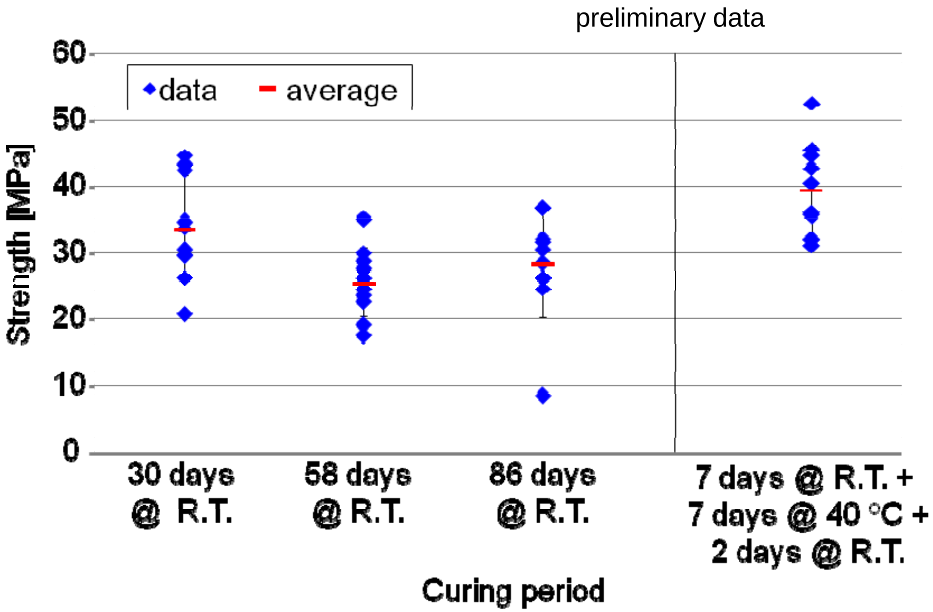
• Temperature of silicon 8mm from beam centre (good agreement with PT1000 measurements)

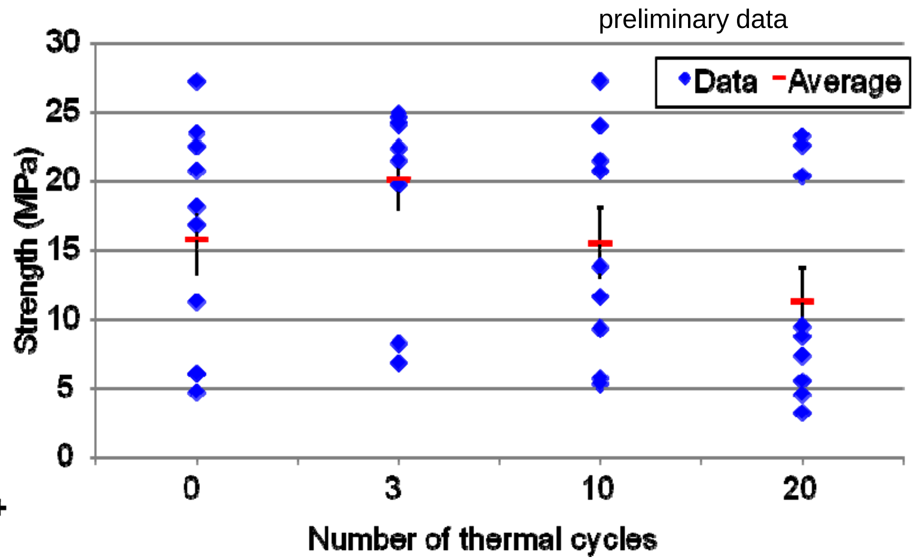
Hydroxide Catalysis Bonding



- Research on bonding is currently focussing on strength as a function of curing length and thermal cycling
- see poster 39 (van Veggel)







- All samples broke clean across the bond
- Some dimensional checks ongoing

- 30% failed across the bond, 70% failed diagonally across the bulk material
- No difference in strength within standard error of measurements

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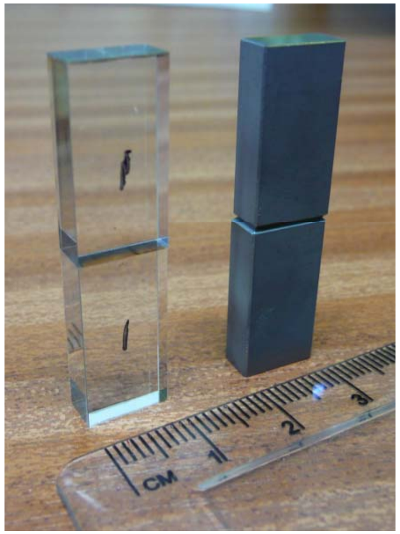
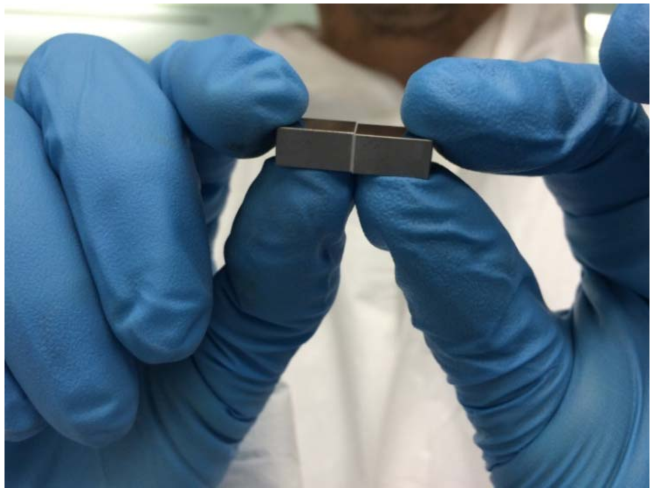
Other Bonding Research

- Thermal conductivity measurements ongoing of:
  - 5x5x40 boron doped P-type hydroxide catalysis bonded silicon sample (and reference)
  - Indium bonding of 3 sapphire samples and 3 silicon samples indium (with gold chrome adhesion layers from Gooch and Housego)

- Strength testing of indium bonded silicon samples with ~500 nm thick pure indium evaporated coating

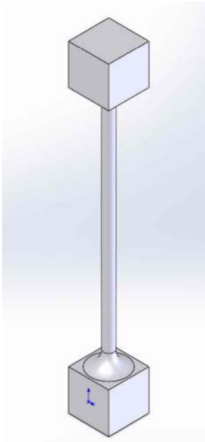
- Measurements started to determine the mechanical loss of a sapphire-sapphire hydroxide catalysis bond (sample ICRR, reference measured Jena)

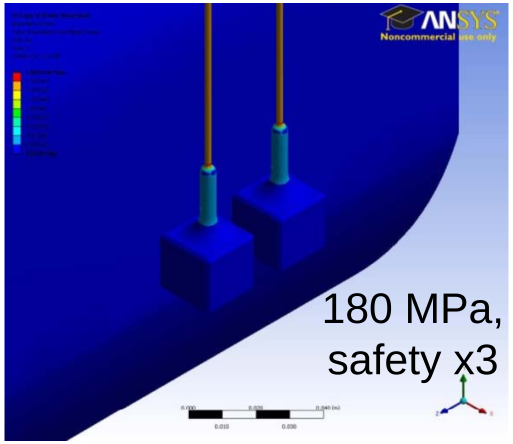




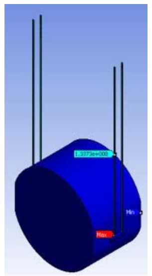
Suspension Modelling

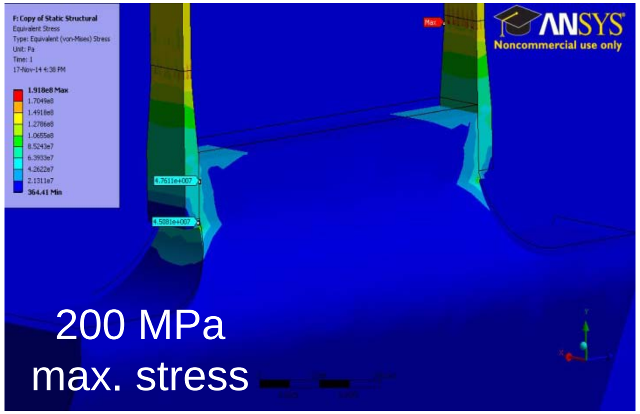
- FEA modelling of static/dynamic stress and thermal noise



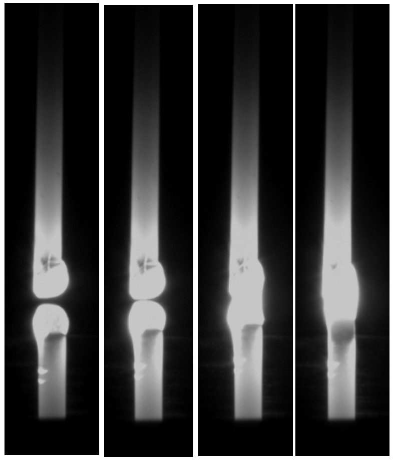


- Silicon ‘dog-bone’ with 100mm long 5mm diameter rod
- Fibre is grown from the rod.
- Plan to measure the thermal conductivity of the melt region





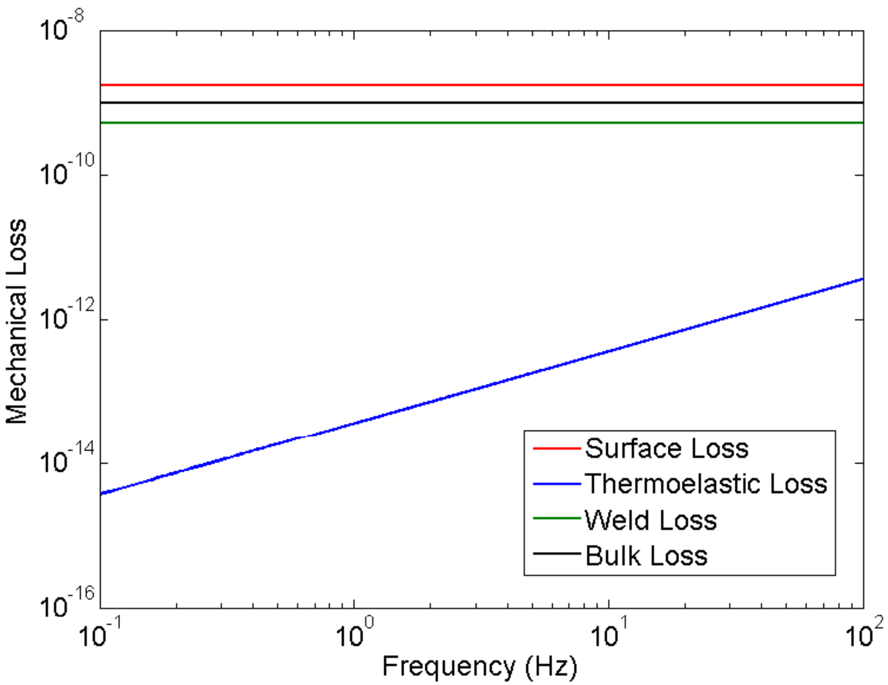
- Ribbons are easier to fabricate from wafers, but attachment is a challenge
- Ribbons are not as stiff as fibres => more sensitive to bond loss

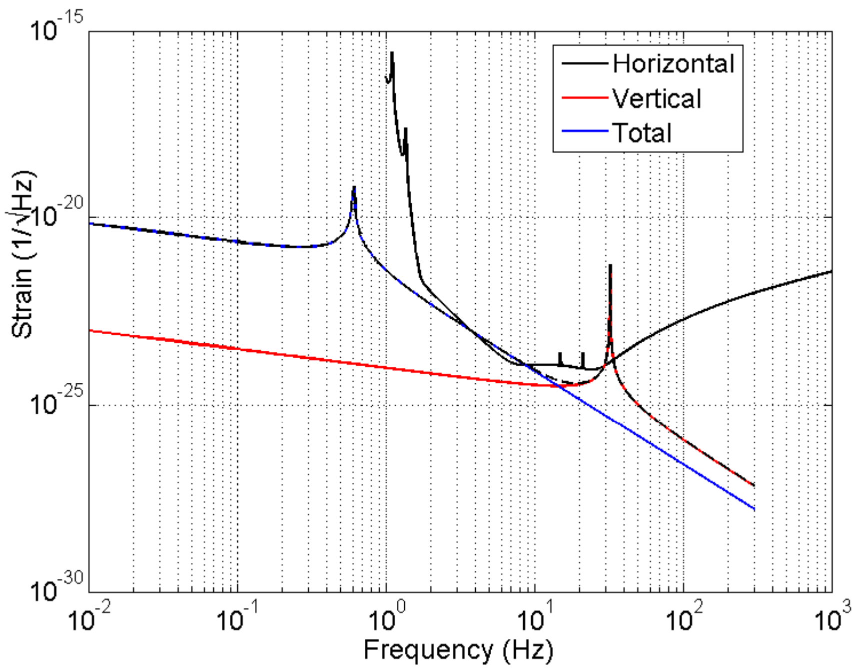


- “welding” crystalline materials
- Generate melt and feed crystal to join liquid bridge
- Plan to measure the thermal conductivity of the weld

Suspension Modelling

- Circular silicon fibres which can be grown or welded seem to be an interesting method for suspension construction
  - – good performance in terms of stress (safety factor x3).
  - – end attachment points are relatively easy to slot into hydroxide catalysis bonded inserts on the side of the test mass





Summary

- Plenty of R&D focussed towards low thermal noise suspensions
  - Warm upgrade work is well aligned with aLIGO upgrades and ET-HF (heavy silica test masses and long thick suspension fibres)
  - New pulling machine will facilitate fibre research
  - Interesting results on thermoelastic cancellation
  - Next steps will focus on fabricating a 160kg suspension
- Cold upgrade work is well aligned with KAGRA and ET-LF (sapphire/silicon)
  - Work ongoing to develop fibre crystal growth apparatus (measurements of emissivity at 10.6μm)
  - Bonding tests will focus on thermal cycling, influence of thermal expansion between different crystal orientation, surface quality, curing time/method
  - An important step is engineering the suspension => looking at realistic technique to grow and attach fibres
  - Jointing of crystalline materials via “welding” is interesting, and the thermal conductivity of the “polycrystalline phase” will need to be assessed