Cryogenic suspensions development at the Glasgow Cryogenic Interferometry Facility

KAGRA International Workshop, Perugia 2026

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Overview

Glasgow Cryogenic Interferometry Facility

Cryogenic suspension development:

- Silicon fibre production (at IKZ Berlin)
- Silicon fibre characterisation
- Sapphire fibre production
- Sapphire laser welding
- Suspension thermal noise modelling
- Bonding of crystalline materials

Introduction

Glasgow Cryogenic Interferometry Facility

Cryogenic suspension development:

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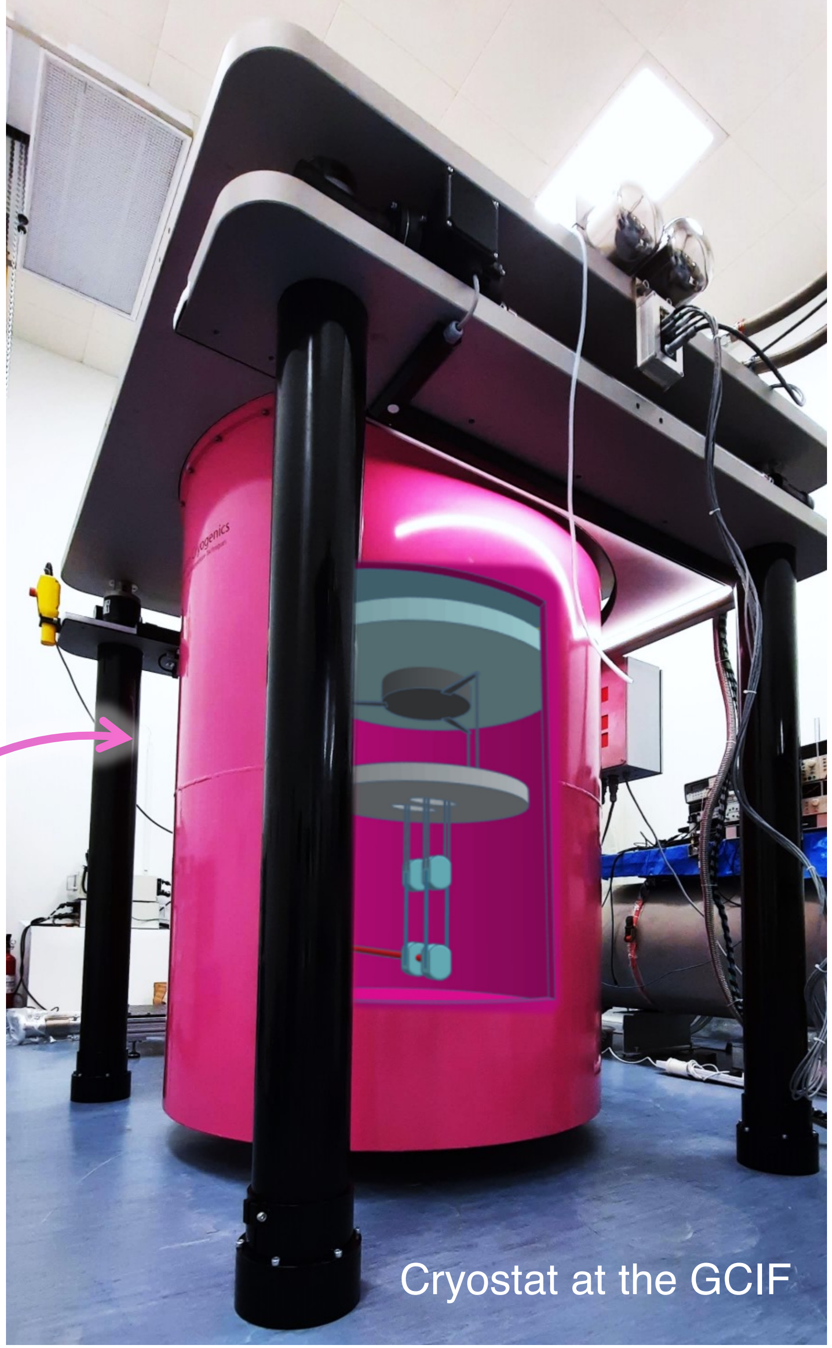
The GCIF

The Glasgow Cryogenic Interferometry Facility is a research facility developed by the Institute for Gravitational Research at the University of Glasgow.

The research at the GCIF will address critical R&D for:

- Einstein Telescope
- LIGO Voyager
- Cosmic Explorer
- KAGRA

Plans for a demonstration of a fully crystalline cryogenic suspension!



Cryostat at the GCIF

The GCIF

Glasgow Cryogenic Interferometry Facility

Research themes:

- Monolithic Crystalline Suspensions
- Silicon – Sapphire Bonding
- Cryogenic Coatings and Substrates
- Cryogenic Suspension Sensors and Actuators
- Long Wavelength Laser Stabilisation
- Cavity Control

Research activities:

- Demonstration of a cryogenic monolithic suspension system
- Demonstration of heat extraction from a triple suspension system

- Demonstration of coating technology
- Direct coating thermal noise measurement

- Shadow sensing technology development
- ES drive actuation techniques

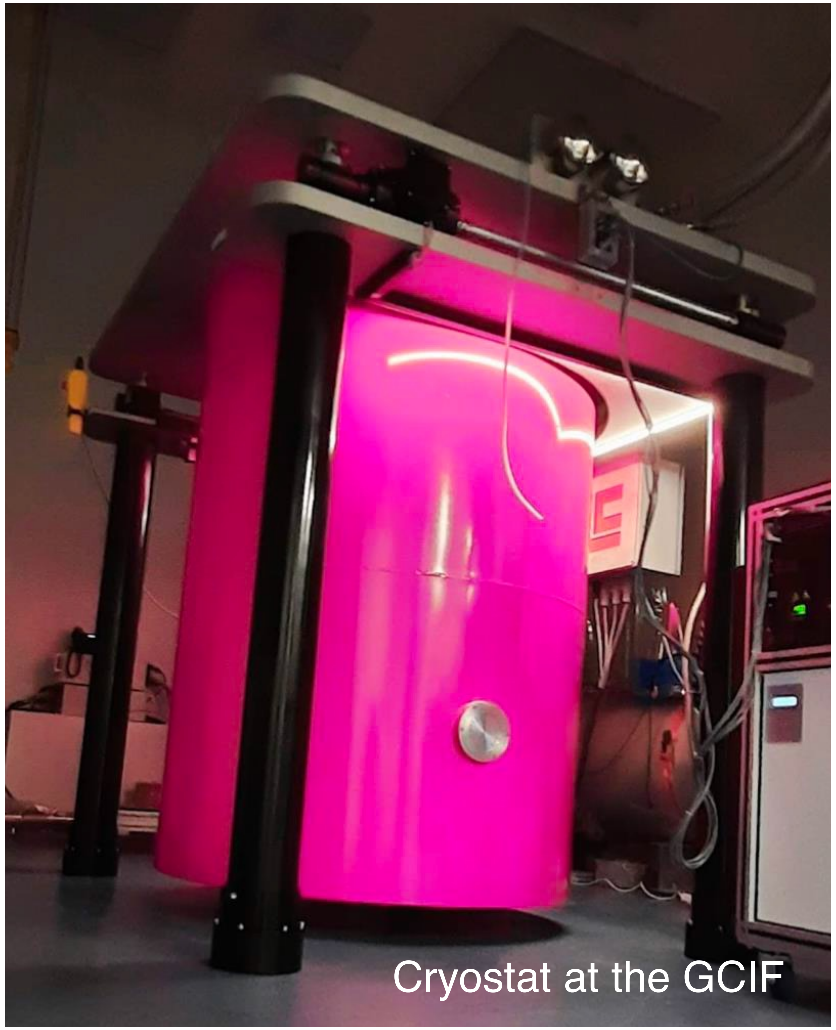
- Frequency stabilization, intensity stability , mode cleaning

- 1550 nm and 1980 nm Pre-stabilised Laser system concepts

- Demonstration of control and locking of a suspension cryogenic cavity

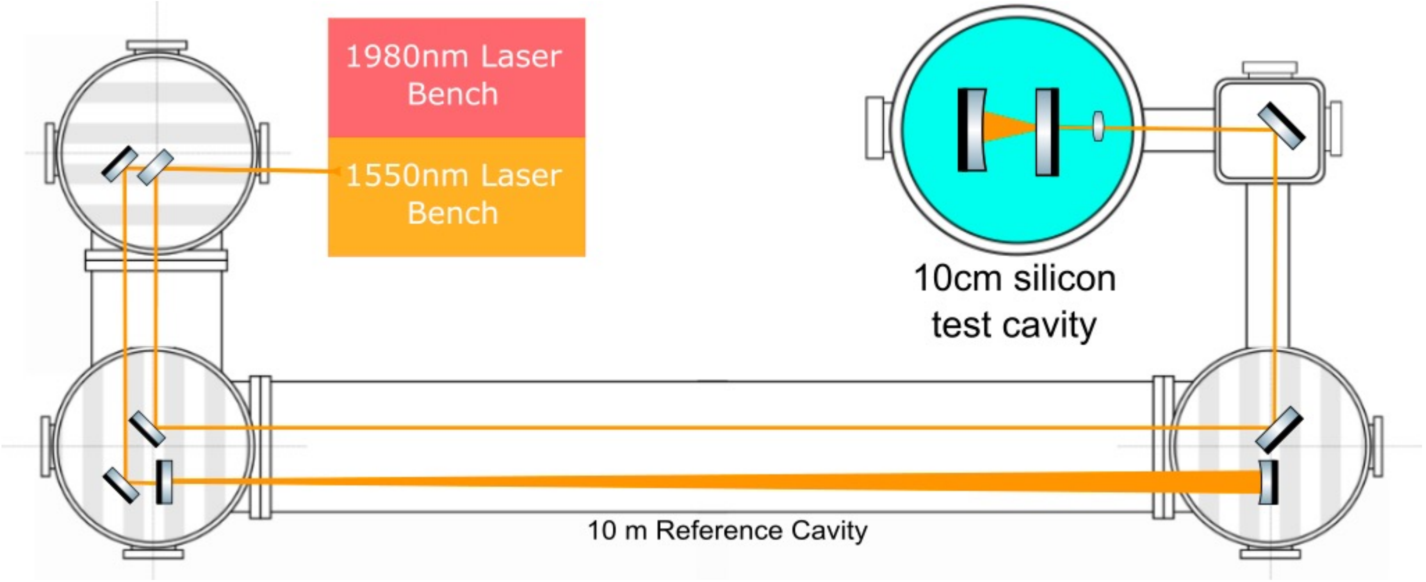
The GCIF

Glasgow Cryogenic Interferometry Facility



Cryostat information:

- Closed cycle pulsed-tube helium cooling of apparatus down to 7K
- Space for two 1kg triple suspension and reaction chains
- Inner chamber dimensions: 1m tall, 1 m in diameter.



System layout

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Glasgow Cryogenic Interferometry Facility

M0 =Cold plate

6x steel blade springs
6x 30cm steel wire

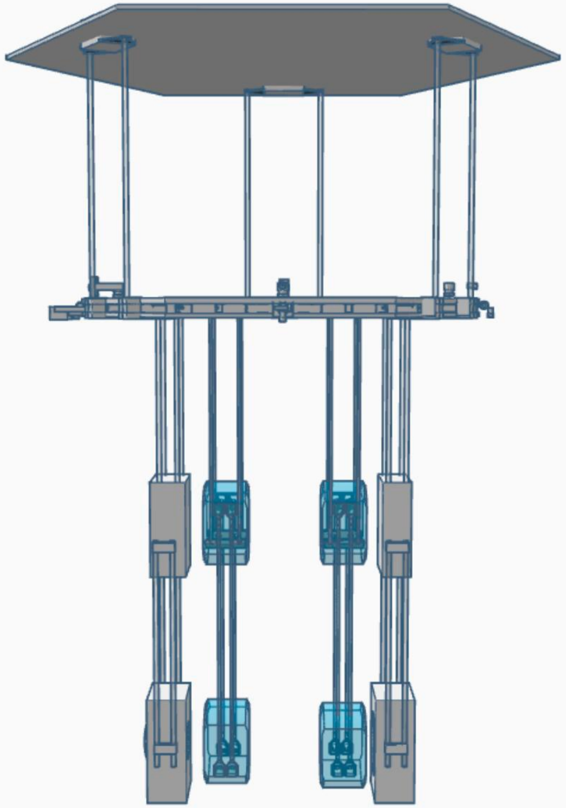
M1=Common Platform

8x steel blade springs
8x 30cm steel wire

M2 = Penultimate silicon 1kg mass

8x 25cm crystal fibres

M3 = Test-Mass 1kg silicon mirrors



4K Cold plate

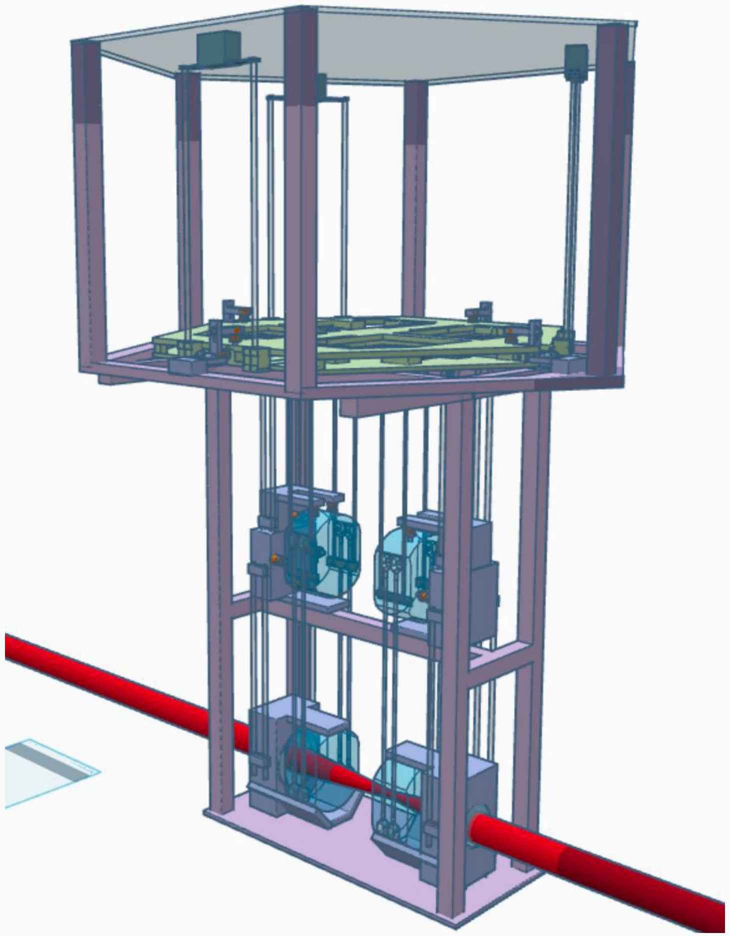
Support Structure

Common Platform

Double pendulum test mass chains

Reaction masses

Pre-stabilised laser input



Cryogenic suspension development

Glasgow Cryogenic Interferometry Facility

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- Bonding of crystalline materials

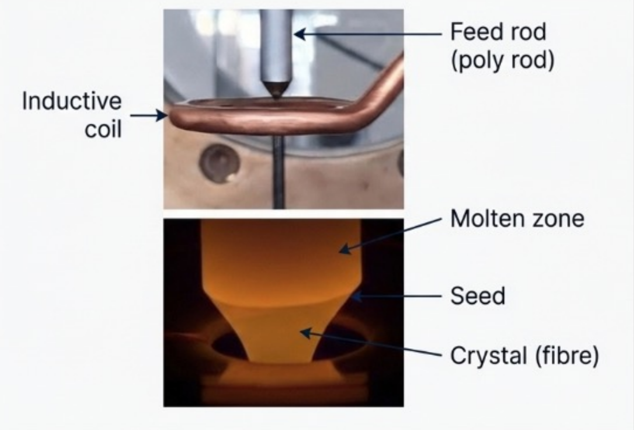
ikz LEIBNIZ-INSTITUT FÜR KRISTALLZÜCHTUNG
im Forschungsverbund Berlin e.V.

Silicon fibre production

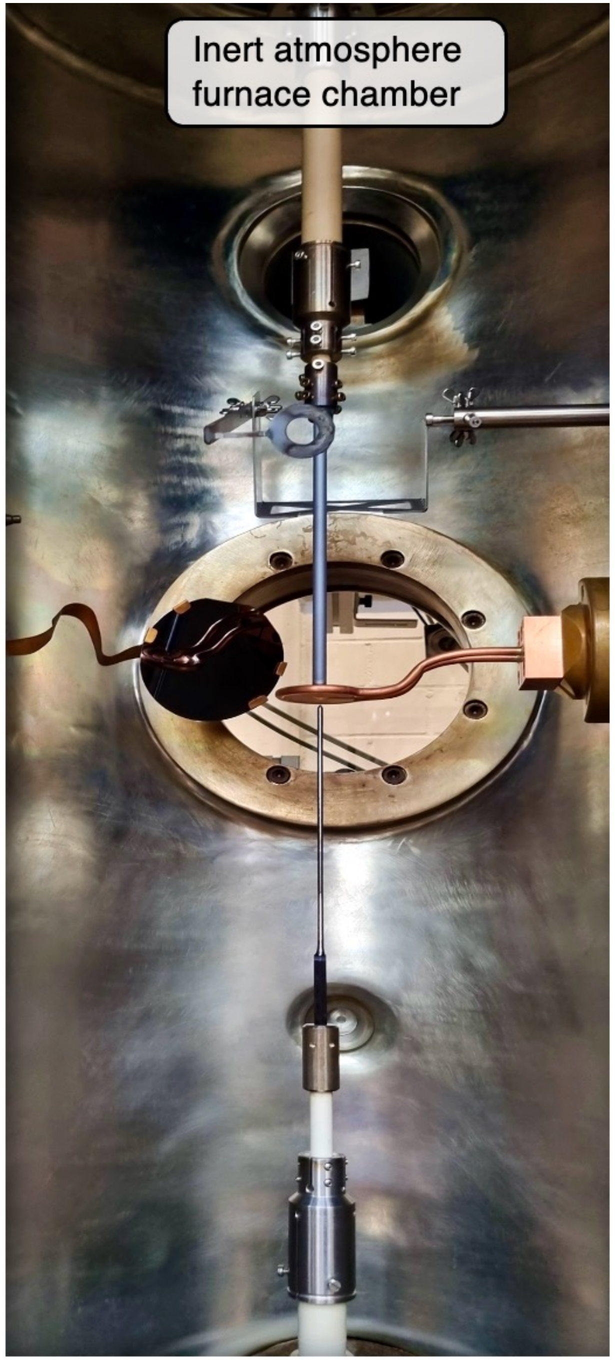
Float-zone technique produces *high purity, contaminant free*, *single crystal uniform* silicon fibres with exceptionally good surface quality.

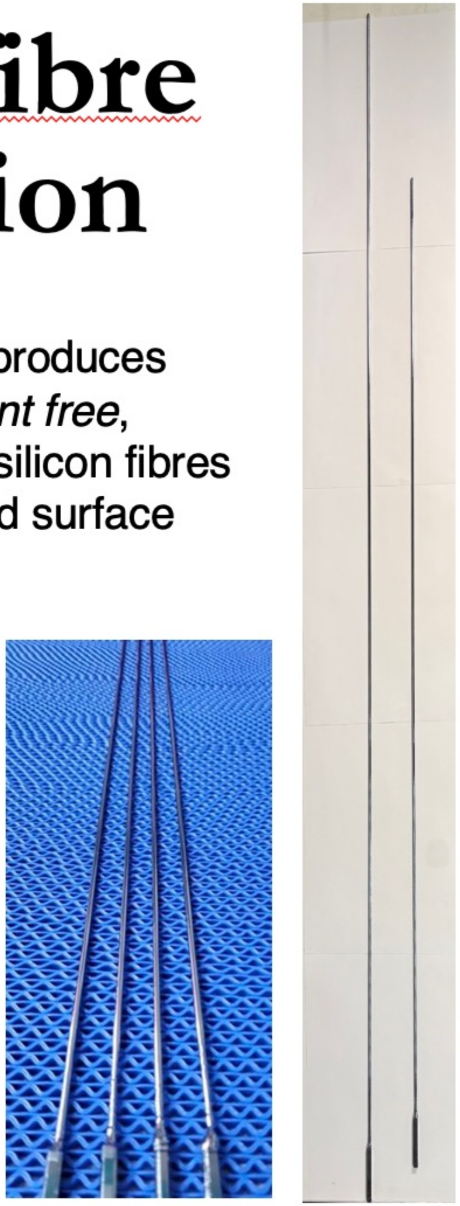
Method

1. A silicon feed rod is melted at the bottom using an inductive coil
2. The molten zone contacts a monocrystalline seed
3. The seed is moved downwards, and crystallisation begins
4. Molten silicon solidifies into a large single crystal silicon fibre without direct contact with seed rod, minimising impurities



Growth direction





ø 3 mm 150 and 120 cm fibres, respectively

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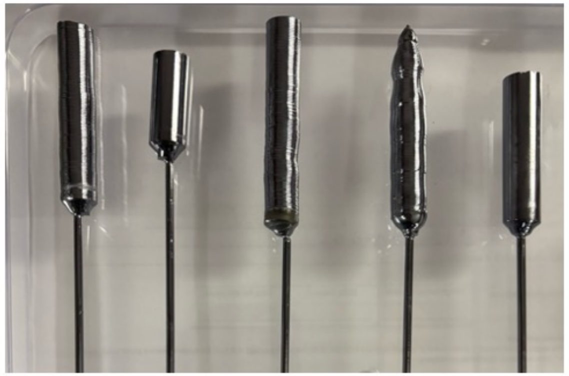
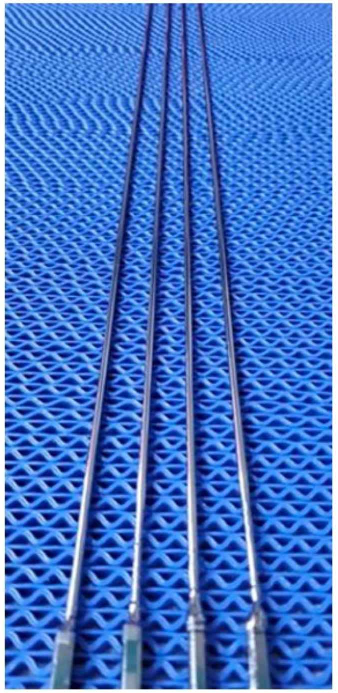
Silicon samples produced

For more information on the silicon characterisation see the talk of Michele Dicorato tomorrow

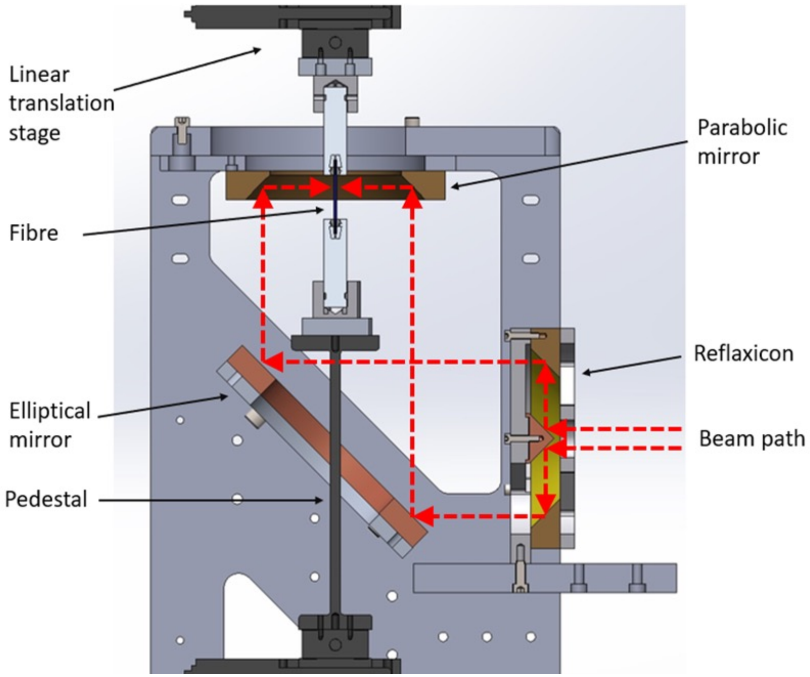
Welded fibres:	Shaped fibres:	Grown fibres:
3 mm diameter welded to < 14 mm ”head”	3 to 8 mm diameter, up to 150 cm length	1 to 8 mm diameter, up to 150 cm length





Sapphire fibre growth

Using our Crystal Growth Machine (CGM), the **laser heated pedestal growth** method was used to **develop a process for growing sapphire fibres** [1] up to 1 mm in diameter, and up to 350 mm in length



Further development and characterisation to continue after an upgrade to the CGM. Plans to explore inducing specific neck geometries in fibres.

*Grown **sapphire fibre** produced with low diameter variation, good surface quality and peak strength of 792 MPa (unbroken).*

[1] J. Callaghan. "Development of crystalline suspension fibres for next generation gravitational wave detectors." PhD thesis, University of Glasgow, Aug 2024

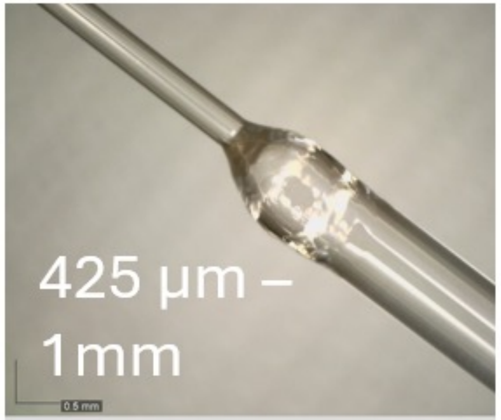
Sapphire Laser Welding

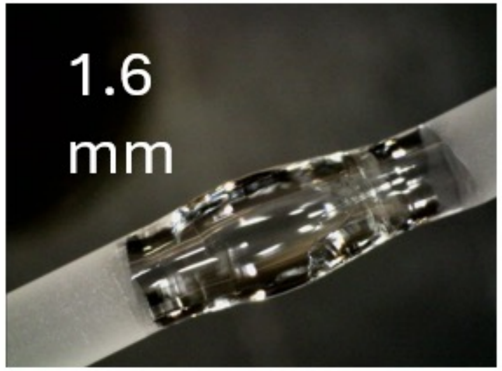
- The **sapphire laser welding method** was developed at Glasgow [2], with a variety of different diameters successfully attached

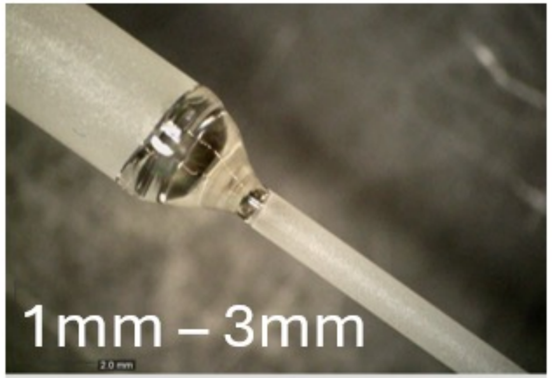
- The method was found to be **repeatable**, **reliable**, and **repairable** across over 100 samples

- Three sample sets were produced with differing surface finishes

- A **laser polishing process** was also developed to increase tensile strength







[2] Docherty, J. P., et al. "Laser welding of crystalline sapphire for use in future generation gravitational wave detector suspensions." Physical Review D 113.2 (2026).

Crystalline fibre parameters needed for the development of a suspension system

Property	Silicon	Sapphire
Crystallinity	Monocrystalline	Monocrystalline
Thermal conductivity at 20K	4500 W/m/K	6000 W/m/K
Tensile strength	335 MPa + ongoing	1 GPa + ongoing
Mechanical loss	Measurements ongoing	Measurements ongoing
Bonding	Demonstrated	Demonstrated
Welding	Demonstrated; characterisation ongoing	Demonstrated; characterisation ongoing

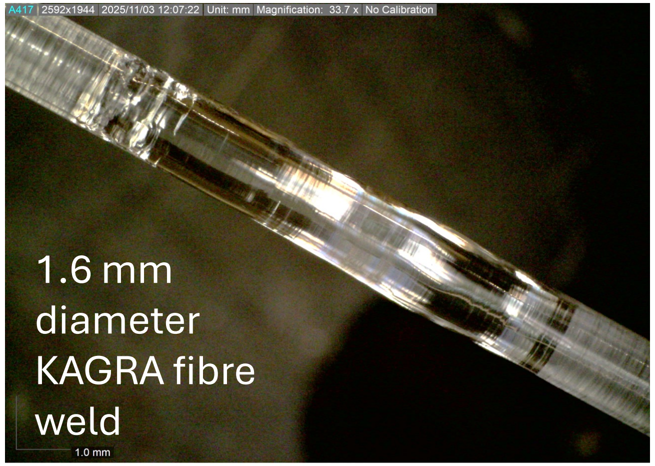
Characterisation of welded samples

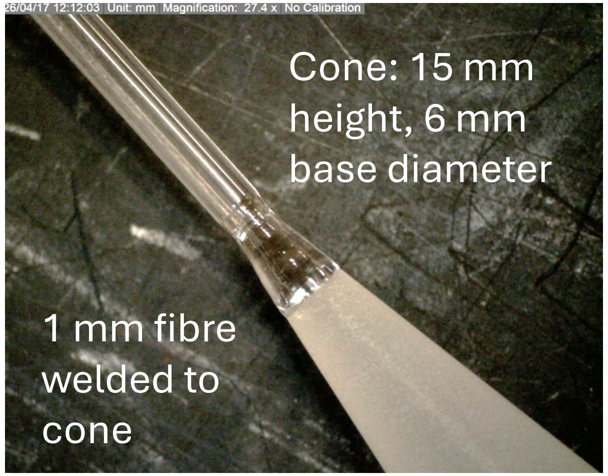
Characterisation	Result
Crystallography via X-ray diffraction	Arbitrary c-axis rotation at weld region, measured to be at most 200 μm
Tensile strength	Welds stressed up to 1.1 GPa without breaking
Thermal conductivity	No measured observable reduction in TC due to welding
Quality factor/mechanical loss	Highest average Q measured to be 3.2e6, allows for an estimate of surface and weld loss decoupling

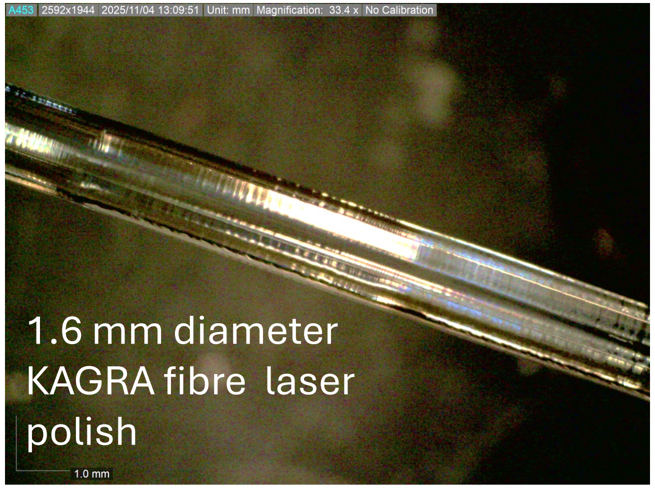
Recent welding progress

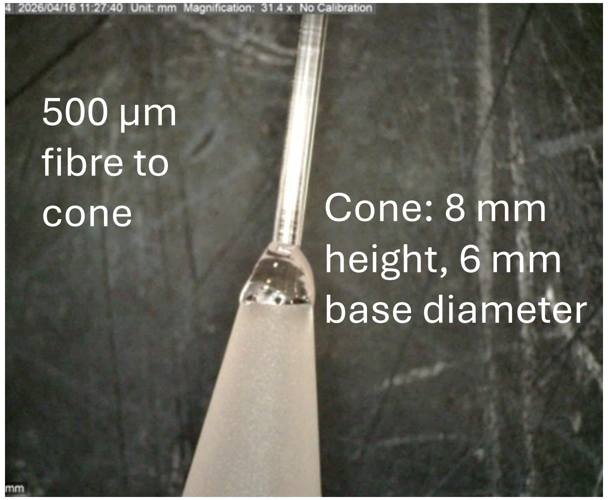
For more information on the welding and polishing of KAGRA fibres, see talk by Munetake Otsuka tomorrow

- Collaboration with researchers from KAGRA to explore applying laser welding and polishing to KAGRA fibres
- Collaboration with ET-Pathfinder to develop sapphire suspension prototypes with welded anchor ends
- Using sapphire cone samples from ET-Pathfinder, **we have successfully welded to cone geometries**, a crucial step towards developing realistic sapphire suspensions
- Characterisation including strength, angular and length accuracy, installation processes and mechanical loss to come









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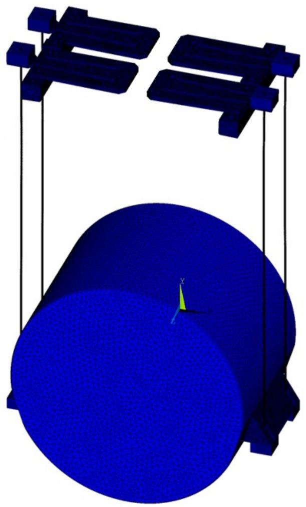
Suspension thermal noise modelling process

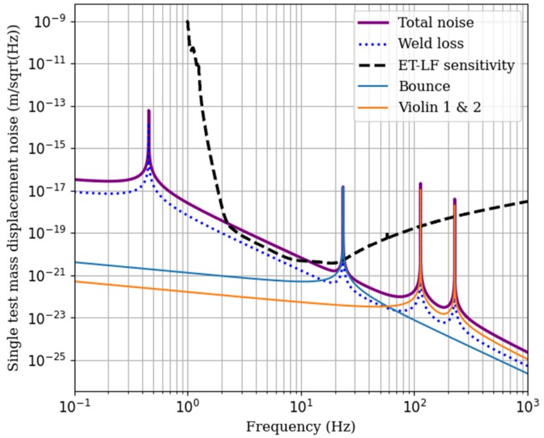
Mechanical loss measurements

Mechanical loss decoupling (jointing and surface)

FEA Model of suspension design



Calculate suspension thermal noise



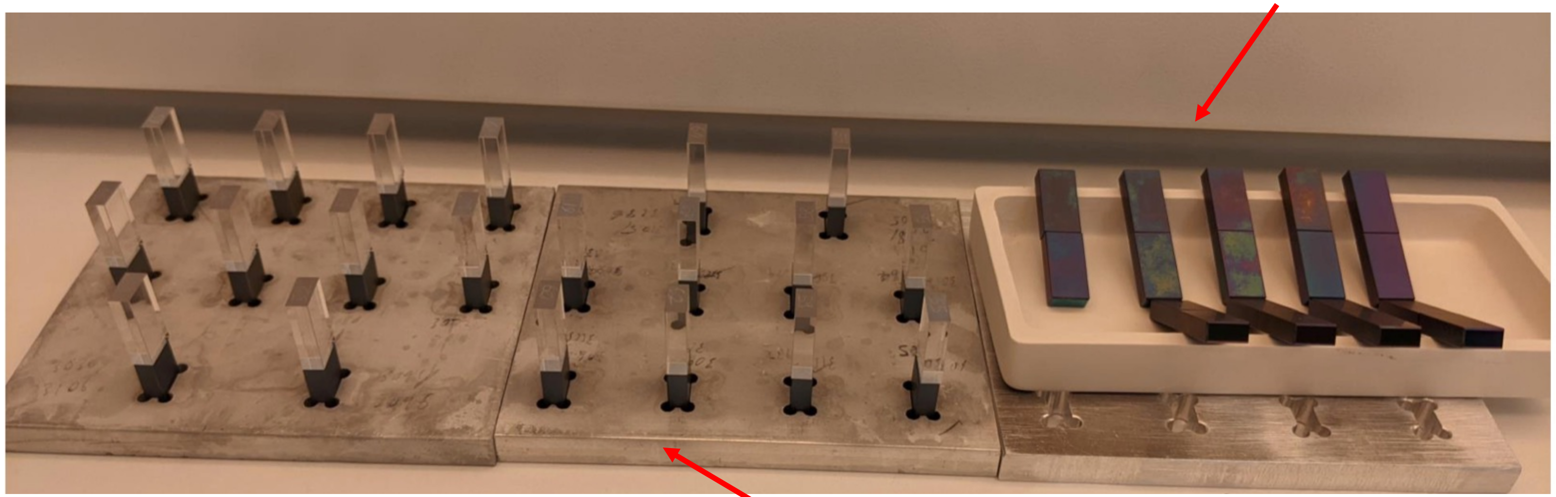
Repeat with design changes!

We have modelled an ET scenario with welded sapphire fibres using loss measurements. This will also be done for KAGRA once loss terms are defined.

Bonding of crystalline materials

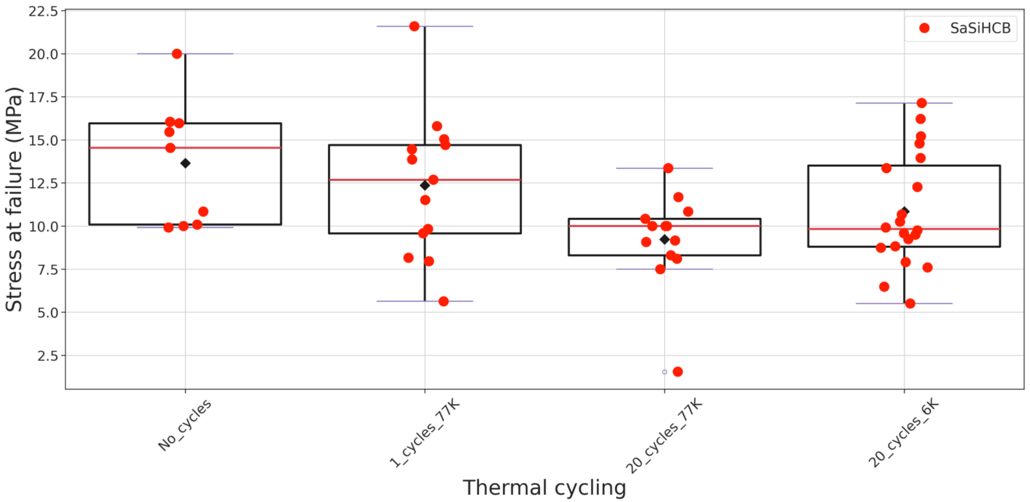
Hydroxy-Catalysis Bonding

Directly bonded Si samples annealed to 1000 C



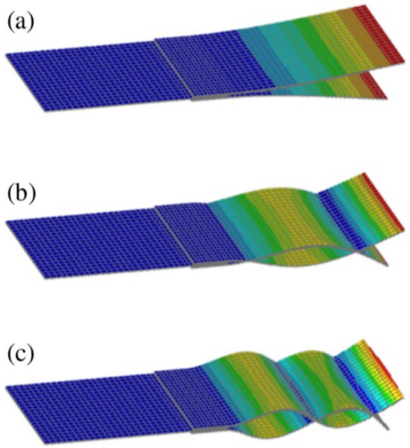
Silicon/Sapphire sodium silicate bonds after several thermal cycling down to 4K

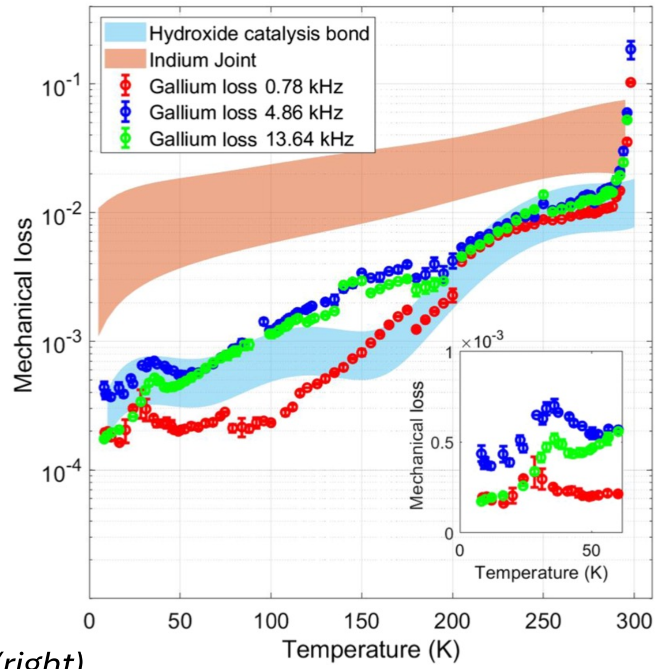
4-point bending strength of HCB Silicon to Sapphire depending on thermal treatment



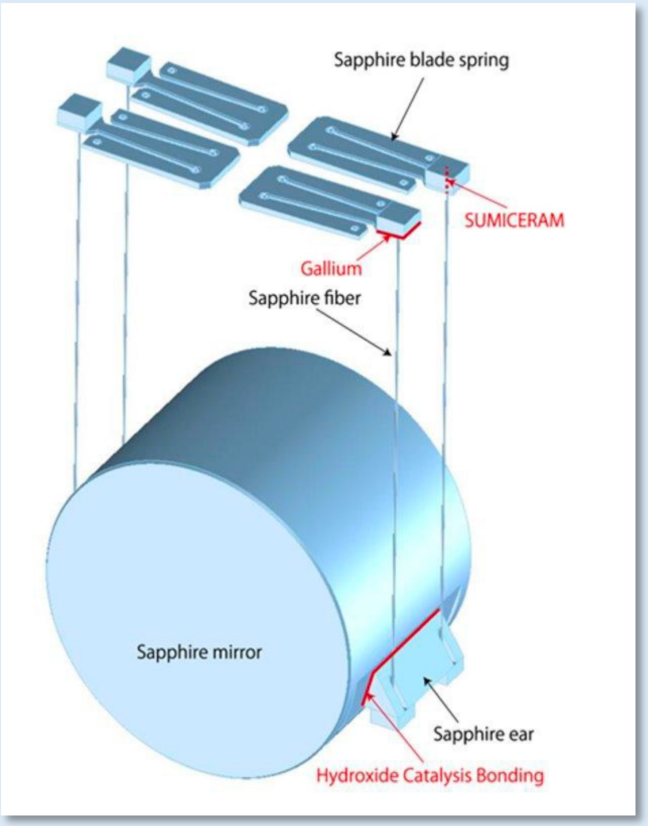
Bonding of crystalline materials

Gallium bonding





FEA of the resonant modes of Gallium bonded Si tuning forks (above), mechanical loss measurement results (right).



Currently collaborating with KAGRA to better understand the loss contributions due to Sumiceram bonds.

[3] Karen Haughian et. al. "Temperature Dependence of the Mechanical Dissipation of Gallium Bonds for Use in Gravitational Wave Detectors" Phys. Rev. Lett. 132, 231401 (2024)

Conclusion

The **Glasgow Cryogenic Interferometer Facility** addresses key R&D challenges for future gravitational-wave detectors operating at cryogenic temperatures.

Both **sapphire and silicon suspension fibres have been developed** for cryogenic detector applications, with extensive characterisation completed and further studies ongoing.

Sapphire laser welding is a promising technique for fibre-to-mirror jointing in cryogenic suspensions.

Ongoing collaboration between the Glasgow group and researchers from KAGRA is exploring the application of laser welding and polishing techniques to KAGRA suspension fibres.

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Thank you!

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