Development of a thin silica fibre pulling machine

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Overview

- Motivation for a thin fibre pulling machine
- Description of fibre pulling machine
- Fibre characterisation:
  - -Geometries of pulled fibres
  - -Breaking stress
  - -Young’s modulus of selected fibres
- Future upgrades
- Summary

Motivation for thin fibres

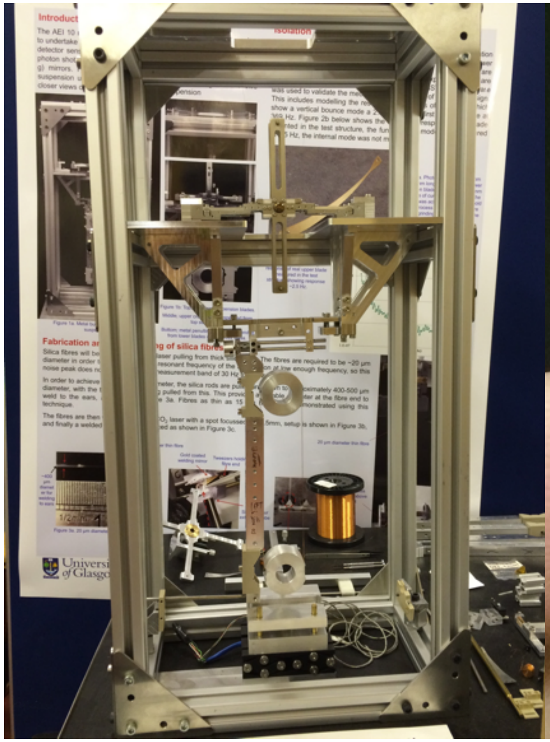
- Thinner fibres to suspend small optics for:

  -AEI 10m prototype (30 μm diameter 20 cm long) [1]

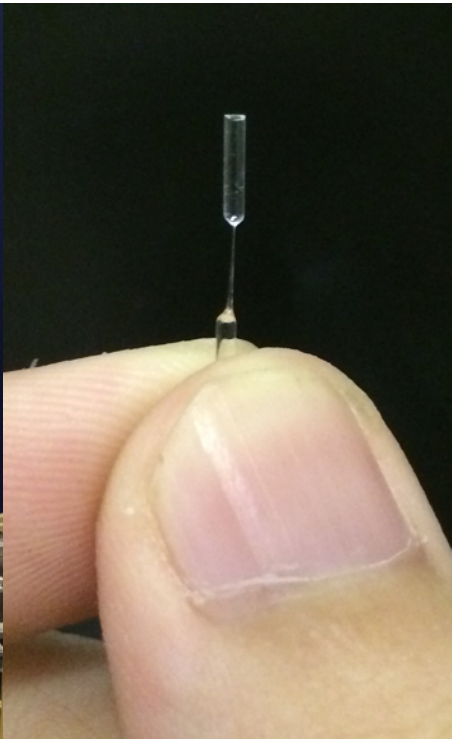
  -Radiation pressure experiments with light masses [2]

  -8 μm 1 g mirrors (See poster by Jan Hennig: 'How to suspend a mirror as light as a one dollar note')

- Flexures in borehole gravity meters (50 μm diameter 6 mm long)



AEI suspensions with 100 g mirror mass



6 mm 50 μm fibre

[1] arXiv:1111.7252 [physics.optics]
[2] arXiv:1405.2783 [gr-qc]

Thin fibre puller

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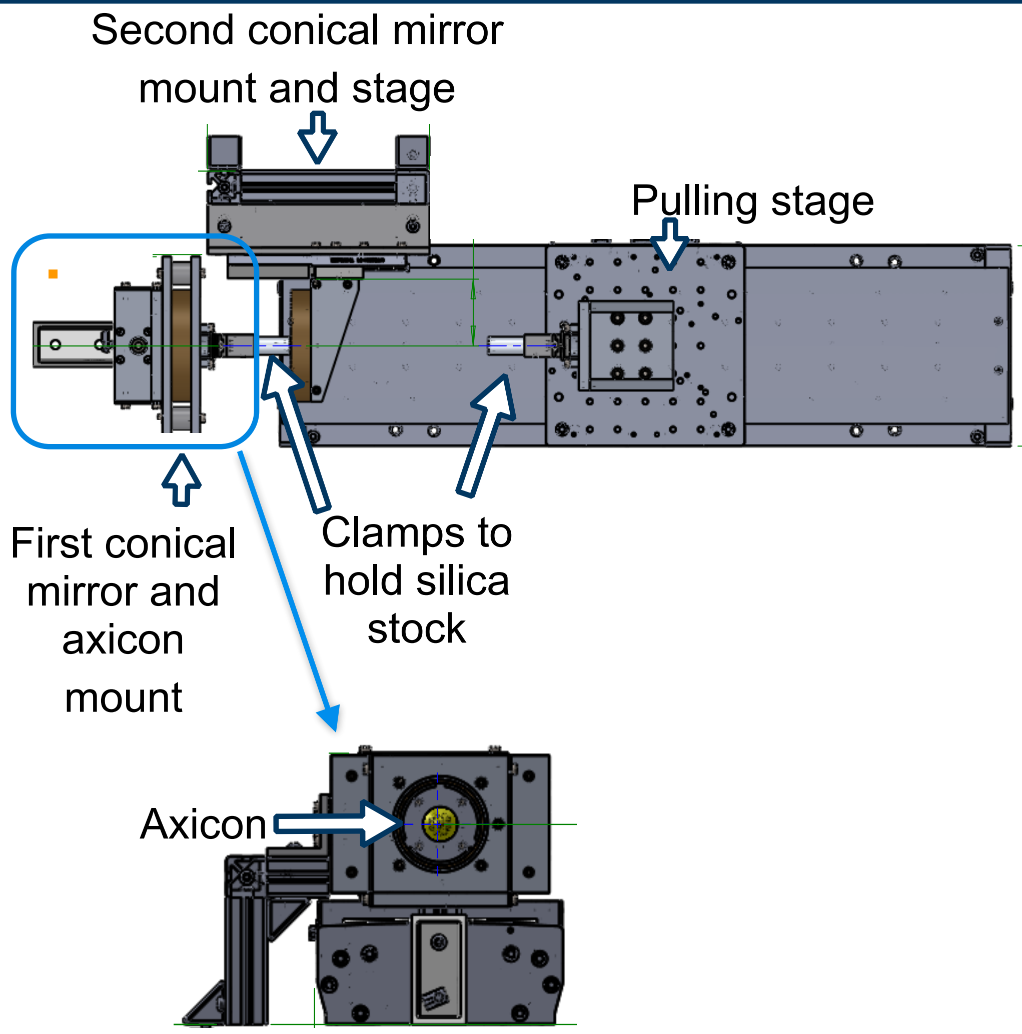
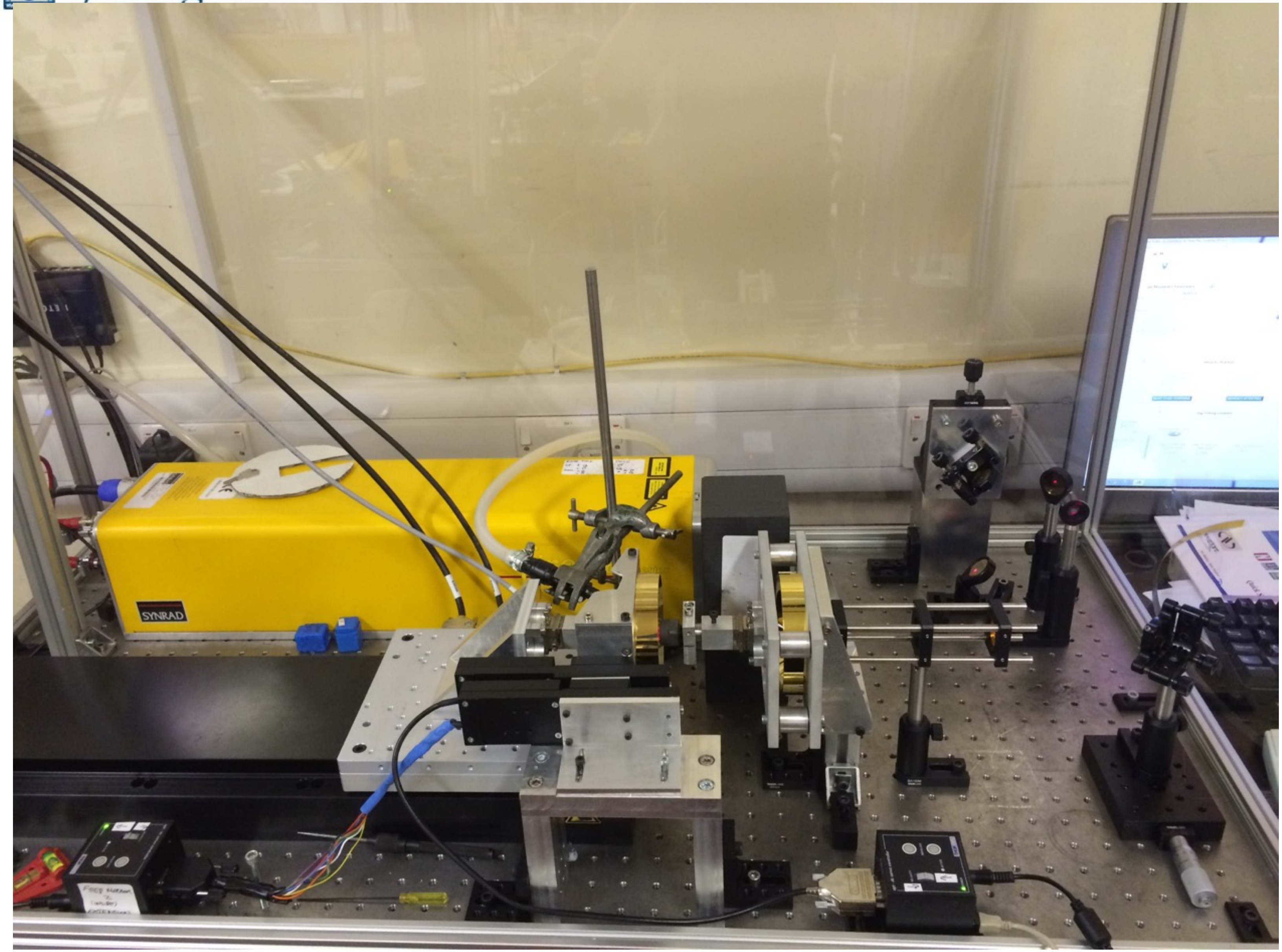
- Pulling machine utilises the high velocity and acceleration of the Newport IMS-400LM
- Stage has maximum travel length of 400 mm and maximum velocity of 500 mm/s
- The stock is heated with a 100 W CO_2 laser
- The beam passes through a ZnSe lens system to give beam waist of approximately 100 μm at focus
- The beam is spread around the stock via the use of an axicon and two conical mirrors
- Pulling stage pulls one end of the silica stock to create fibre



Drawings courtesy of Dr Liam Cunningham and Mr Russell Jones

Thin fibre puller



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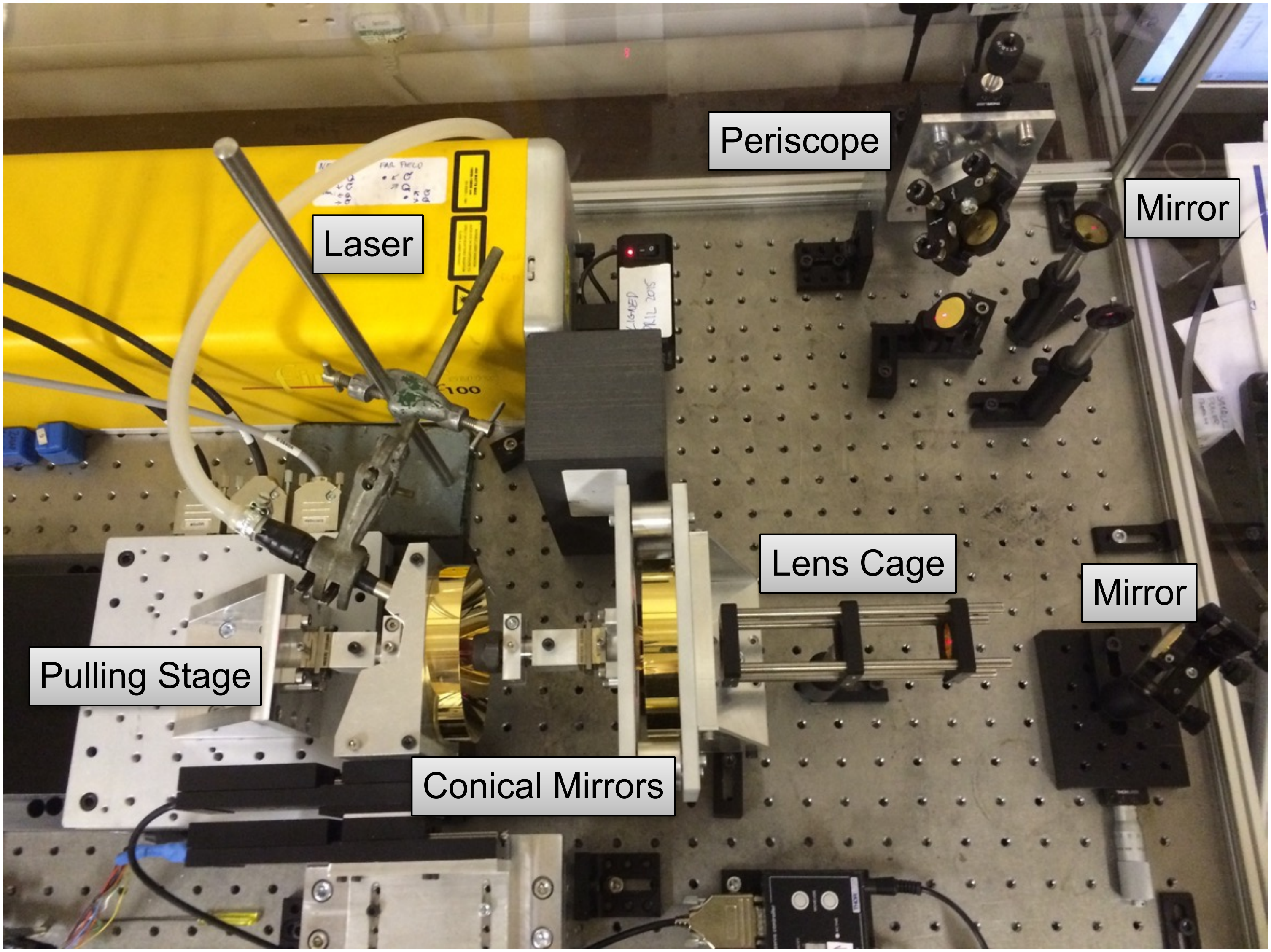
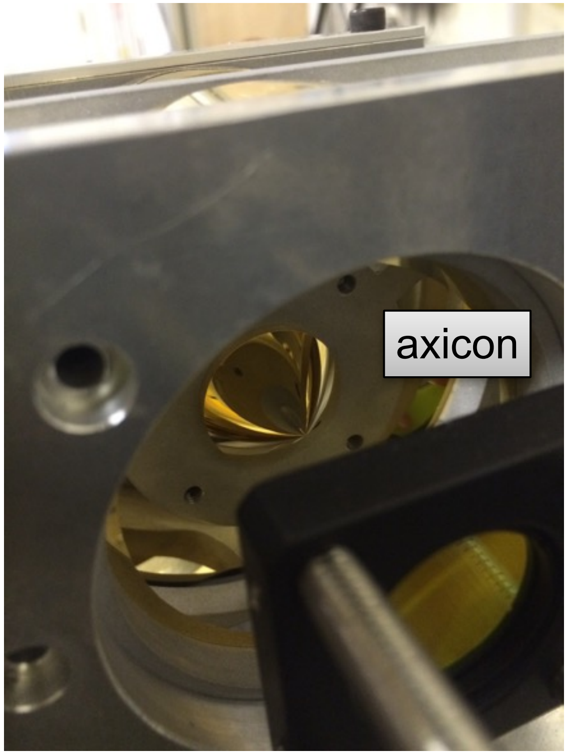
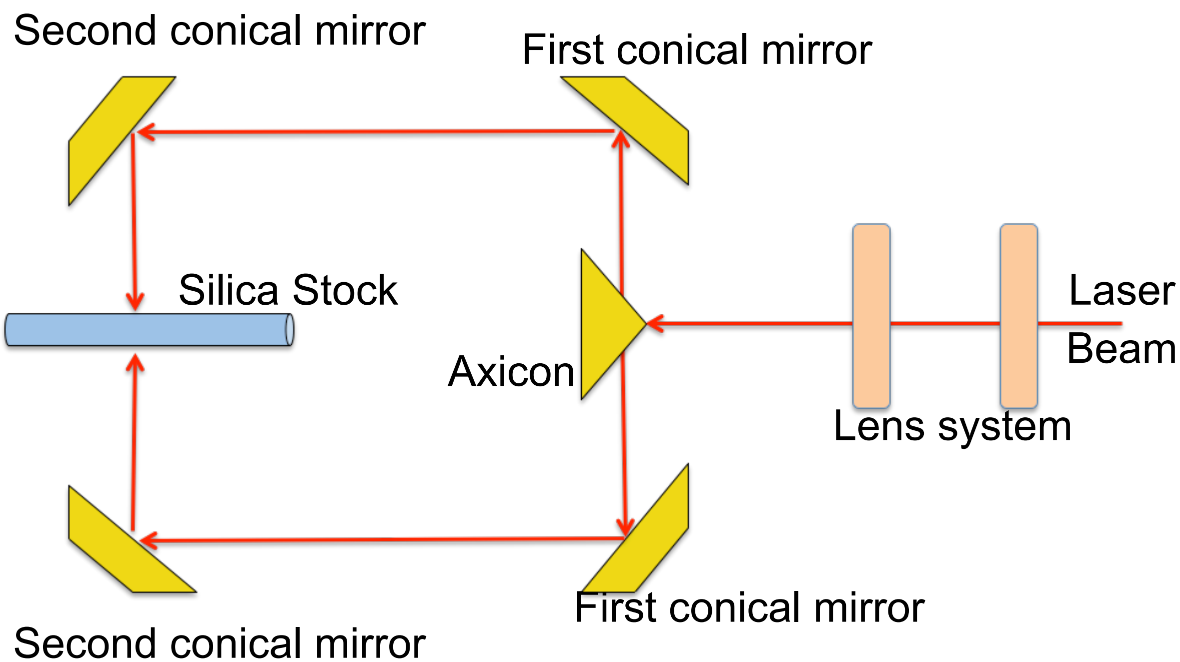


Thin fibre puller





- The use of an axicon allows a stable delivery of the beam to the silica stock due to its fixed position

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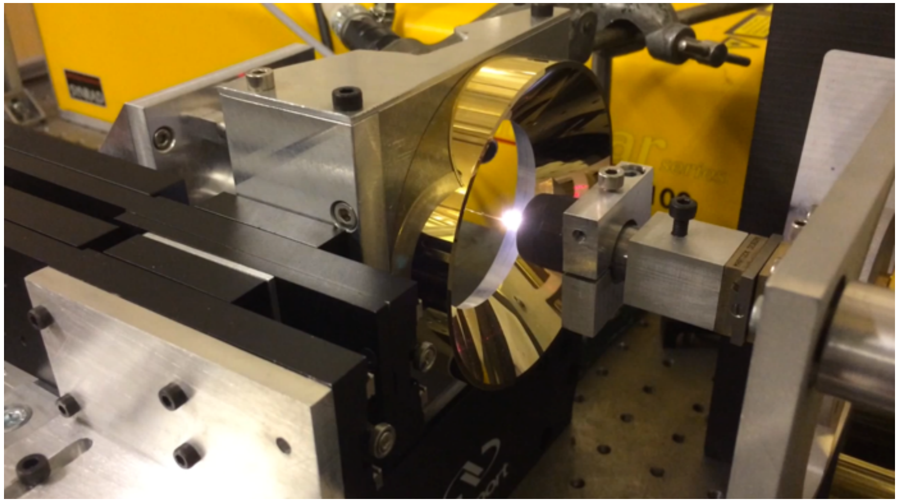
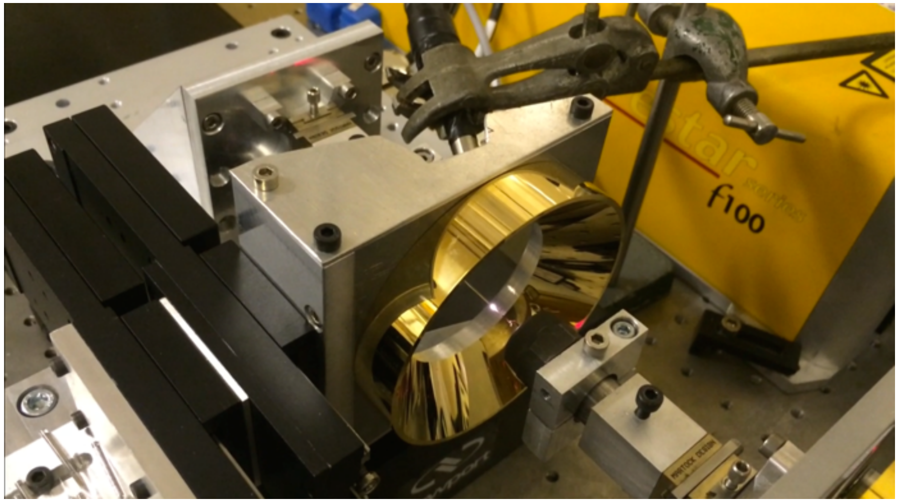
Thin fibre puller

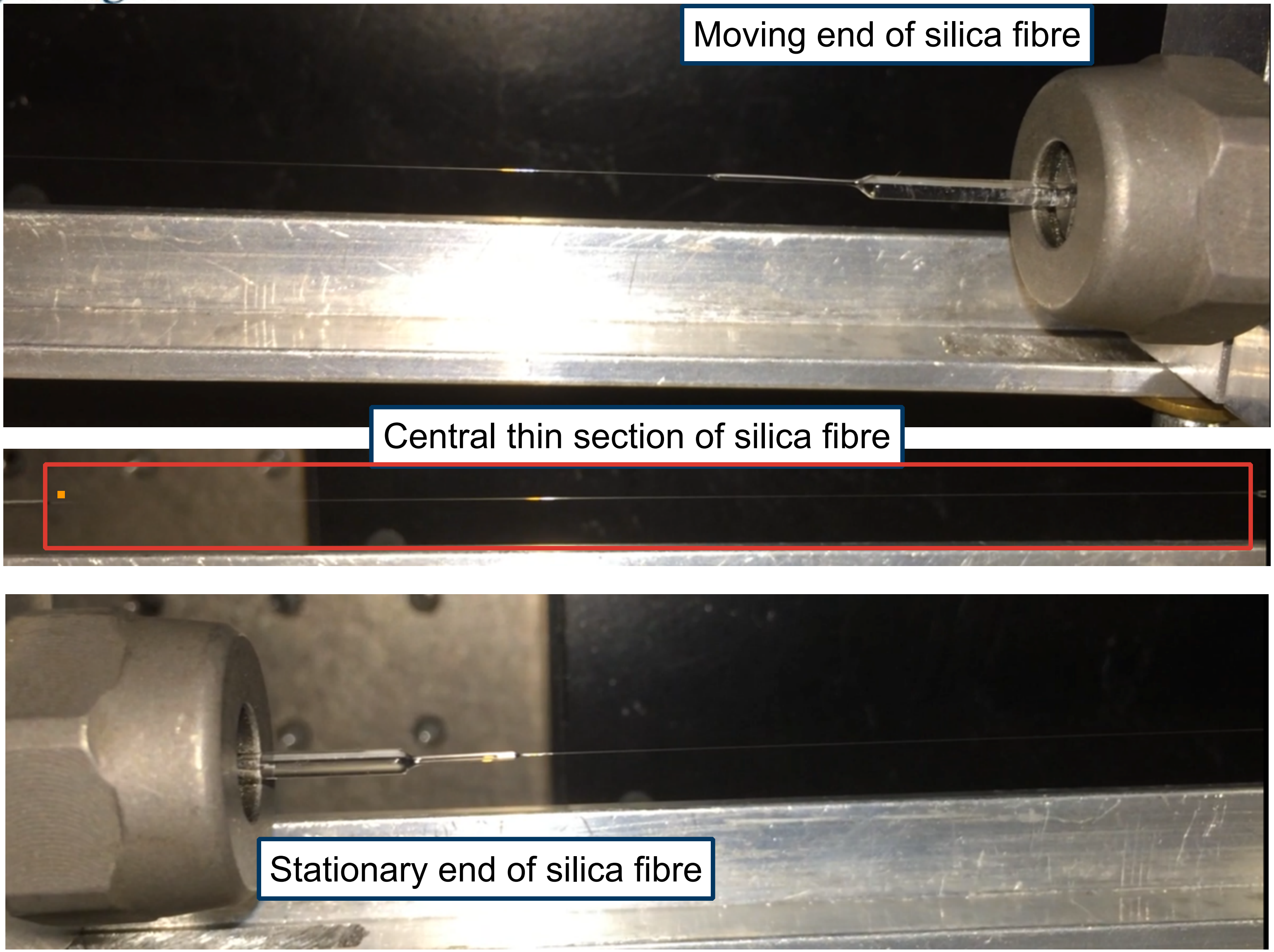


- Laser heating up the silica stock and starting to pull

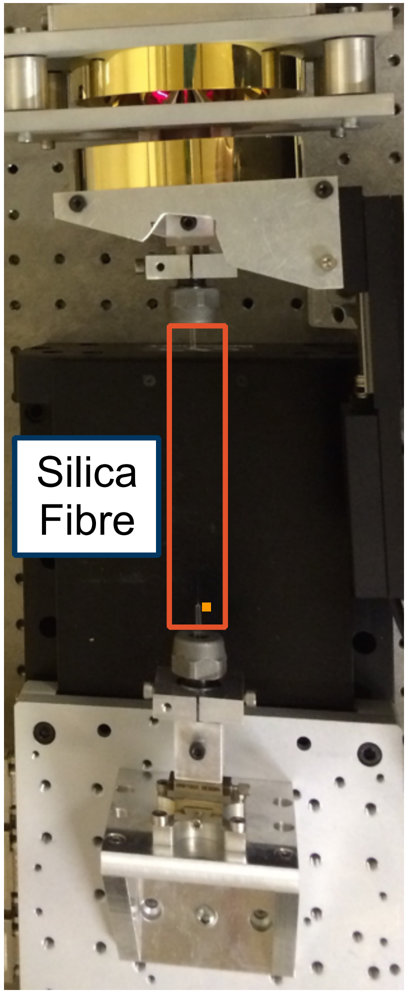


- Conical mirror on motorised stage moves at 0.1 mm/s
- This ensures that the silica stock wont run out during the pull
- Pull lasts approximately 1 second

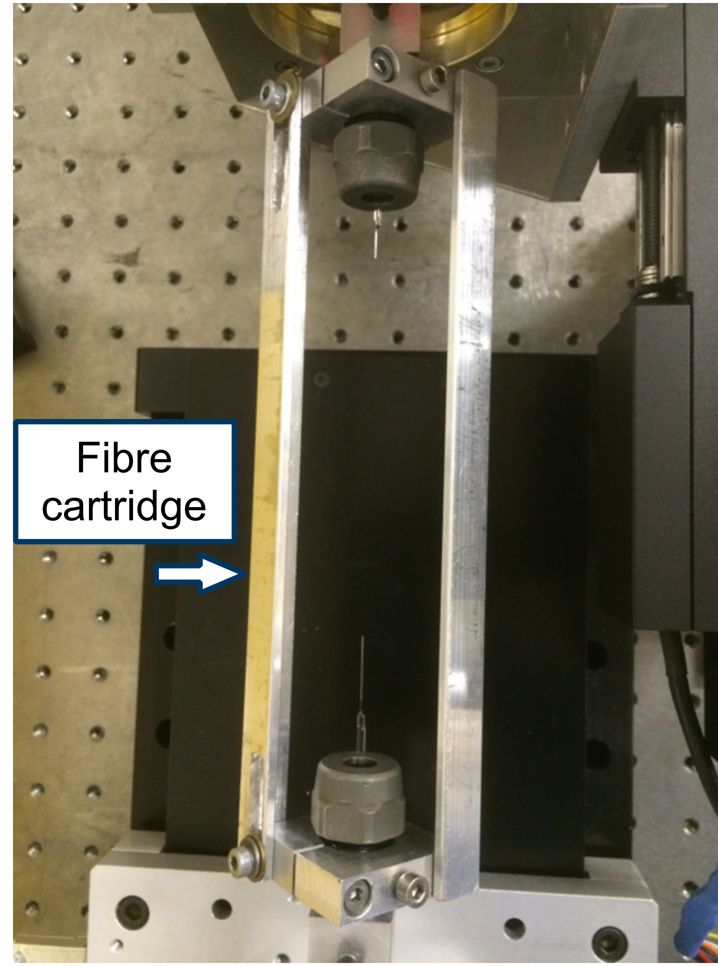
Thin fibre puller



Thin fibre puller

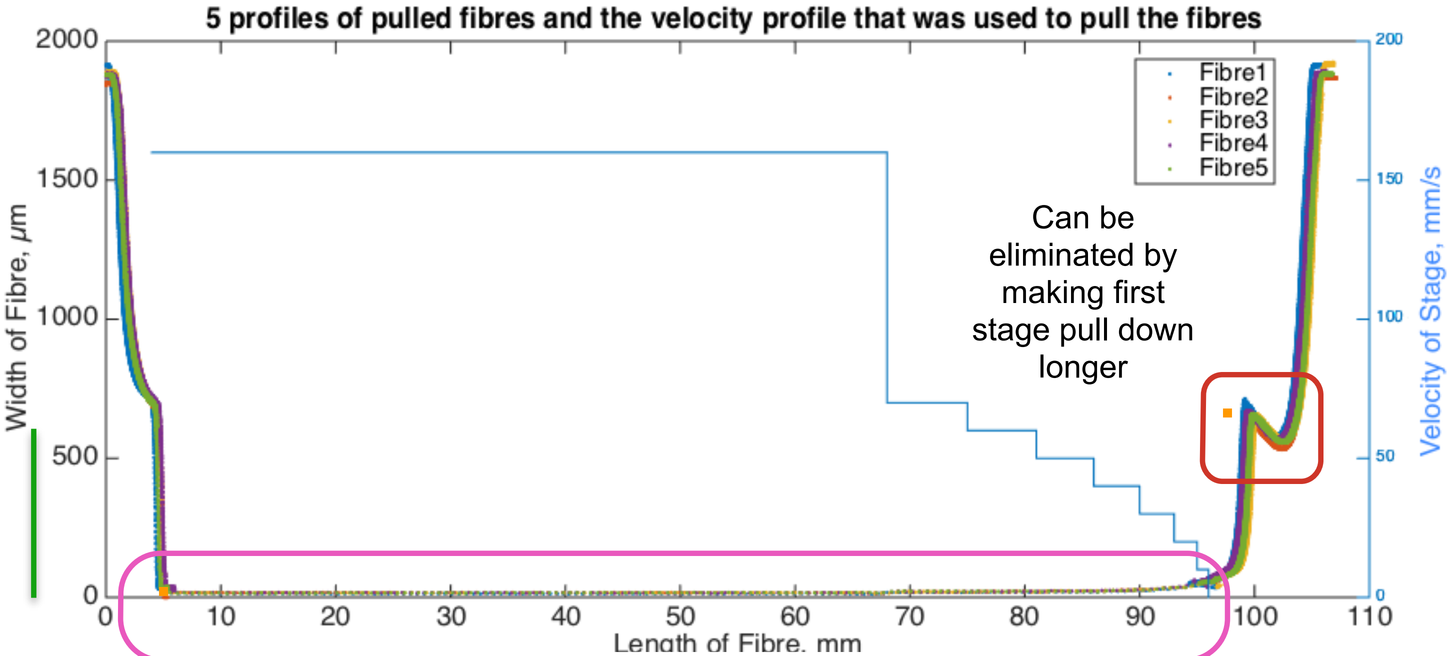


- Metal brackets attached to the fibre clamps
- This allows extraction of the fibre without physically touching the fibre
- Fibre can then be transported around lab for profiling[3], strength testing, laser cutting etc



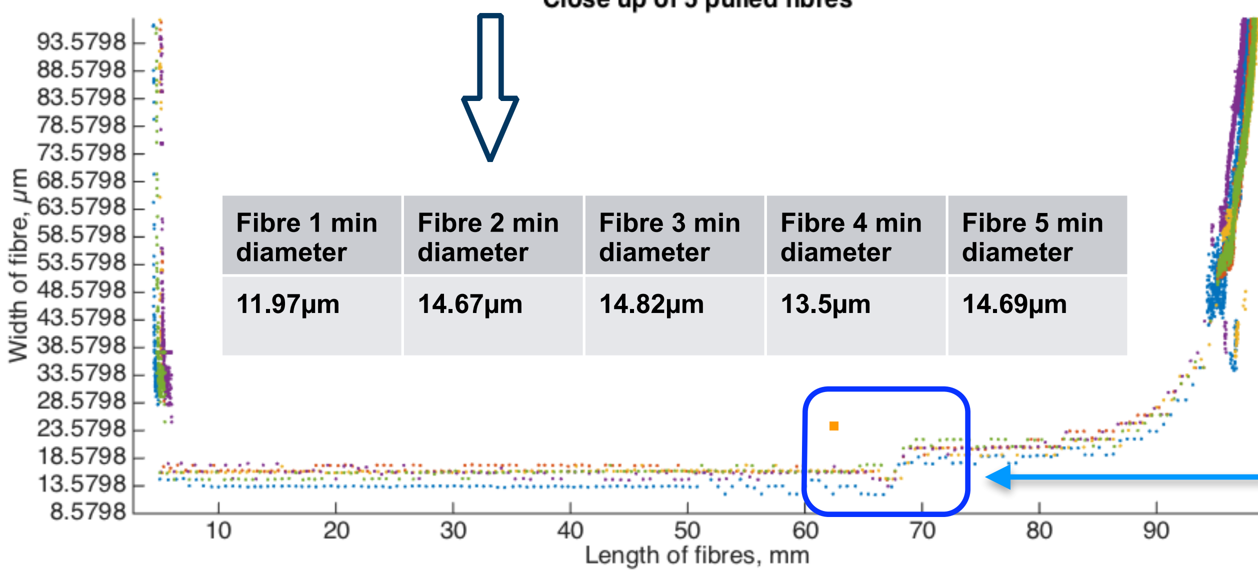
[3] http://www.researchgate.net/publication/51085528 (Review of Scientific Instruments)

Fibre geometries - 2 stage pull



First pull down to approx 650μm

Second pull down between 10 and 20μm

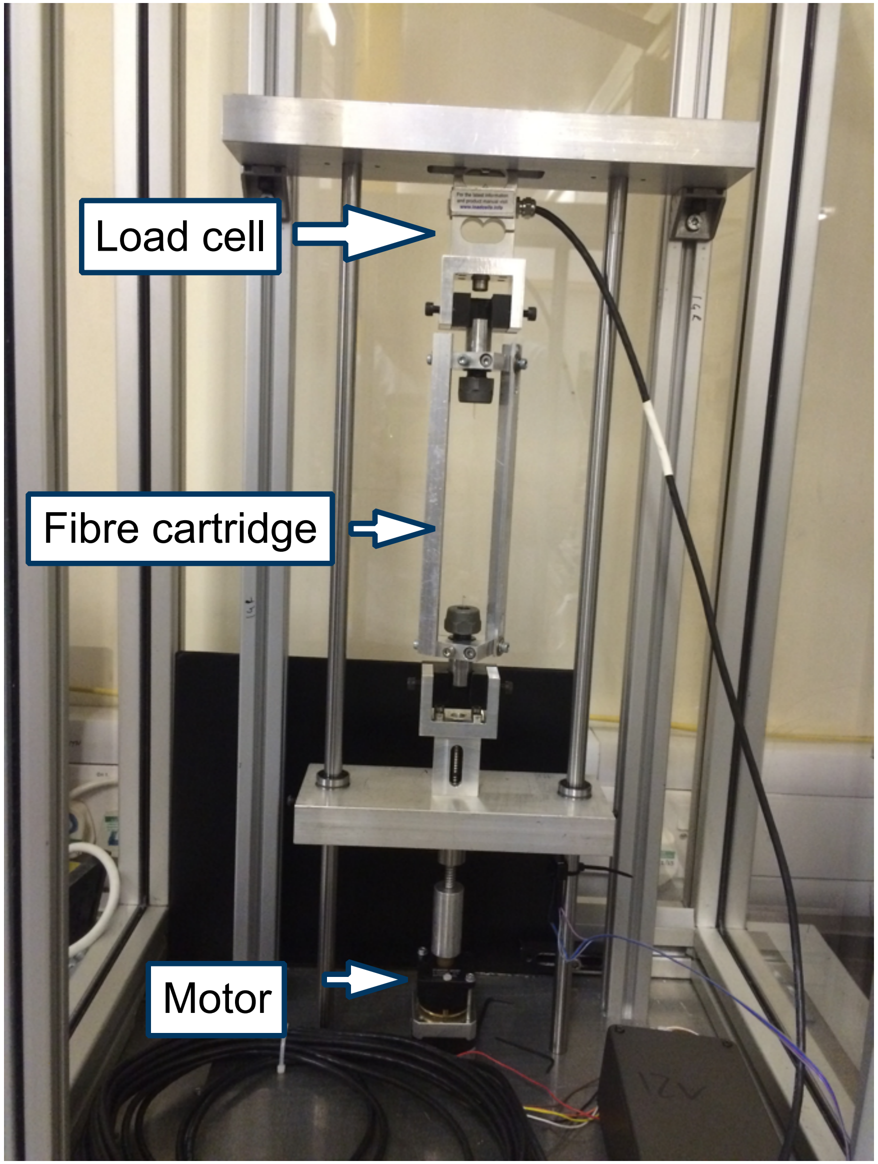


Fibre 1 min diameter	Fibre 2 min diameter	Fibre 3 min diameter	Fibre 4 min diameter	Fibre 5 min diameter
11.97μm	14.67μm	14.82μm	13.5μm	14.69μm

Sudden change due to sharp increase in stage velocity

Strength testing

- Fibres were placed in a small scale strength tester
- Motor pulls down one end of a fibre until it snaps
- Extension of fibre measured using callipers in equal time intervals
- Breaking force recorded



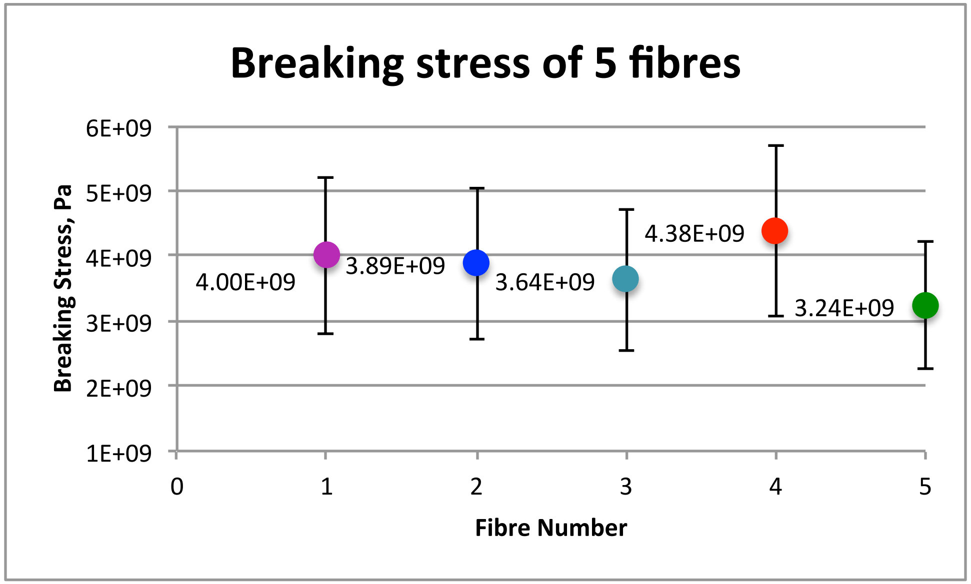
Strength testing

- Breaking stress average of 3.83 GPa for 5 fibres
- No laser polish during fibre pulls. This could further increase the breaking stress [4]
- Breaking stress is calculated via:

$$Stress = \frac{force}{area}$$

where the area is the cross sectional area of the fibre at its thinnest point

- Large error occurs due to the error in the fibre width (15%)
- Fibres are on the limit of what the profiler can focus on to.
- Future camera upgrade is planned to decrease error.



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[4] http://eprints.gla.ac.uk/93995/

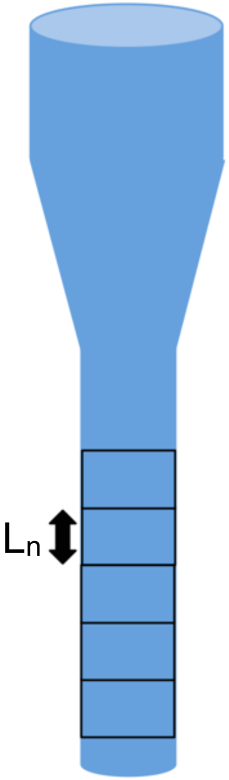
Young's modulus

- The Young's Modulus, Y, found by breaking fibre into equal sections of length L_n
- Each profiled section will have a slight variation in diameter as the fibre is not perfectly uniform
- L_n determined via profiler segments
- The extension, ΔL_n, of each segment can be calculated via:

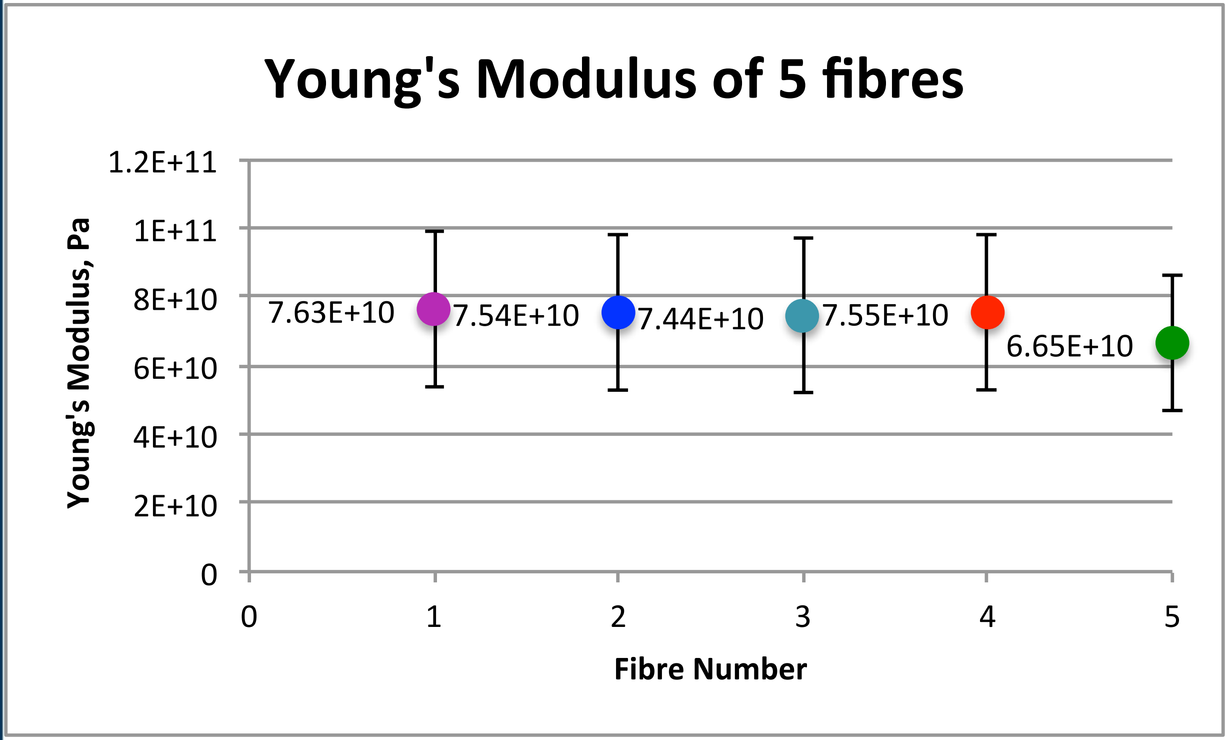
$$\Delta L_n = \frac{L_n F}{YA}$$

where F is the force required to break the fibre and A is the cross sectional area of the fibre segments

- Summing up all ΔL_n will give the total extension of fibre
- Young's modulus is adjusted until the calculated extension is equal to the experimentally measured extension of the fibre



Young’s modulus



- Fibres give an average Young’s modulus of 73.62 GPa
- Within range of that of bulk silica, 73 GPa [5]
- Error in Young’s modulus values due to error in fibre radius

[5] http://www.crystran.co.uk/optical-materials/silica-glass-sio2

Summary

- A pulling machine has been built that is capable of producing strong/consistent fibres < 15 μm
- Young's modulus of pulled fibres agrees with literature value of fused bulk silica
- Fibres could increase in strength if laser polished
- On going and future work:

  -Independent magnetic encoder to measure pulling stage position during pull

  -Camera to monitor the laser power and heat distribution around stock

  -Camera and lens upgrade for the fibre profiler to decrease error in fibre radius

  -Various upgrades to bench equipment (mount holders, lens system etc) to improve the long term alignment of the pulling machine