Suspension fibers for large masses of Advanced Virgo Plus and beyond

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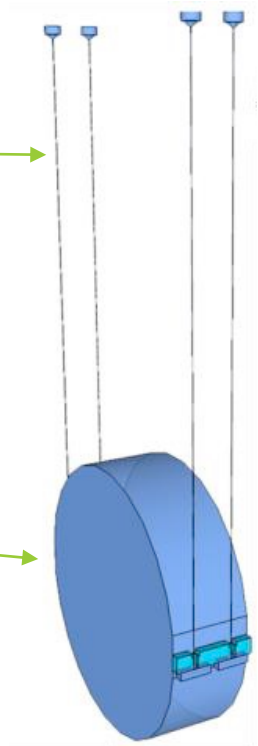
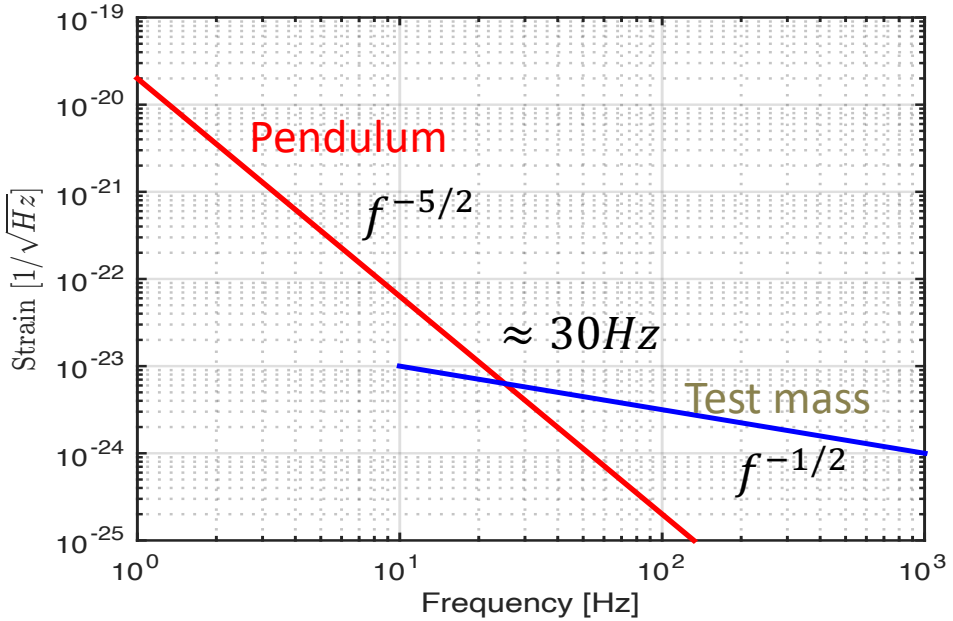
Suspension thermal noise

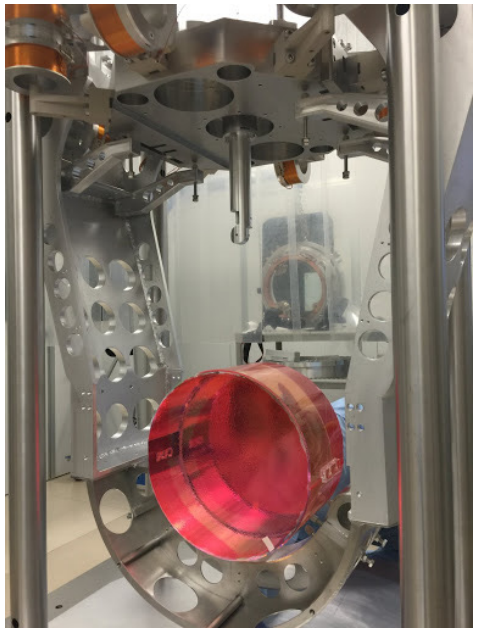
Thermal fluctuation is a source of displacement noise of the GW detector test masses

Suspension thermal noise: **fibers** (pendulum, violin), upper clamps and hydroxide catalysis bonding(HCB)

Mirror thermal noise: mirror bulk, lower clamps and HCB, mirror coating







Large Masses for AdV+

$$S_x \propto \frac{Td\phi}{w^2}$$

T = temperature

d = coating thickness

ϕ = loss-angle (mechanical dissipation)

w = Beam diameter

The AdV+ strategy involves the large beam use with **larger and heavier mirrors.**

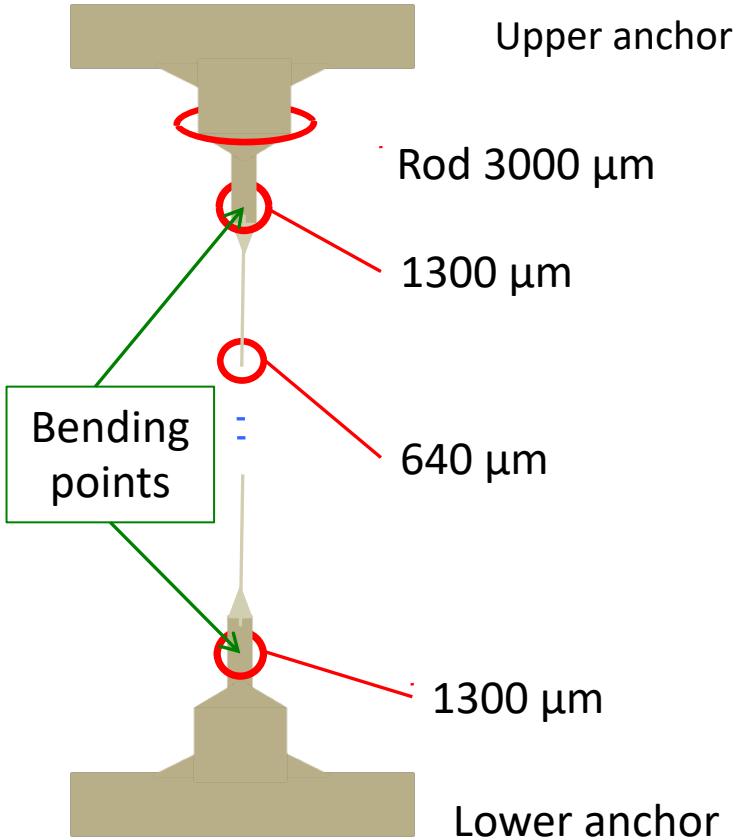
	AdV	AdV+
Test masses Input	42 kg	42 kg
Test masses End	42 kg	105 kg

To keep the same stress as for AdV (~800 MPa) the current diameter of the fibers must increase

AdV fiber diameter	AdV + LM fiber diameter
0.400 mm	0.640 mm

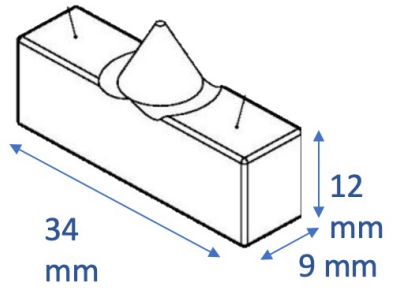
Violin and bouncing mode frequencies will be virtually unchanged.

AdV+ large mass fiber design



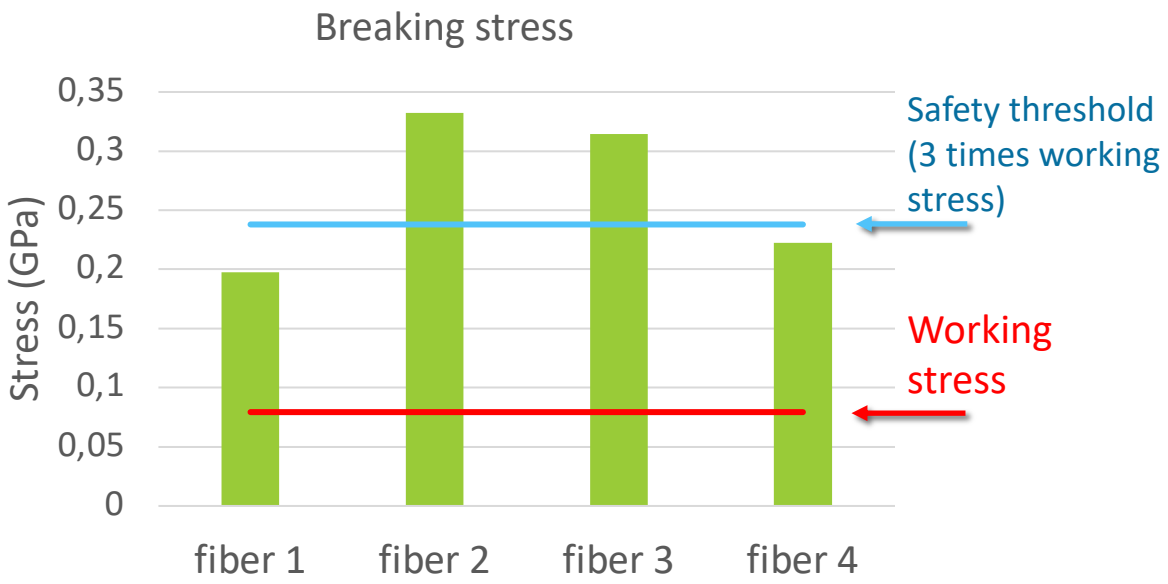
- Working load: 26.25 Kg
- Working length: 700 mm
- Breaking load > 3 times the working load
- Profile: dumb-bell shaped fiber for thermoelastic noise reduction
- bending points position vertically placed in the center of gravity of the marionette and of the mirror to avoid mechanical coupling

In the actual anchor design for AdV+ LM is the same as AdV.



From repeated measurement: Anchor Breaking load > 100 kg

Breaking test – preliminary results



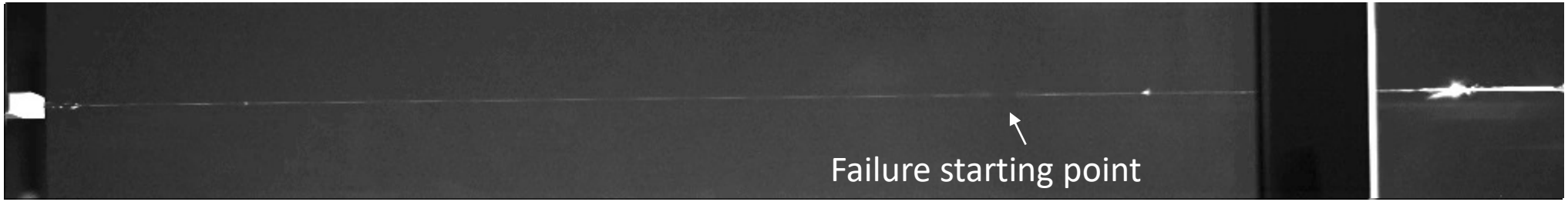
The parts that can be the cause of rupture are:

- Anchors
- Welding part
- Fiber

in breaking tests with such high loads the fiber is destroyed and it is not possible to trace the cause without a high-speed camera.
Just the fiber 2 rupture was recorded.

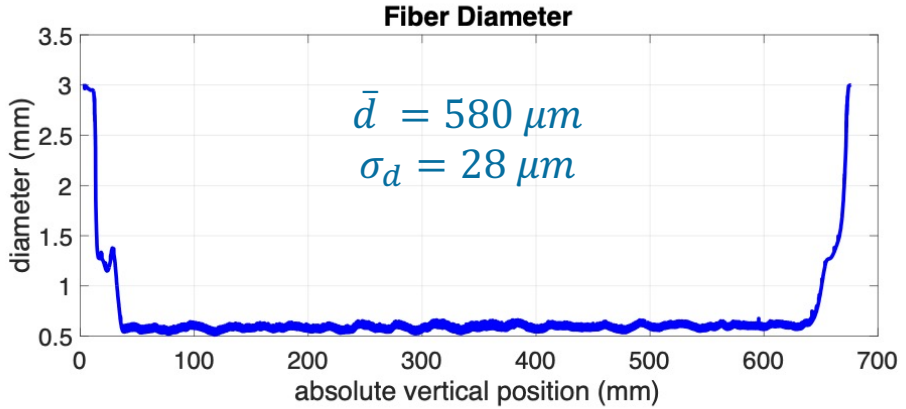
Fiber n. 2 breakage

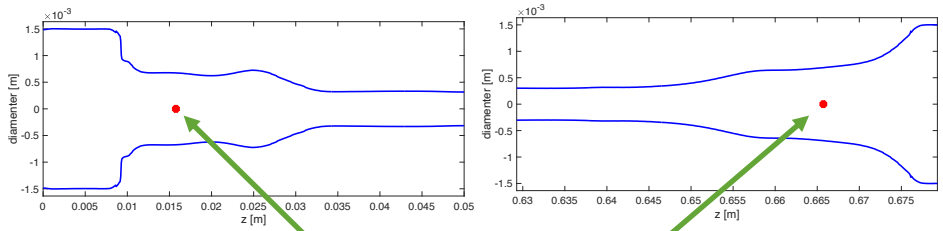
Fast camera Mini AX50:
Frame rate 15300fps
Resolution: 1024 x 128

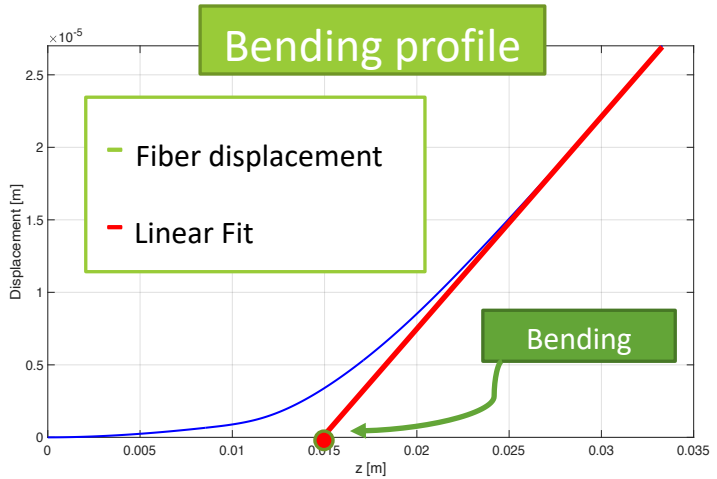


Profiling (fiber n.2)

The fiber 2 was profiled with a microscope moved along all its length, with an edge detection algorithm







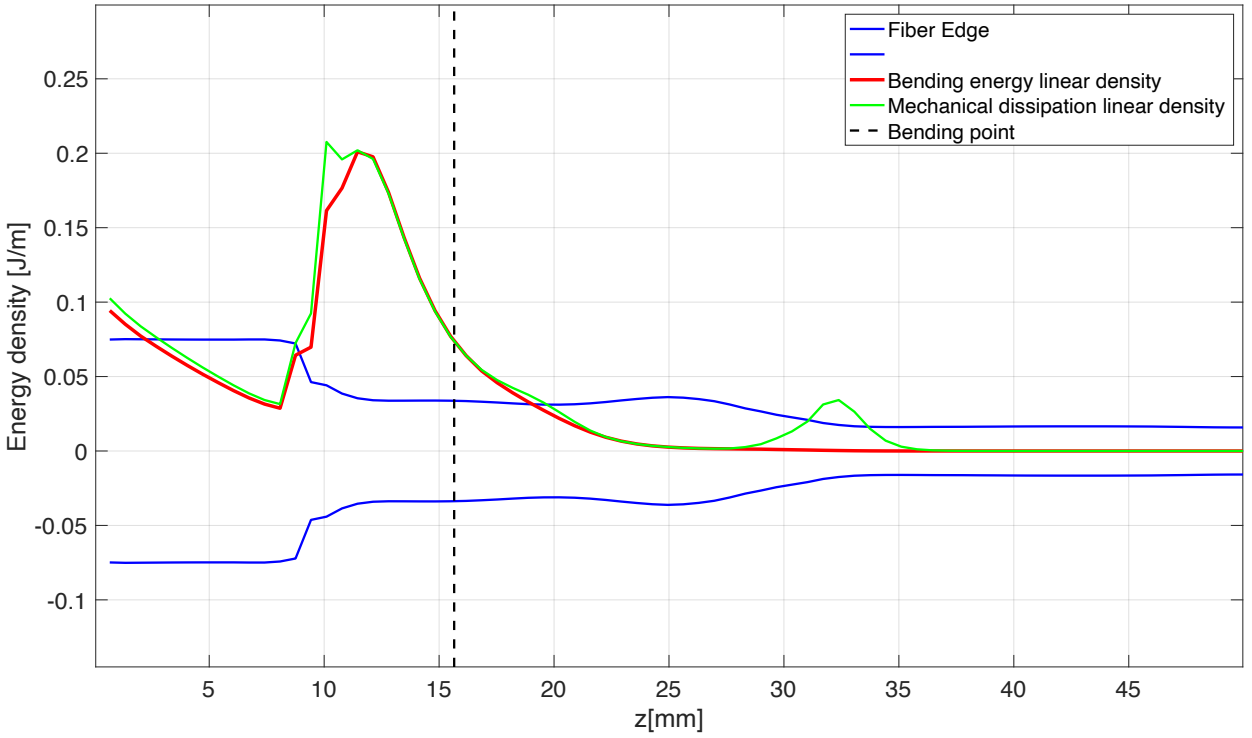
Starting from the fiber thickess, the material parameter, and the load is possible trought a FEM simulation to find the bending geometry, and thus the mending points.

F. Piergiovanni et Al. **Journal of Physics: Conference Series**. 228, 012017 *(2010)*

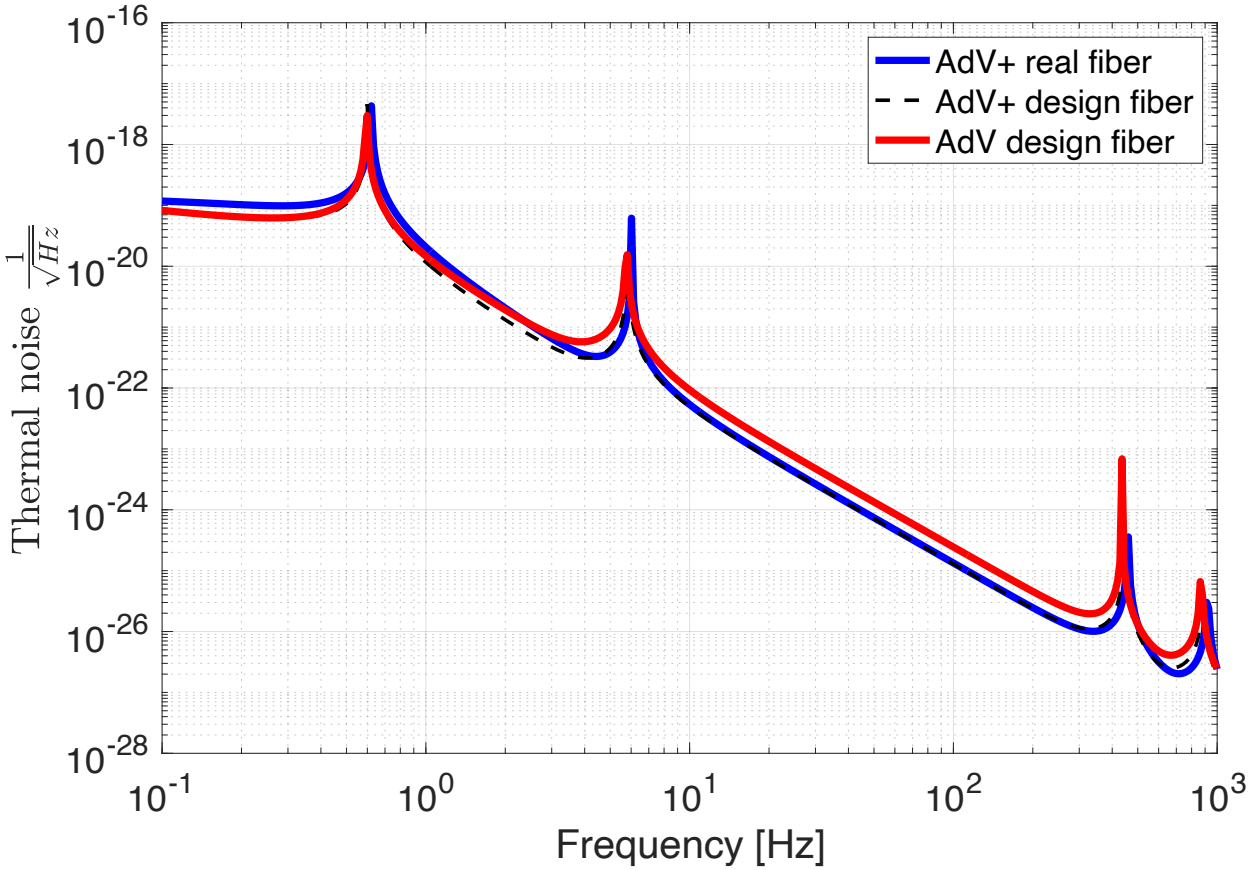
The bending points are correctly placed in the thicker region.

Bending Energy

- The bending energy linear density (red line) is concentrated in the part with diameter = 1.3 mm
- The thermoelastic noise is dumped (G. Cagnoli and P. Willems **Phys. Rev. B** 65, 174111 (2002))
- The mechanical dissipation linear density (red line) follow the energy. The little discrepance is due to the the change of loss angle due to the thicknes.



Thermal noise



Total loss angle

$$\phi_{TOT} = D(\phi_{TED} + \phi_{bulk} + \phi_{sup})$$

Dilution factor → $D \propto d$

ϕ thermoelastic → $\phi_{TED} \approx 0$

ϕ bulk → $\phi_{bulk} = cost$

ϕ superficial → $\phi_{sup} \propto d^{-1}$ $\quad \phi_{sup} \gg \phi_{bulk}$

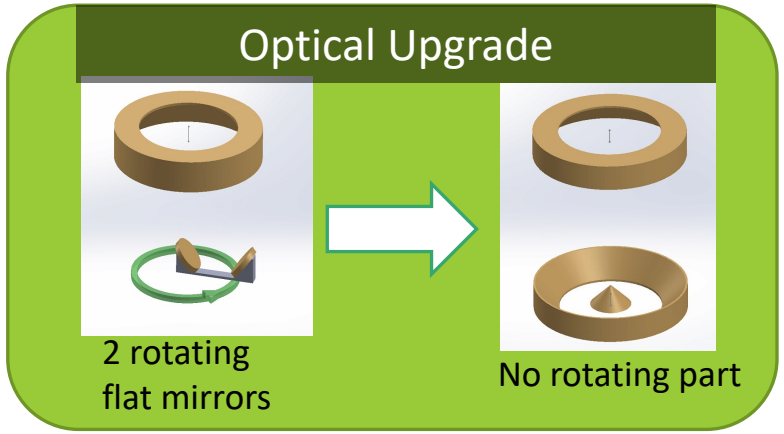
$$\phi_{TOT} \approx costant$$

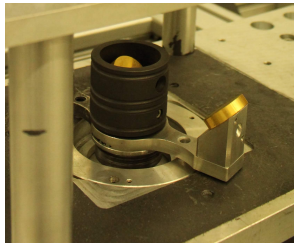
- The discrepancy of the resonant frequencies (pendulum, bouncing and violin) is due to the different length of the fiber with respect the specification.

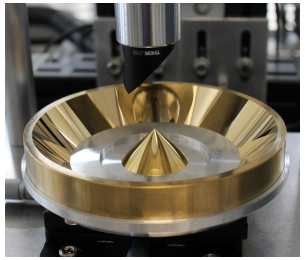
AdV+ Fiber Pulling Machine @Urbino Lab

To increase the simmetry and the stability of the production we developped a new R&D pulling machine at the Urbino Lab.

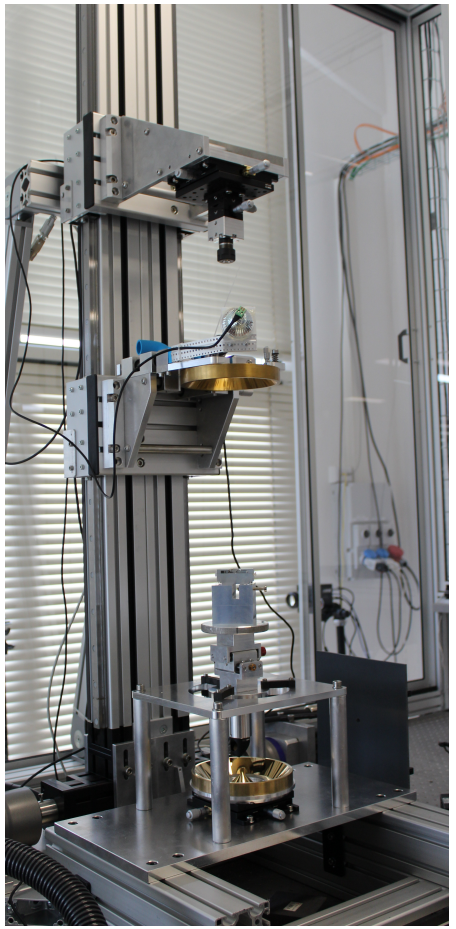
- Optical system upgrade
- new clamping systems
- the machine is now completed and working
- The best pulling parameters are under investigation







cylindrical symmetry
heating



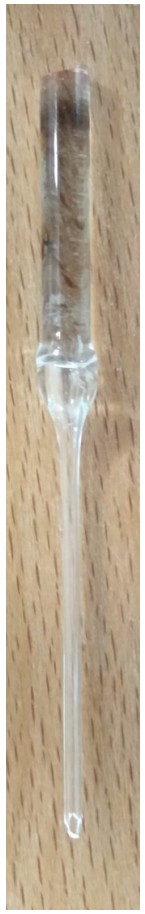
Preliminary plan towards a silicon fiber

Source: cover image of Ballato and Dragic, the American Ceramic Society
http://doi.org/10.1111/jace.12516

- We want to use our fiber pulling machine @Urbino Lab to perform some test on **silicon** fiber production.

- Technology:
  - **Pulling-down system using a silicon core surrounded by a silica cladding** [*presentation of Ursula Gibson at the ET symposium 2020 (Instrument Science)*]
  - The moving arms of our silica fiber machine can be used as a pulling down system
  - The CO_2 laser can be used to melt the silica cladding and the silicon core

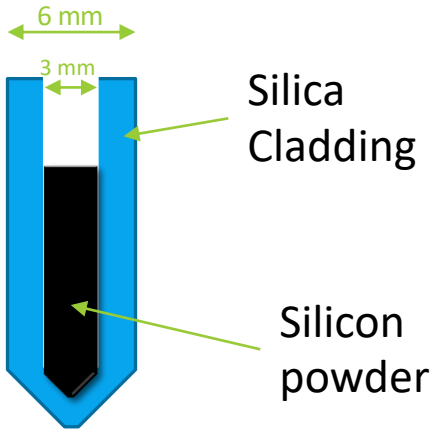
Preliminary tests on silicon

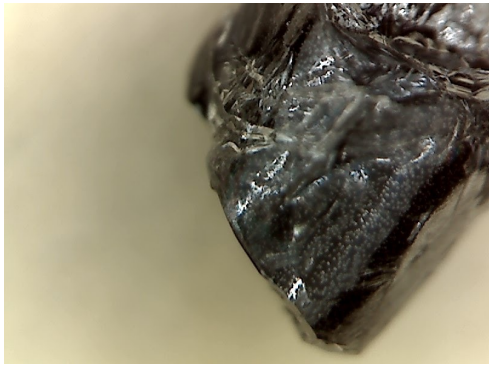


Empty silica pipe reshaped

Thanks to Ursula Gibson for providing us with the material and support for the first tests

- ✓ The Pulling down operating mode was tested successfully on silica rod
- ✓ An empty silica pipe was pulled to obtain a different diameter
- ✓ we prepared a silica pipe of 6 mm of external diameter and 3 mm of internal diameter, with silicon powder obtained from a wafer.
- ✓ The silicon melting point was reached inside a silica cladding (~140W)
- ✗ The reshape of the two materials is under investigation

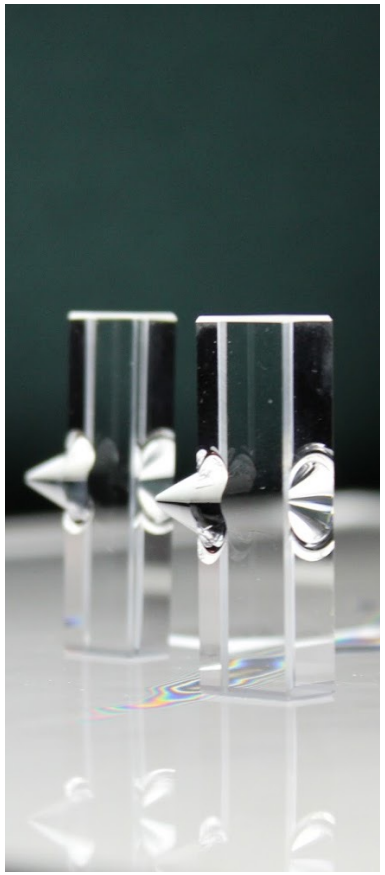




Melted silicon

Conclusion

- Large masses upgrade for AdV+ has a huge impact on the monolithic suspension and on the silica fibers
- Fiber specifications changed to maintain the same safety margin, resonant frequencies and thermal noise
- Preliminary results show that the desired breaking load could be reach: a new statistic from the production @Urbino Lab is needed
- A procedure for **silicon** fibers fabrication for 3G Gravitational waves interferometers with the fiber pulling machine is under investigation: some preliminary steps are done.



Thank you for your attention!