# Towards a Monolithic Suspension for the Einstein Telescope: Crystalline Silicon Welding


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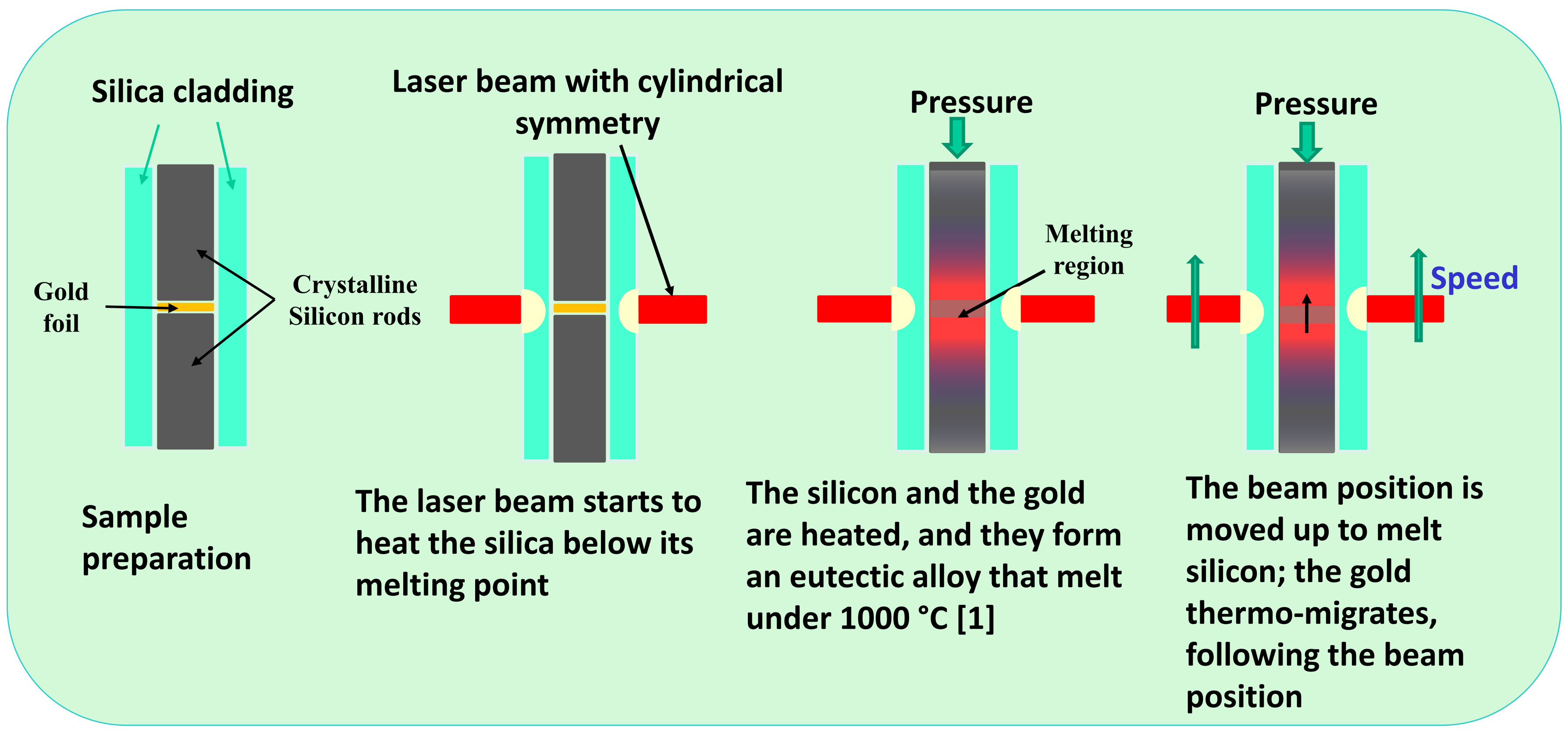
## Introduction

Silicon is one of the candidates for the construction of monolithic mirror suspensions of 3rd generation GW detectors. In this context, one of the open challenges is the realization of the interfaces between the suspension fibers and the rest of the system. Having a technology that allows the welding of two crystalline components is therefore a first crucial step. With this aim, we decided to investigate the possibility of welding two silica cladded crystalline silicon rods using a technique developed by Clemson University (Prof. Ursula Gibson). The inserting of a thin gold leaf between the two rods creates a eutectic alloy, which improves the quality of the weld. Through the Virgo silica fiber production machine, which is equipped with fine control of movements and CO2 laser power, soldering is carried out and then followed by recrystallization of the soldered part and migration of the gold residue. The technique will be described in detail and the promising results of the preliminary tests will be presented.

## Silicon welding

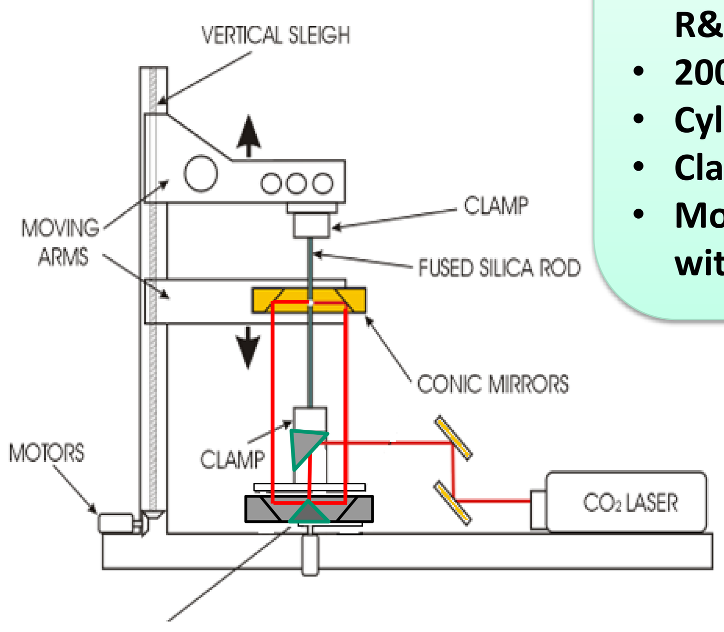
- Silicon is one of the main candidates for the realization of a monolithic ET suspension
- A technology to weld 2 elements of crystalline silicon could be extremely useful
- Silicon is highly reactive when heated in air
- Keeping mono-crystalline structure is not trivial





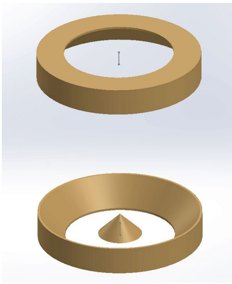
[1] Song et Al. *Nat Commun* **13**, 2680 (2022)

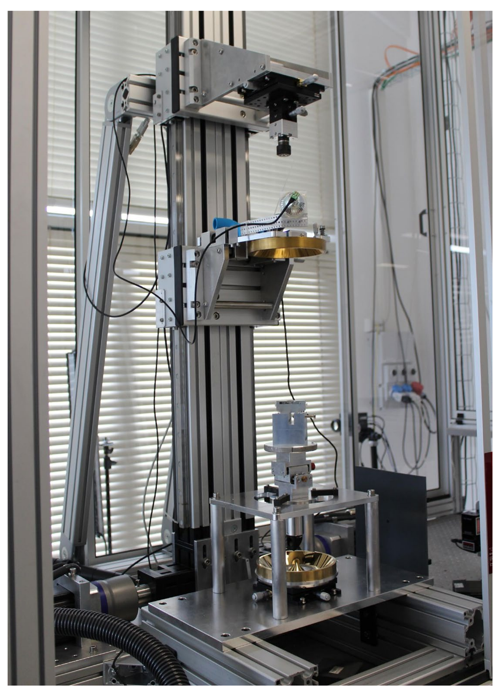

## Experimental set up




Axicon and conic mirror

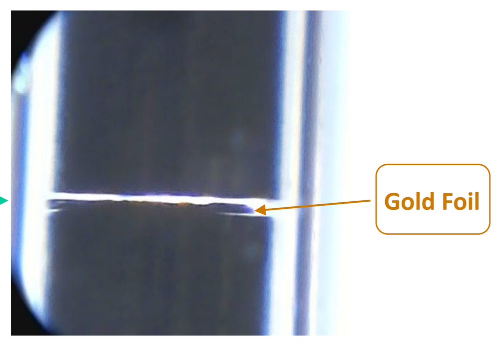
- The machine used is the fiber pulling machine, developed @Urbino Lab for Virgo silica fibers R&D
- 200 W, $CO_2$ Laser
- Cylindrical heating system.
- Clamps for rods
- Motors to move the heating point with a low speed of $10^{-5}$ m/s

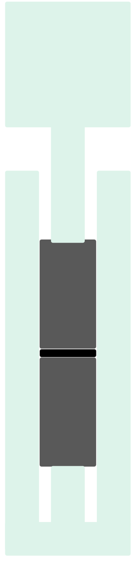




## Samples

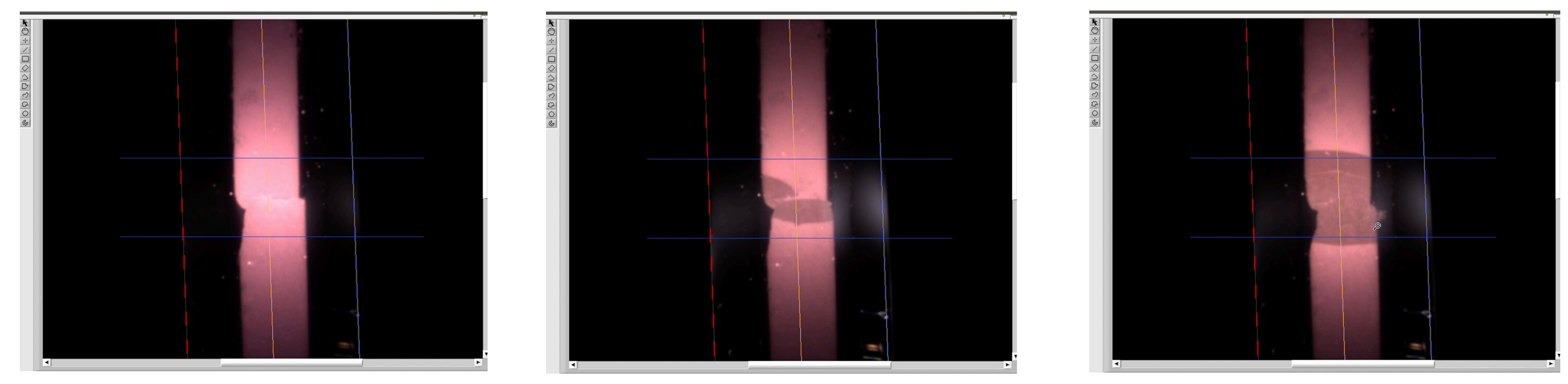
- Crystalline Silicon rod diameter: 1 mm.
- Silica Cladding diameter: 2.2 mm or 3.0 mm.



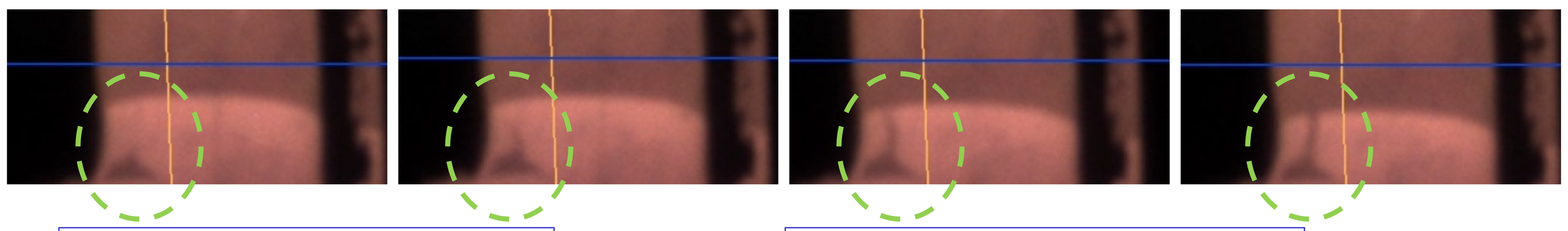
- contact pressure of the 2 rods is realized with the weight of a silica rod 3 mm thick and ~10 mm long.

## Gold-silicon alloy melting point



- Starting the heating process, the silicon starts to emit.
- Increasing the power, the state transition is visible (darker region). The dimension of this area is related to the laser power.
- Laser power: 24W; silica cladding diameter: 3mm; silicon diameter: 1mm

## Gold thermo-migration



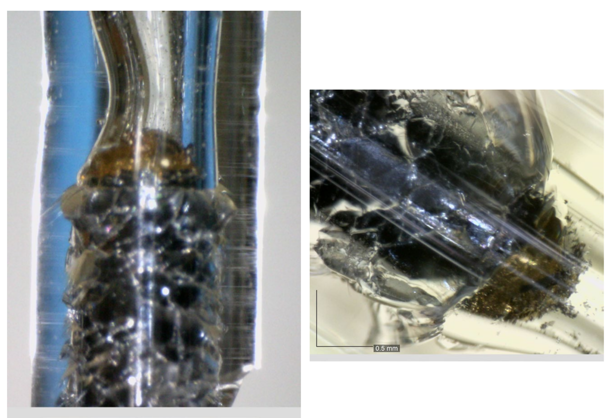
The gold thermo-migrates following the region with higher temperature [2].

Silicon recrystallizes oriented as the rod below (to be confirmed) and it is free of gold.

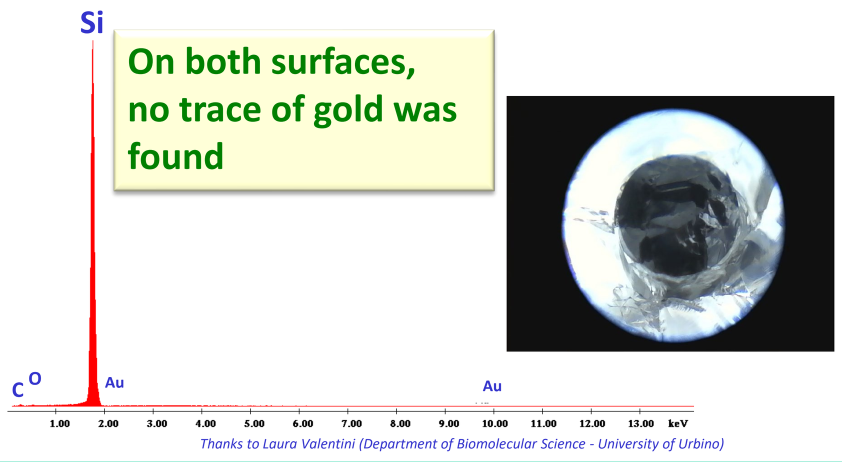

[2] Sørgård et al. *Opt. Mater. Express* **10**, 2491-2499 (2020)


## Results

It is possible to observe (qualitatively) the migration of gold at the end of the silicon rod



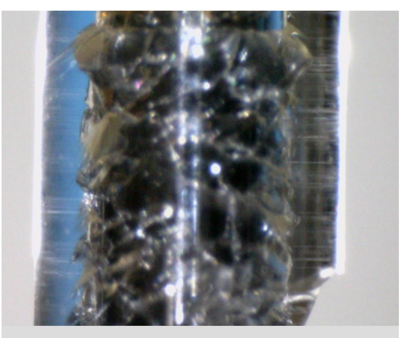
A SEM+ESD analysis was performed on one sample to see the elements on 2 surfaces: the first close to the starting point of the weld, the second a few millimeters above.




## Silica (during welding)

- The silica allows to use the CO2 laser as heating instrument.
- It allows to perform the process in air.

The cooling of the melted silicon produces fractures and deformations of the silica cladding



To prevent it, we are testing different possibilities:

- Using internally coated silica pipes (some problem in controlling the process and see the silicon)
- Increasing the thickness of the silica pipes

- A procedure to remove silica is needed to validate this technique (strength, degree of crystallization) with the future prospect of using this for ET suspension.
- We are currently using mechanical abrasion: high risk of damaging the silicon. We are investigating the possibility of using a chemical agent (HF - hydrofluoric acid)

## Conclusions

Advantages of this technique with our experimental setup:

- No need for controlled atmosphere.
- Fine controlled laser power.
- The mechanical system offers the possibility of low beam speeds (down to 10 µm/s) with excellent control.
- Preliminary results are encouraging.

Future works:

- New tests are needed to develop the procedure: parameters tuning.
- A method to safely remove silica is necessary.
- Breaking loads, purity and crystallization must be measured to verify the goodness of soldering and recrystallization.