A closed loop cryogenic mechanical loss measurement system for cantilever samples

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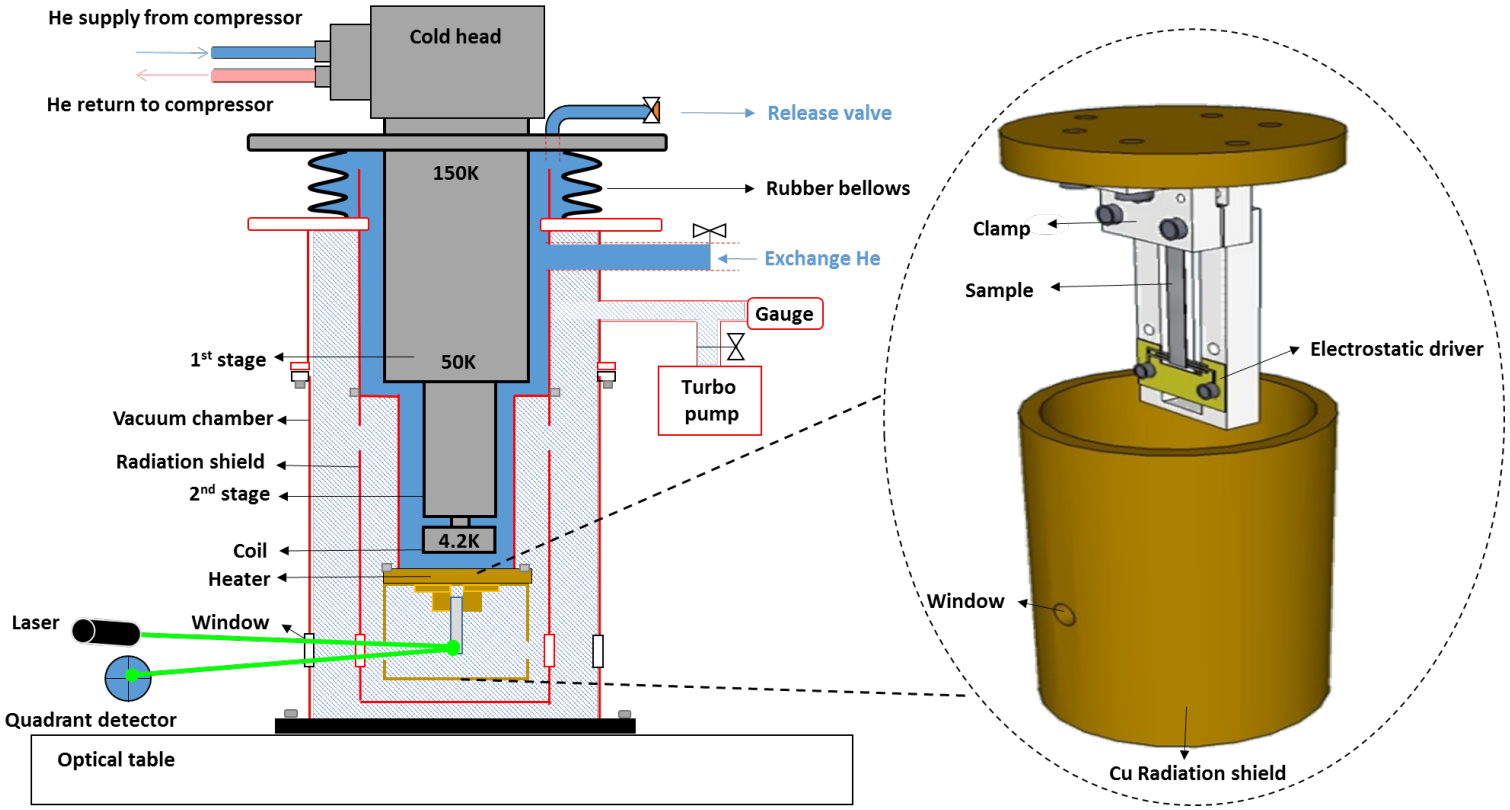
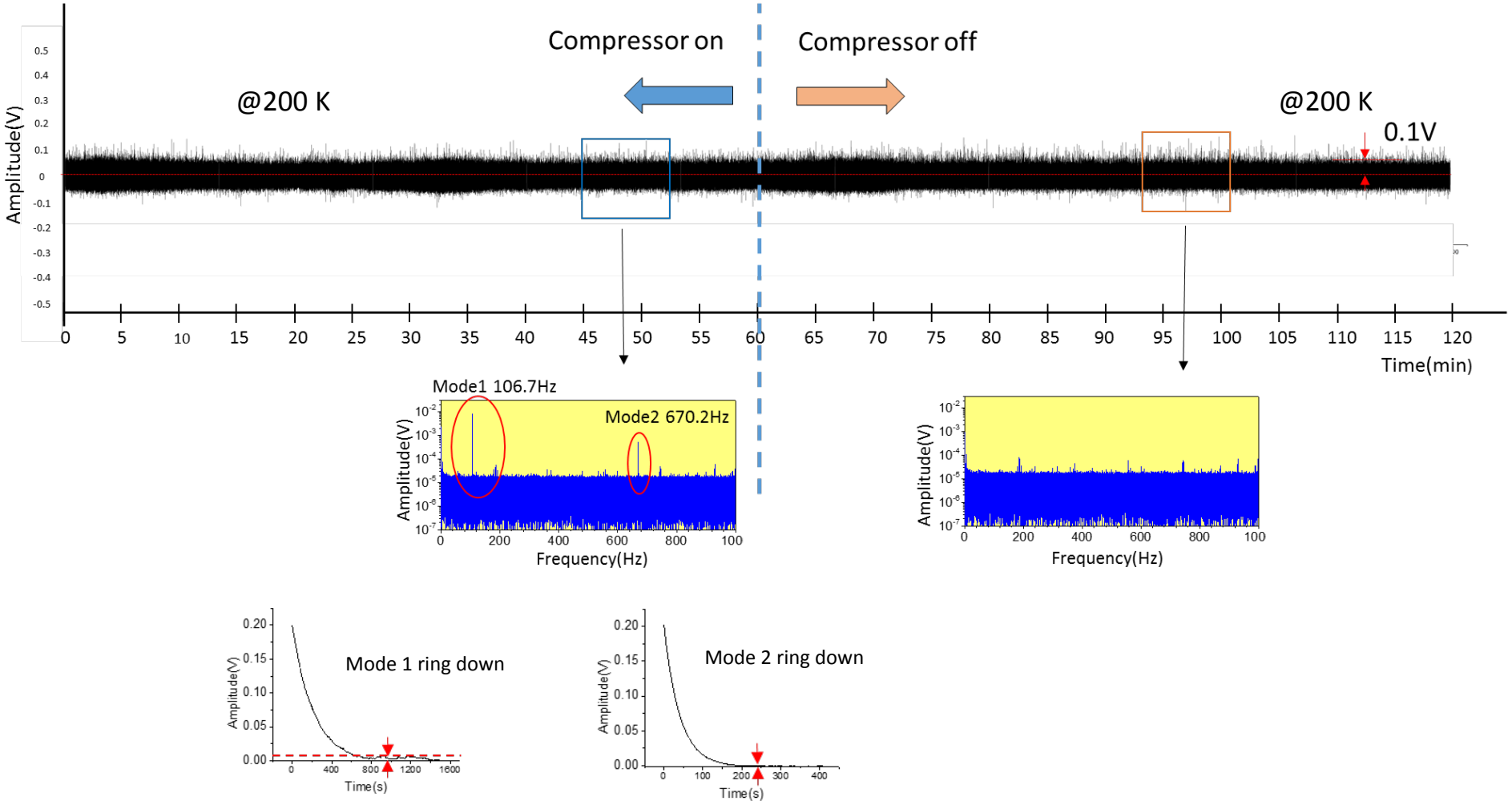
Layout of the cryogenic mechanical loss measurement setup



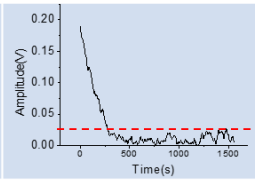
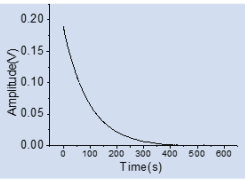
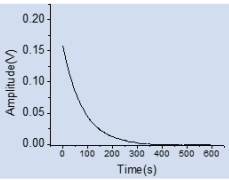
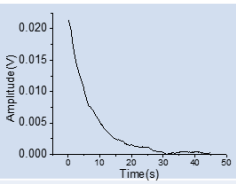
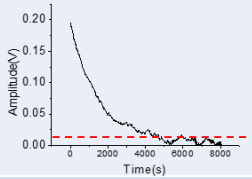
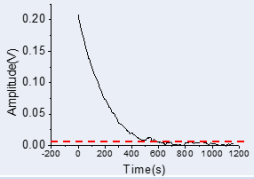
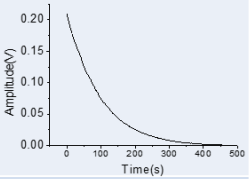
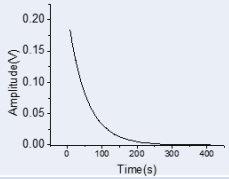
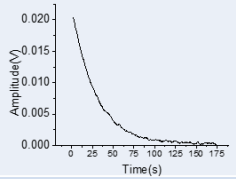
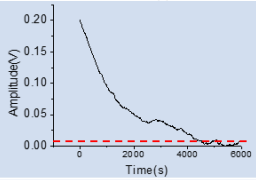
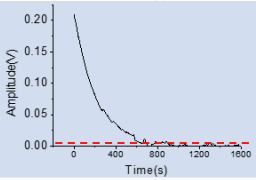
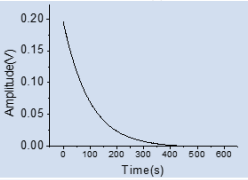
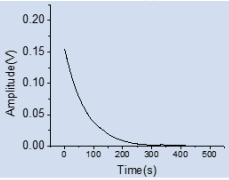
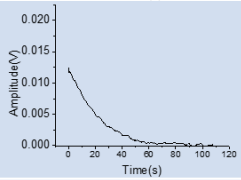
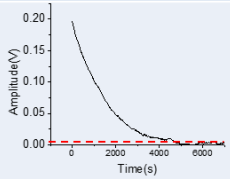
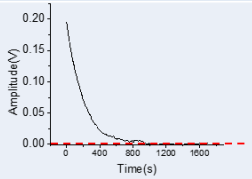
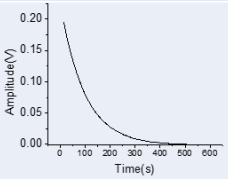
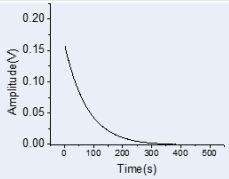
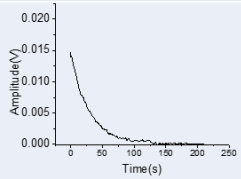
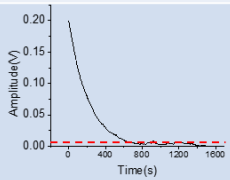
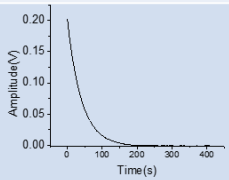
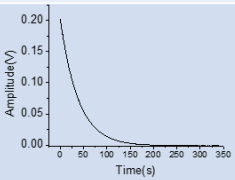
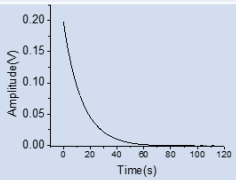
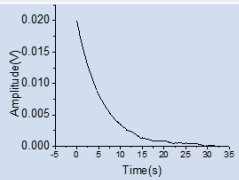
- A JANIS SHI-4XG-15 cryogenic system was setup and modified for measuring the mechanical loss of the cantilever type samples.
- It is a closed loop system, no liquid helium replenishment is required.
- Rubber bellow for vibration isolation between the compressor-connected parts and the cantilever-connected parts.

Vibration isolation



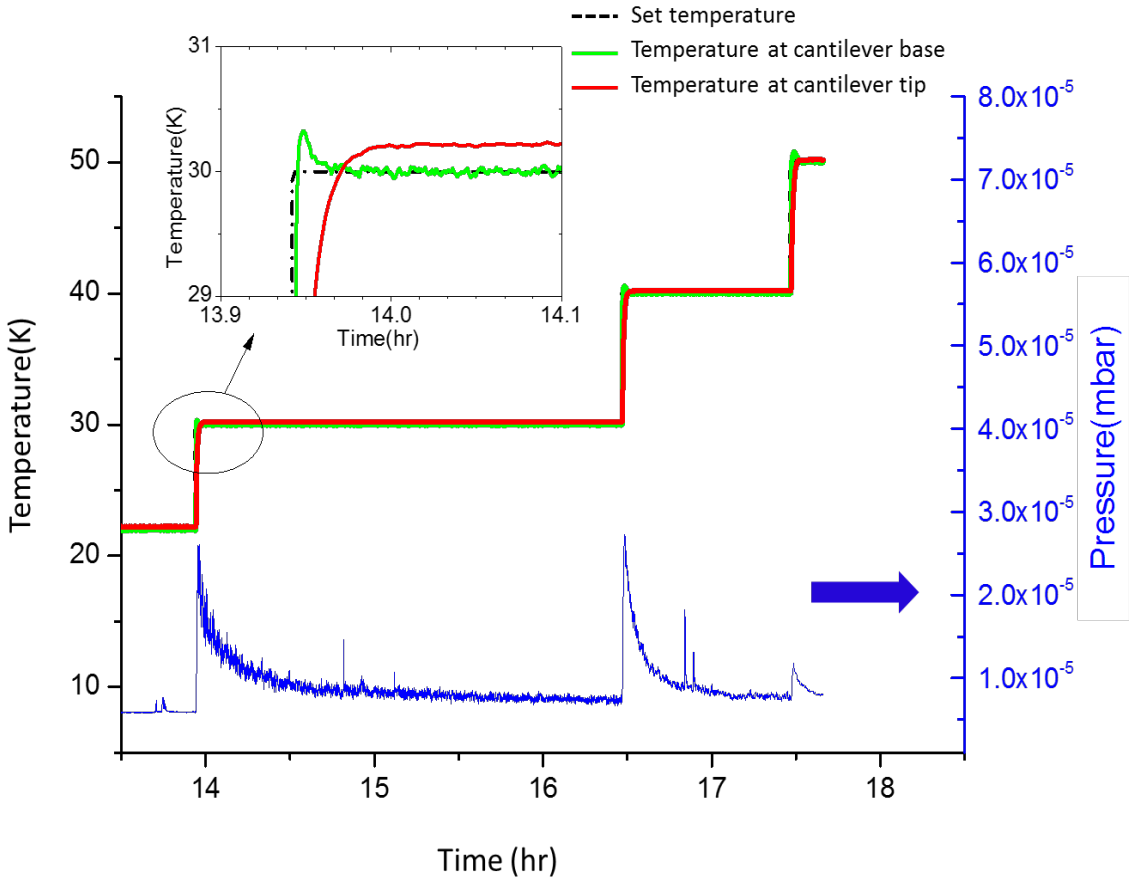
- Compressor excites cantilever modes, noisier for lower order mode.
- The noise affect little on the read out of the ring down parameters.
- Vibration isolation by the bellow is sufficient.

Noise at very low temperature

	Mode1 ~110Hz	Mode2 ~690Hz	Mode3 ~1390Hz	Mode4 ~1900Hz	Mode5 ~3700Hz
5K	Very noisy				
7K					
10K					
20K					
200K					

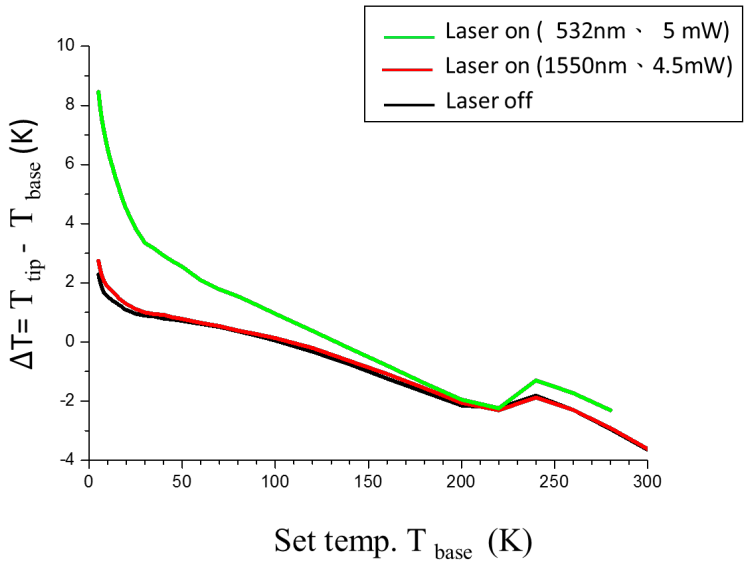
It is very noisy for low order modes at temperature close to 4.2 K, possibly due to turbulence of the liquid/gas Helium in the exchange gas compartment.

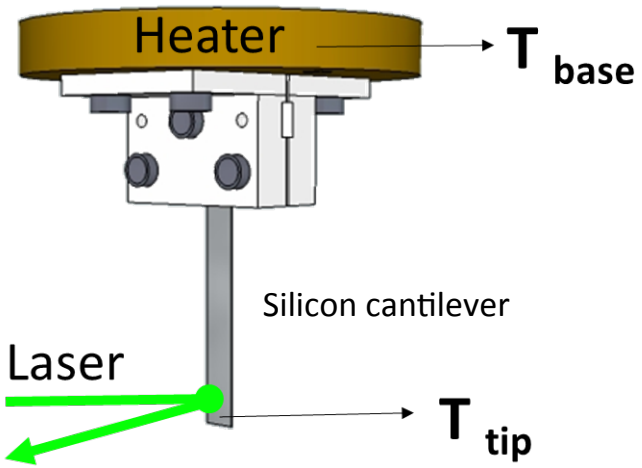
Temperature and pressure stabilization



To avoid the vibration from the turbo pump, the turbo pump is off and detached from the system after the system is cooled down. During the whole measurement process (from low toward high temperature), the vacuum is maintained by the cryogenic pumping of the system itself.

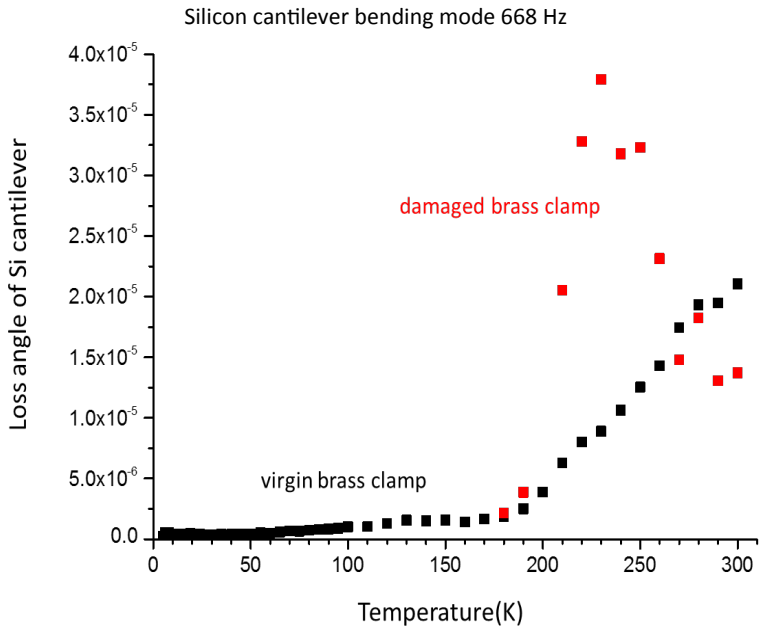
Temperature gradient on the silicon cantilever

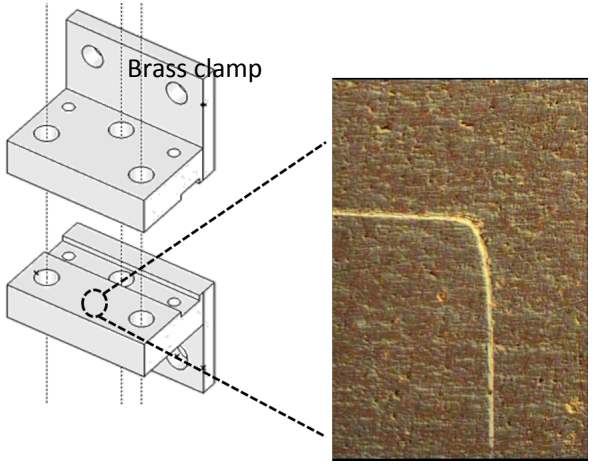




- The Si cantilever is 30 mm in length
- There is temperature difference between the tip and the base of the Si cantilever at steady state
- The temperature difference is enhanced by the 532 nm monitoring laser heating
- The laser heating diminished when using 1550 nm as monitor laser

Effect of indentation on the brass clamp



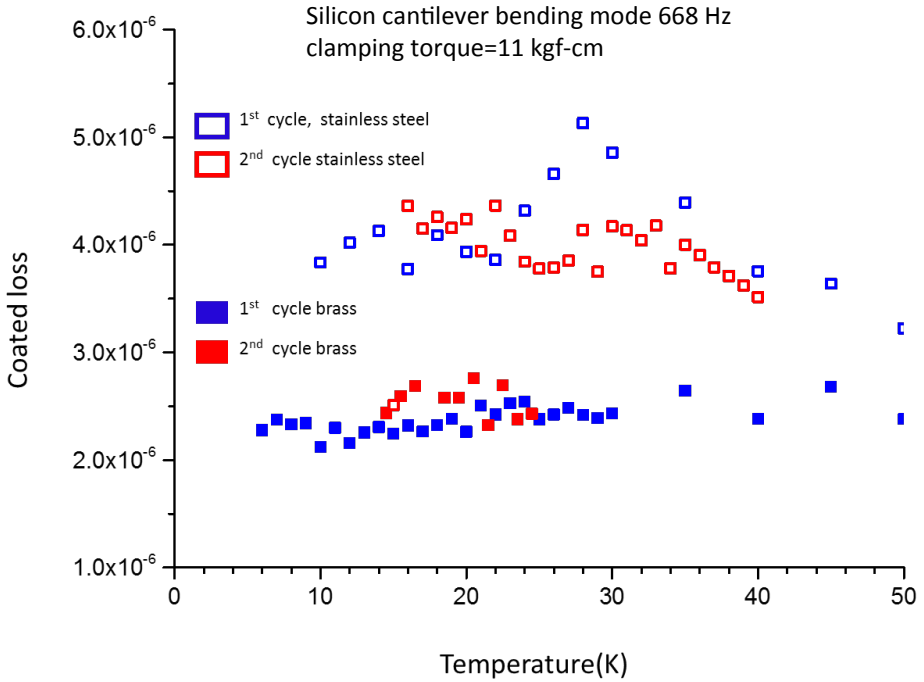


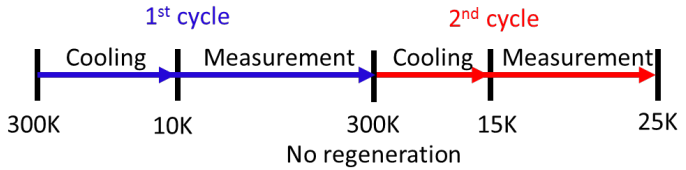
Clamp damage: Indentation of the cantilever edge on the brass clamp by high clamping torque

Brass clamp has good thermal conductivity and lower mechanical loss than the stainless steel clamp, but it is soft, tiny invisible indentation of the cantilever edge may be left on the surface to cause high loss.

Temperature cycling effect

Sample: single IBSD TiO_2 layer on Si

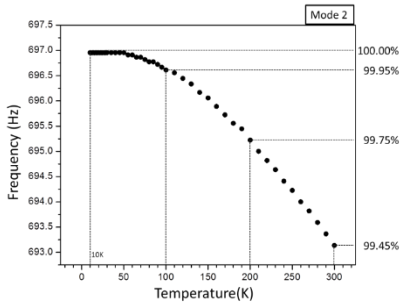


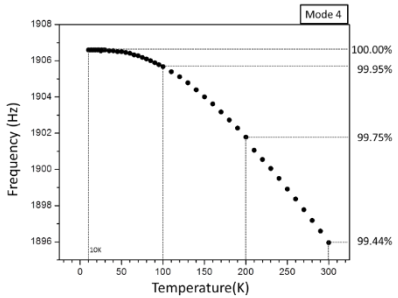


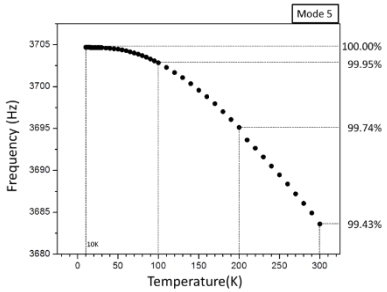
Implication: (1) Temperature cycling may cause difference.
(2) Brass clamp has lower loss than the stainless steel clamp.
(3) Is there low temperature peaks for IBSD TiO_2 ??

Temperature dependent resonant frequency of the Si cantilever

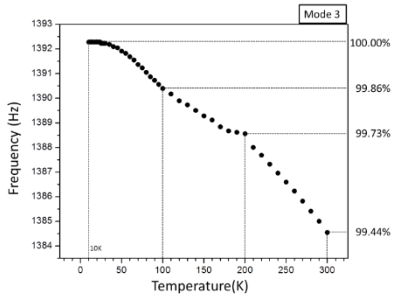
Bending mode

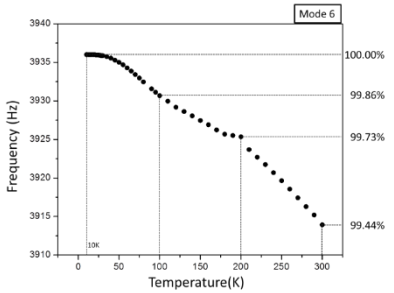


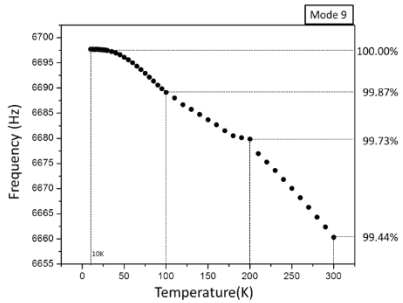




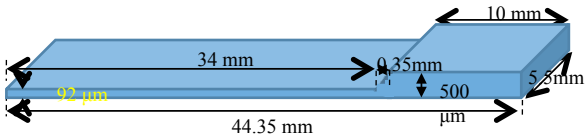
Torsion mode







- We determine frequency of the modes for every temperature setting before ring down measurement
- The characteristics of the temperature dependent frequency for the bending modes consistent with others report.
- The temperature dependent frequency for the torsion modes has not been reported elsewhere. Need analysis if necessary.
- There is a kink at 200 K for the torsion modes



Measurement strategy

- In view of the long decay time or high error level for some measurements, a measurement strategy has to be planned beforehand in order to save measurement time and yet not to loss important information.

For example:

- 1st mode of the standard cantilever (~107 Hz) has long decay time and noisy at very low temperature, it could be skipped from measurement to save time.
- 3rd mode (the lowest frequency torsion mode) could be skipped from measurement if necessary due to long decay time (low thermoelastic loss).
- Pressure re-stablization for a new set-temperature is the most time consuming step, temperature increment should be planned to save time.
- Bending modes at 1800 Hz and 3600 Hz (the 4th and the 5th modes) very often have higher re-clamping errors, more re-clamping has to be done or totally skipped in order to save time.

Conclusion

- The closed loop JANIS cryogenic system is generally acceptable for the purpose.
- We have implemented the system for full scale automation. The system is capable of measurement from 5 K to 300 K at selected temperature increment and selected modes. 20 days of continuous operation from 5 K to 300 K on measurement of silicon cantilever without human attendance was demonstrated.
- More experiences need to be accumulated to understand the clamp behavior for reliable measurement.
- Different measurement strategy need to be planned for different samples and situations.