

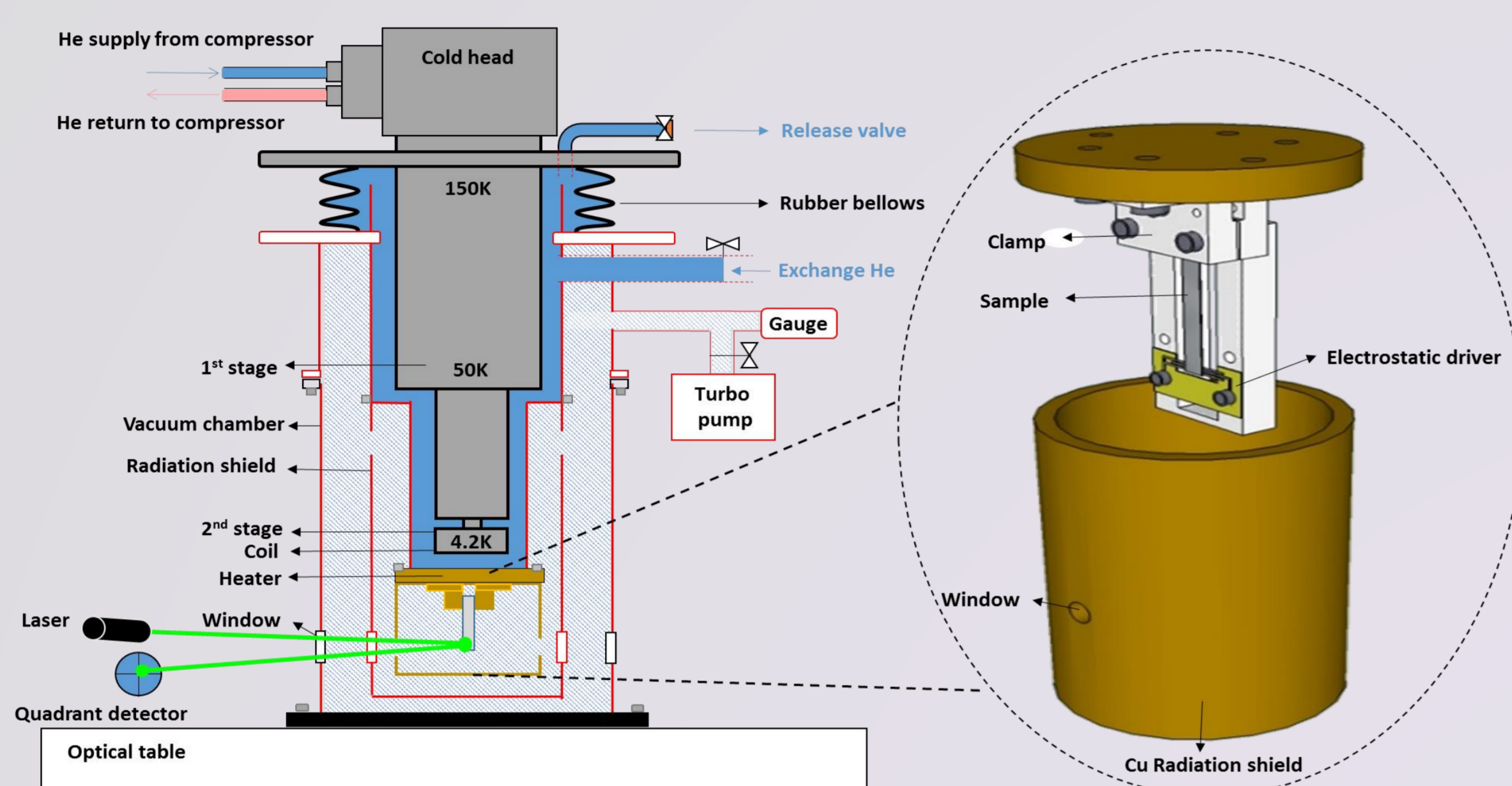
Preliminary Results of Cryogenic Losses for Titania, Silica, Silicon Nitride Films and Silicon Substrate

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Introduction

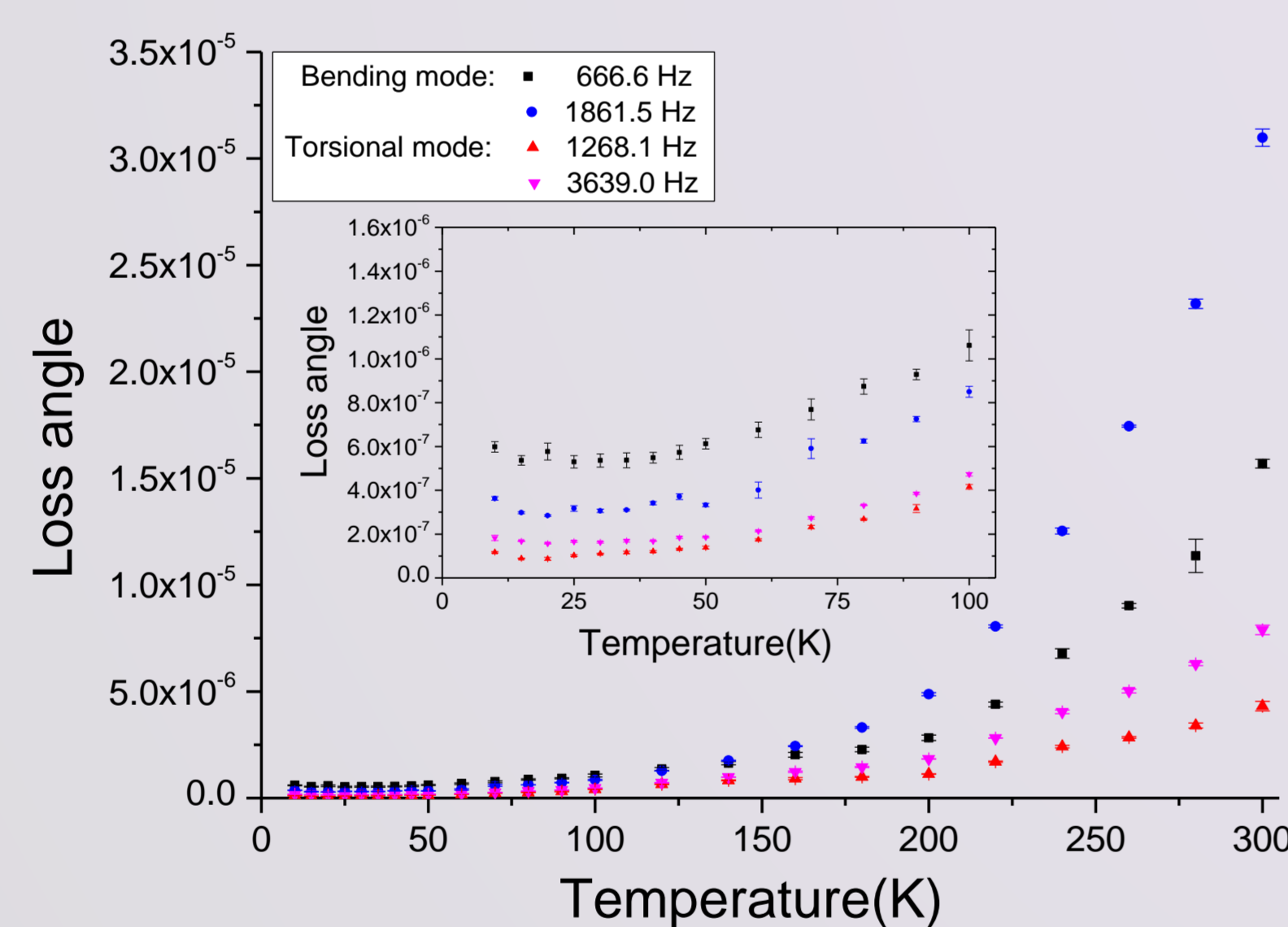
We used our closed-loop cryogenic system to measure the mechanical losses of titania and silica films that were deposited by in-house ion beam sputter (IBS) system and silicon nitride films that were deposited by plasma-enhanced chemical vapor deposition (PECVD) system. Preliminary results are presented here. The IBS titania does not show cryogenic peak and the loss angle is in 10^{-4} range. The as-deposited IBS silica film has a cryogenic peak around 80K and the peak shifts to around 20K after 600°C annealing. Silicon nitride film with 0.87 nitrogen to silicon ratio has a cryogenic peak at around 40K. The silicon nitride film with 0.40 nitrogen to silicon ratio, however, does not show cryogenic peak, and the loss angle is 5.5×10^{-5} for 671 Hz and within lower 10^{-4} range for higher order modes at 10K. $\text{SiN}_{0.40}$ is a promising film in terms of mechanical loss.

Cryogenic loss measurement setup



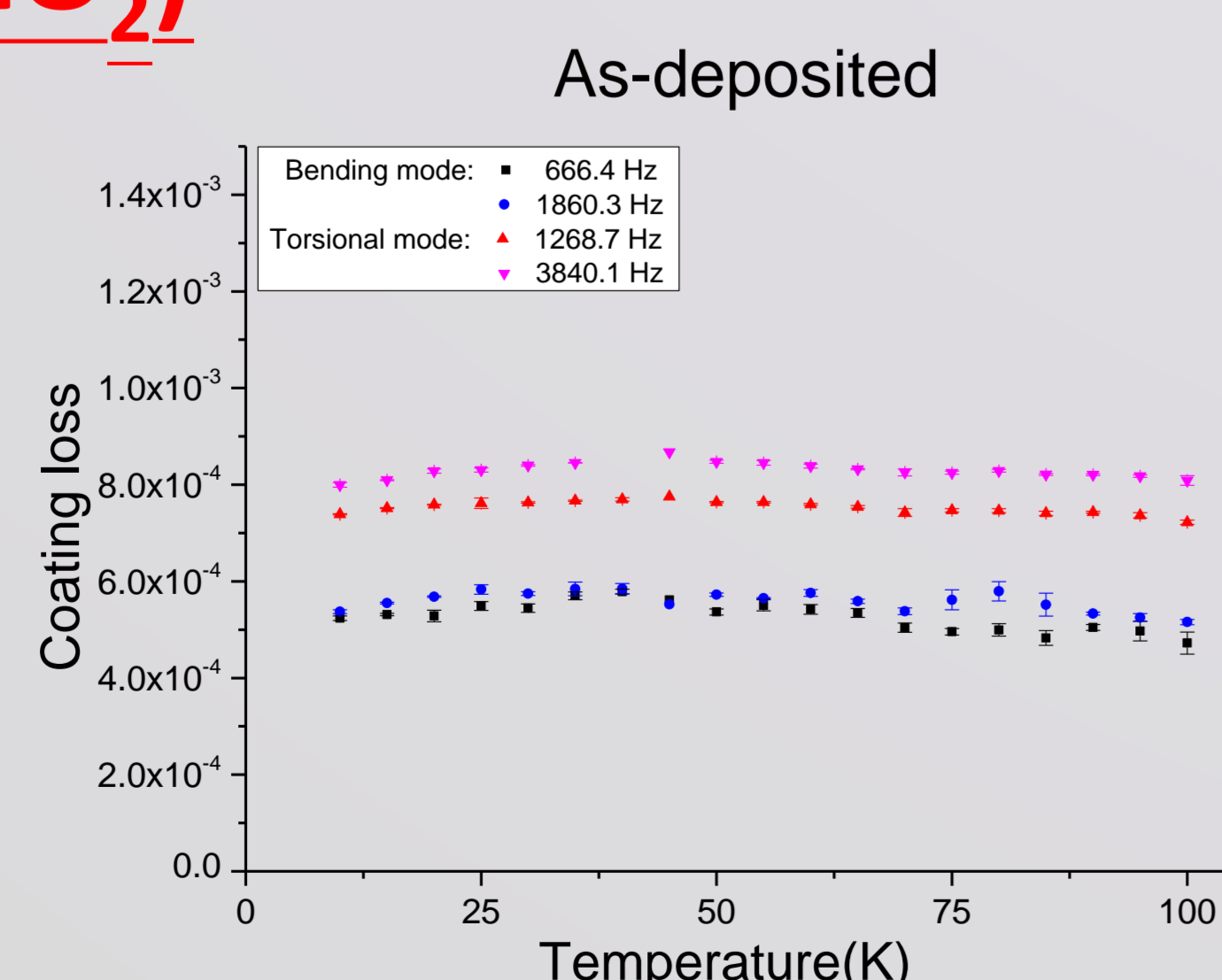
- The cryogenic system is a JANIS SHI-4XG-15, it is a closed-loop system for helium.
- Bellow was used to isolate the vibration from the compressor. The vibration level is smaller than 0.1um at the sample holder.
- Temperature range was from 5K to room temp. with pressure below 10^{-5} mbar[1]

Silicon substrate



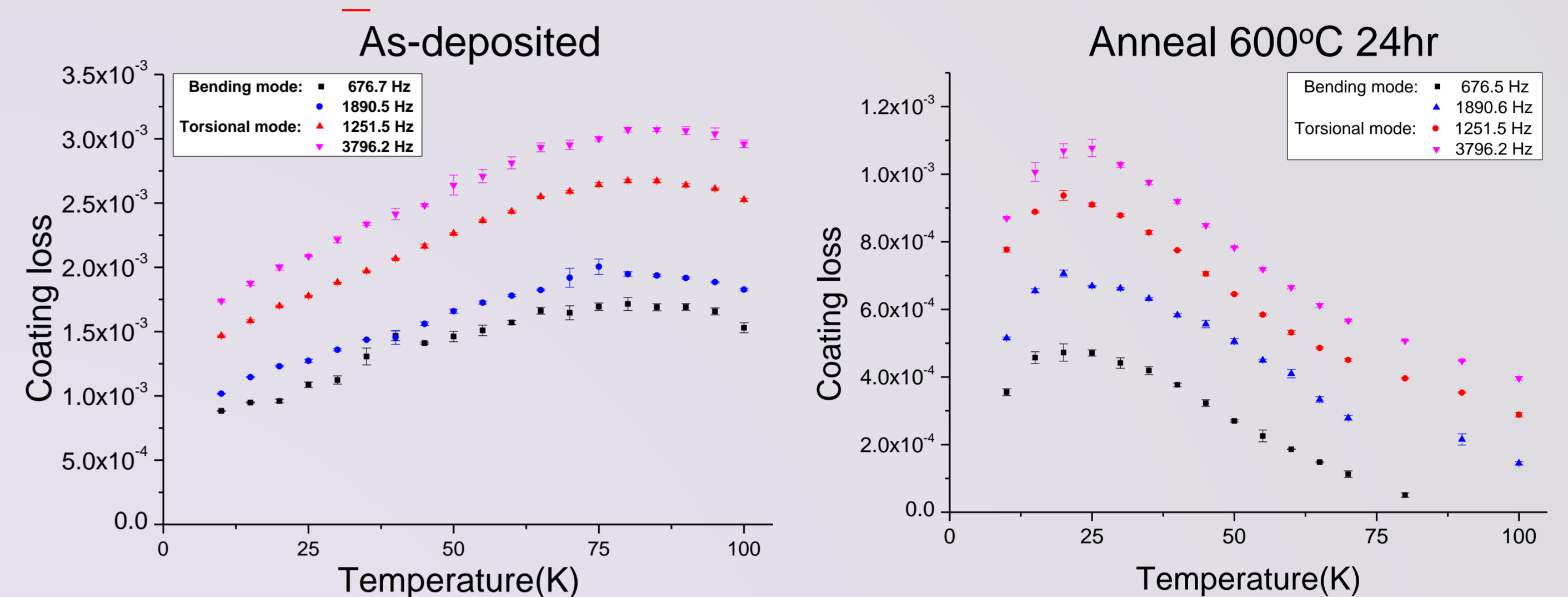
- (100) silicon cantilever without doping.
- Loss angle 6×10^{-7} for 666.6Hz at 10K.
- Torsional modes have lower loss than bending modes through the whole temperature range. (Note that thermal-elastic loss contributes to bending modes loss significantly only at high temperature).

Titania (TiO₂)



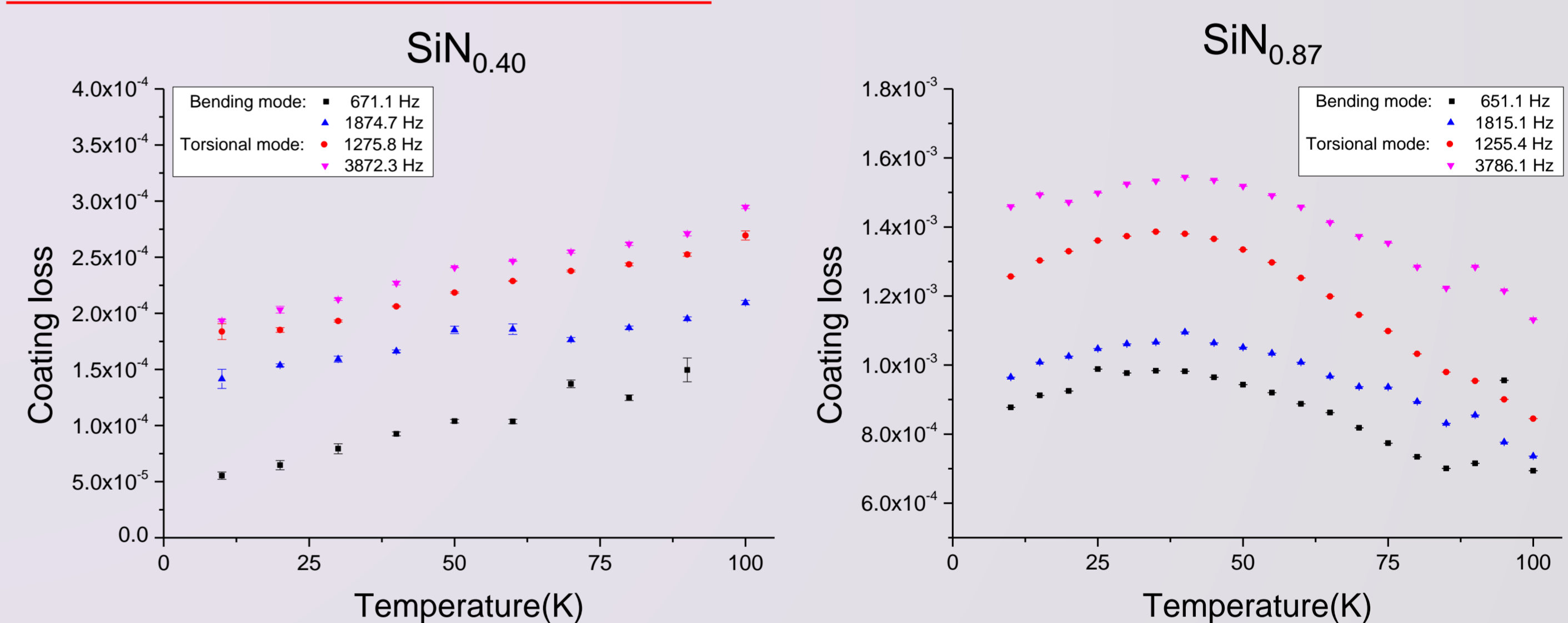
- Coating method: In-house IBS
- There is no cryogenic peak.
- Loss angle is nearly constant with respect to temperature.

Silica (SiO₂)



- Coating method: In-house IBS
- The as-deposited silica film has a cryogenic peak at 80K
- The peak shifted to 20K after 600°C 24 hours anneal and the loss decreased into 10^{-4} range.

Silicon Nitride (SiN_x)



- Coating method: Plasma enhanced chemical vapor deposition (PECVD) at Nano Device Laboratory (NDL) of Taiwan.[2]
- Cryogenic behavior of SiN_x is composition-dependent.
- $\text{SiN}_{0.87}$ has a cryogenic peak at ~40K.
- $\text{SiN}_{0.40}$ does not show cryogenic peak.
- $\text{SiN}_{0.40}$ has loss angle of 5.5×10^{-5} for 671 Hz at 10K.

Conclusion

materials	this work					reference		
	SiO ₂	SiO ₂	TiO ₂	SiN _{0.40}	SiN _{0.87}	Ta ₂ O ₅	Ta ₂ O ₅ :14.5%TiO ₂	SiO ₂
coating method	IBS	IBS	IBS	PECVD	PECVD	IBS	IBS	IBS
heat treatment	AD	600°C 24hr	AD	AD	AD	600°C 24hr	600°C 24hr	600°C 24hr
φ@10K	8.8×10^{-4}	2.9×10^{-4}	5.2×10^{-4}	5.5×10^{-5}	8.8×10^{-4}	$\sim 4.4 \times 10^{-4}$ [3] @~13K	$\sim 4.5 \times 10^{-4}$ [3]	$\sim 7.7 \times 10^{-4}$ [4]
φ _{peak} @LT(<100K)	1.7×10^{-3}	4.2×10^{-4} @~80K	no peak	no peak	9.8×10^{-4} @~40K	1.1×10^{-3} @~20K[3]	1.1×10^{-3} @~20K[3]	8.6×10^{-4} @~20K[4]

Mode: this work ~670Hz : Reference ~1000Hz

- IBS titania film does not show cryogenic peak.
- The as-deposited IBS silica has cryogenic peak at 80K and the peak shifts to around 20K after 600°C anneal.
- For silicon nitride films, the cryogenic loss behavior is highly dependent on the nitrogen to silicon ratio.
- $\text{SiN}_{0.40}$ showed a very promising loss angle of 5.5×10^{-5} for 671 Hz at 10K and without cryogenic peak.

Reference :

- [1] Shiuh Chao et al., "A closed loop cryogenic mechanical loss measurement system for cantilever samples", LIGO document: G1501048 (2015)
- [2] Shiuh Chao et al., "Mechanical loss of silicon cantilever coated with a high-stress SiN_x film", LIGO document: G1400851 (2014)
- [3] I W Martin, "Comparison of the temperature dependence of the mechanical dissipation in thin films of Ta₂O₅ and Ta₂O₅ doped with TiO₂", Class. Quantum Grav. 26 155012 (2009)
- [4] I W Martin et al., "Low temperature mechanical dissipation of an ion-beam sputtered silica film", Class. Quantum Grav.31 035019 (2014)