Mechanical Loss Reduction for nm-Layered SiO_2 / TiO_2 Composites by Thermal Annealing

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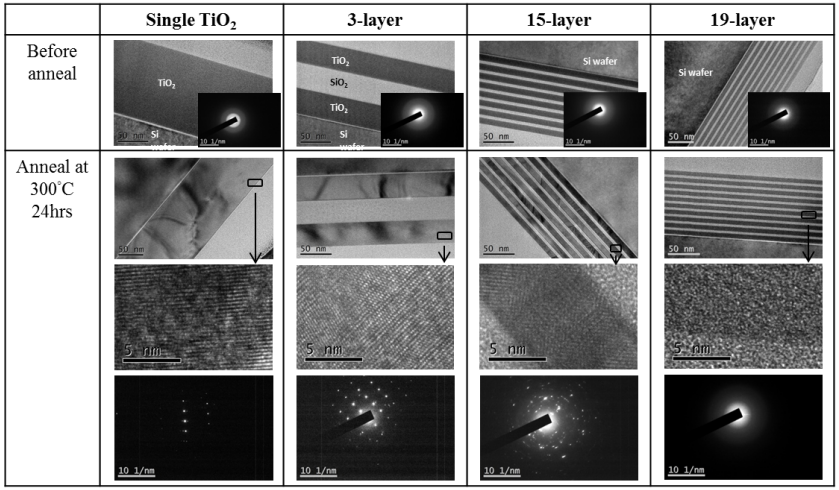
Crystallization of the nm-layer on thermal anneal

nm-layer: alternate TiO_2/SiO_2 thin pairs in nano-meter scale to replace the conventional quarter wave layer [Pinto LIGO-G1000380]

Prototype	Before annealing	225°C 24hr	250 °C 24hr	300 °C 24hr	350 °C 24hr
1 layer	No	No	Yes	Yes	--
3 layer	No	Yes	Yes	Yes	--
5 layer	No	Thr*	Yes	Yes	--
7 layer	No	No	Yes	Yes	--
11 layer	No	No	Yes	Yes	--
15 layer	No	No	No	Yes	--
19 layer	No	No	No	Thr*	Yes

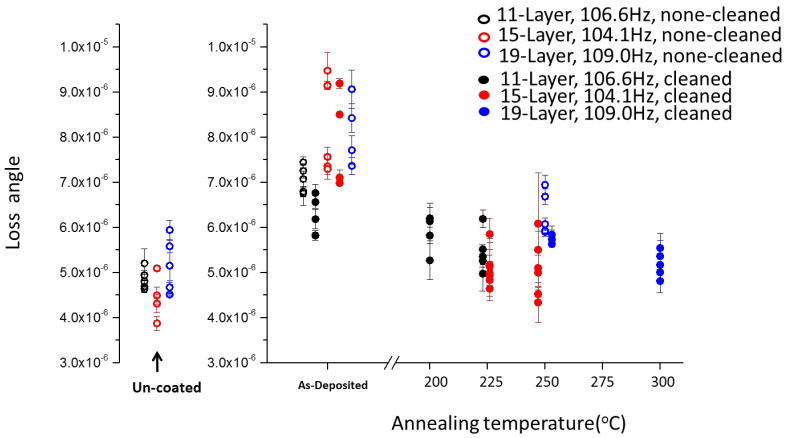


* Weak crystallization peaks could be extracted from the background

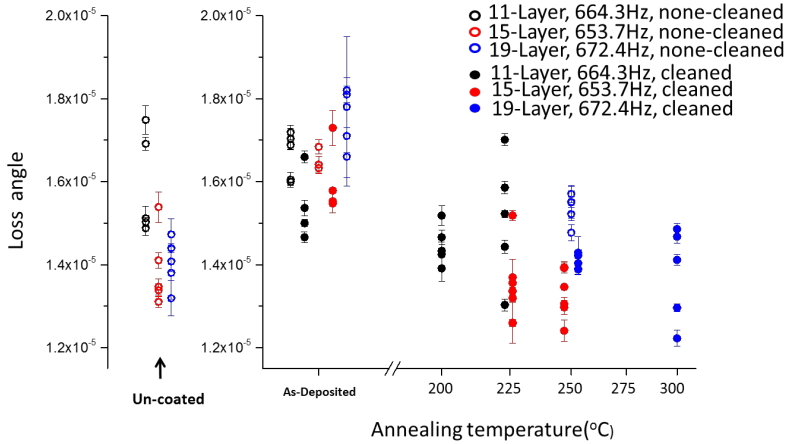
S. Chao et al., LIGO-P1400122

Loss angle of the nm-layer-coated cantilevers

Mode 1 (bending mode ~ 107 Hz)



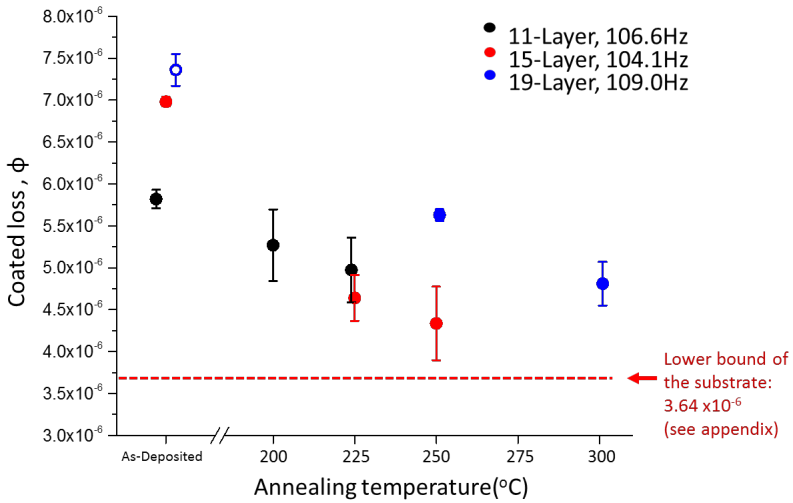
Mode 2 (bending mode ~ 660 Hz)



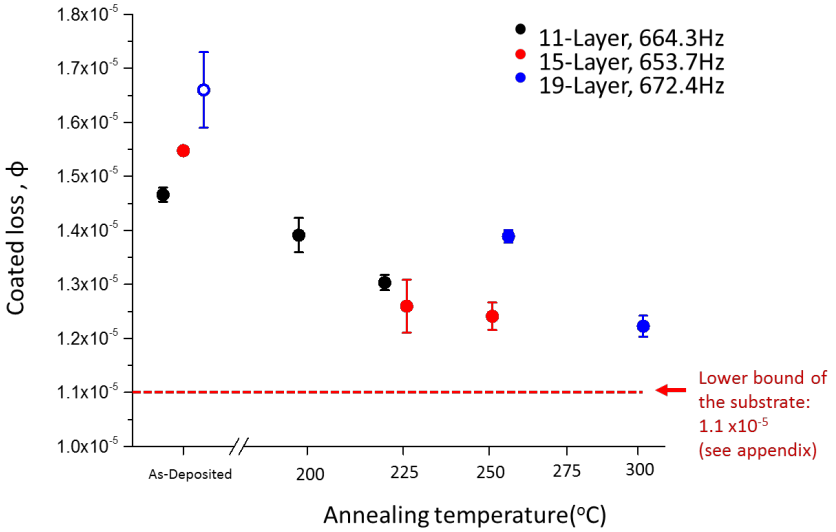
- Each data point represents one clamping, at least 5 times re-clamping were made for each sample.
- Full circle (cleaned): both the clamp surface and the sample surface were wipe-cleaned in between re-clampings.
- Empty circle (None-cleaned): only the clamp surface was wipe-cleaned in between the re-clampings.
- Statistics in appendix showed that noticeable improvement was observed when cleaning both the sample surface and the clamp surface in between every re-clamping.

Loss angle of the nm-layer-coated cantilevers (the lowest loss angle of the re-clampings)

Mode 1 (bending mode ~ 107 Hz)



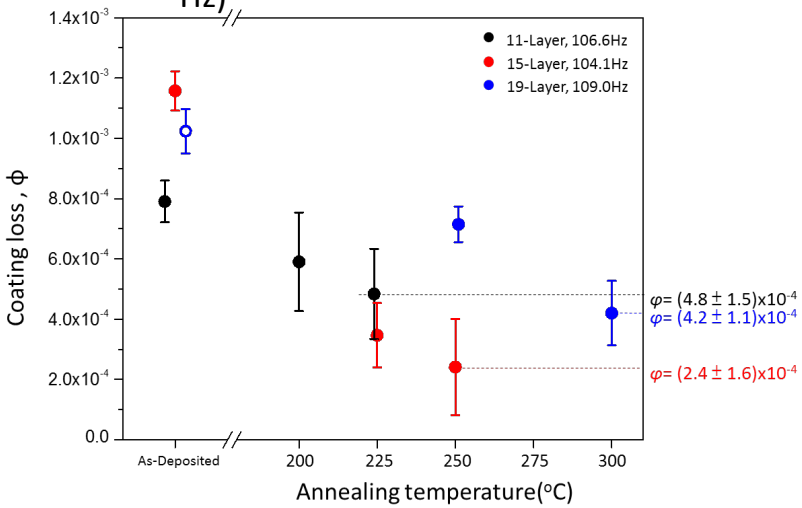
Mode 2 (bending mode ~ 660 Hz)



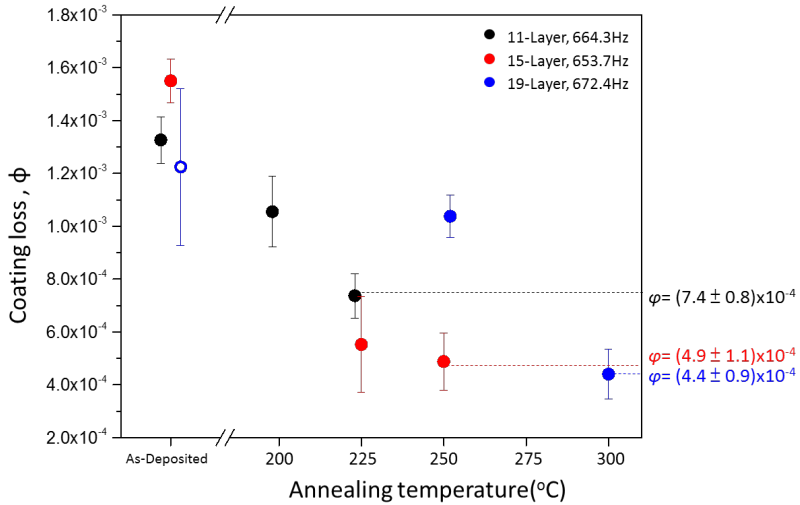
Since the uncoated cantilevers in this experiment were not subjected to cleaning on both surfaces in between the re-clamping, therefore, we use the lowest loss angle from previous large number statistics of the “cleaned” uncoated cantilever for the uncoated cantilever of this experiment.

Loss angle of the nm-layers

Mode 1 (bending mode ~ 107 Hz)



Mode 2 (bending mode ~ 660 Hz)



	11-layer	15-layer	19-layer
Mode1 (~107Hz)	(4.8 ± 1.5) x10^{-4}	(2.4 ± 1.6) x10^{-4}	(4.2 ± 1.1) x10^{-4}
Mode2 (~660Hz)	(7.4 ± 0.8) x10^{-4}	(4.9 ± 1.1) x10^{-4}	(4.4 ± 0.9) x10^{-4}

There is possibility that some of these values were under-estimated. Because, the uncoated losses were the statistically lowest from large sampling, but the coated loss were the lowest from ~5 measurements, thus, the coating losses might be under-estimated.

Conclusion

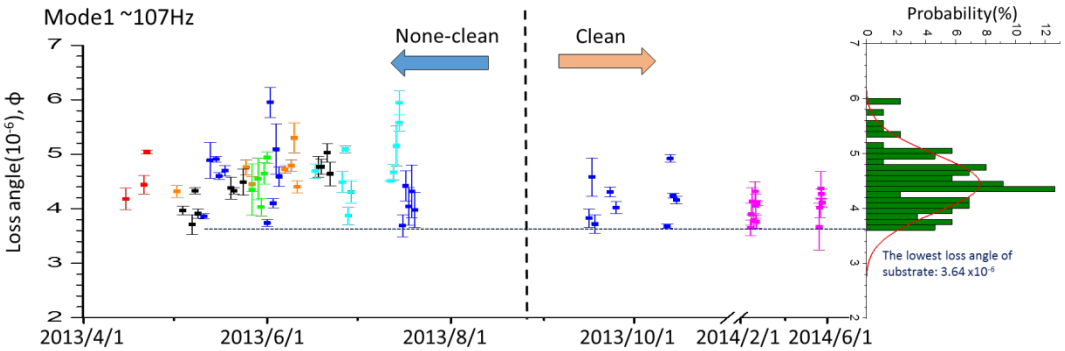
- Room temperature loss angle of the nm-layer coatings were reduced by thermal annealing.
- Fluctuation of the decay time determination from re-clampings was the dominant error in the measurement. Tiny mis-alignment of the clamps could affect the measurement.
- A noticeable improvement was observed when cleaning the surface of the clamp and the sample surface in between re-clamping, indicating that even traces of tiny debris from the action of clamping would affect the measurement outcome.
- A statistical meaningful number of re-clamping, at least 5, were taken for each test, and the lowest loss was taken into consideration instead of the mean value.

Remarks:

- Sample fabrication and loss measurement spanned a period more than two years for this experiment. All the deposition processes and measurement procedures needed to be carefully kept consistent during the course.

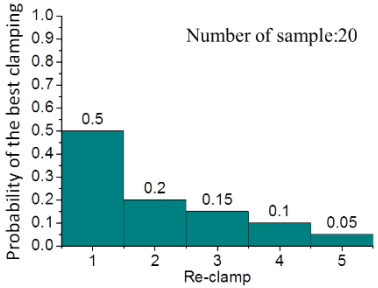
Appendix

Statistics of re-clamping

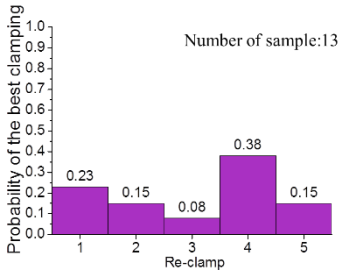


Re-clamping distribution for 19 uncoated silicon cantilevers with 89 re-clampings (clamping torque = 5 kgf-cm)

- cleaned: both the clamp surface and the sample surface were cleaned in between re-clamping.
- None-cleaned: only the clamp surface was cleaned in between re-clamping.



Probability of hitting the lowest loss angle vs. order of re-clamping (none-clean: only the clamp surface was cleaned in between re-clamping)



Probability of hitting the lowest loss angle vs. order of re-clamping (both clamp surface and sample surface were cleaned in between re-clampings)

Conclusion: The action of clamping produces tiny debris that effects the next measurement. It is important to clean both the clamp surface and the sample surface in between every re-clamping.