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Preliminary Results of Modal Analysis on the Cantilever-clamp System for Measuring the Mechanical Loss of Thin Films by means of Cantilever Ring-down Method

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Abstract

Cantilever ring-down method for measuring the mechanical loss of thin films is convenient and fast turnaround for R&D works to select low thermal noise coatings for the mirrors of laser interference gravitational waves detectors. Cantilever with coatings is excited at the mechanical resonant frequencies of the cantilever and decay times of the free damping are measured to deduce the frequency-dependent mechanical loss of the thin films. Based on our experiences, the mechanical loss so measured often suffered large uncertainty for some frequencies upon re-clamping. We have performed modal analysis on our cantilever-clamp system. Normal modes of the cantilever and the clamp were computed by using the COMSOL. Preliminary results showed that for our clamp design, some of the cantilever modes and clamp modes were close in frequency. For these modes, experimental data showed that particularly large uncertainty in loss angle upon re-clamping occurred, which indicating that there are strain energy coupling between the clamp and the cantilever and the coupling is sensitive to the alignment of the clamp and the cantilever. Further analysis on strain energy coupling between the cantilever and the clamp is on-going to study the effect of loss angle contribution of the clamp and mis-alignment of the clamp-cantilever to the measurement.

Table 1. Parameters used in modal analysis of COMSOL.

	ρ (kg/m³)	E (GPa)	ν	α (1/K)	κ (W/mK)	C (J/kgK)
Cantilever (Si)	2329	170	0.28	2.6E-6	130	700
Clamp (SUS420-J2)	7689	215	0.3	9.8E-6	30	460

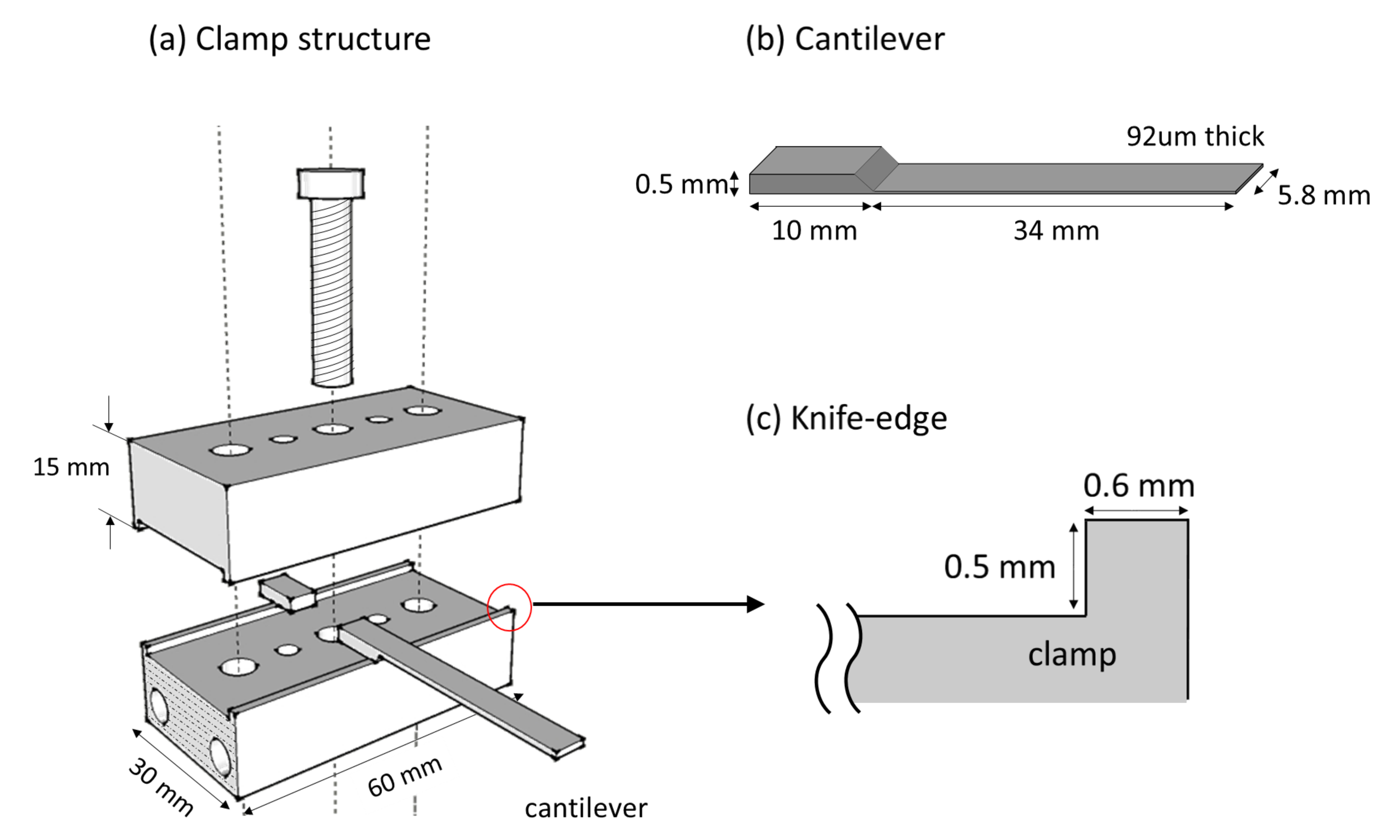

Fig.1 Clamp and cantilever structure.

The clamp is composed of two identical pieces made of stainless steel SUS420-J2. Knife edge with 0.6 mm width on the clamp is the contact region to the thick pad of the cantilever for reducing the friction from contact area between the clamp and the cantilever. One screw on the center of the clamp is used to tighten the clamp and the cantilever. Two alignment pins are used to align the two pieces of the clamp. A fixture was designed (not shown here) and used to align the cantilever to the clamp during loading[1]. The dimension of the cantilever were so designed as to put the fundamental frequency of the cantilever to around ~100Hz that is the most critical frequency range for the GW detector where thermal noise of the mirror coatings dominates. The cantilever with pad was formed by using lithographic method [2][3] out of a commercial (100) un-doped silicon wafer.

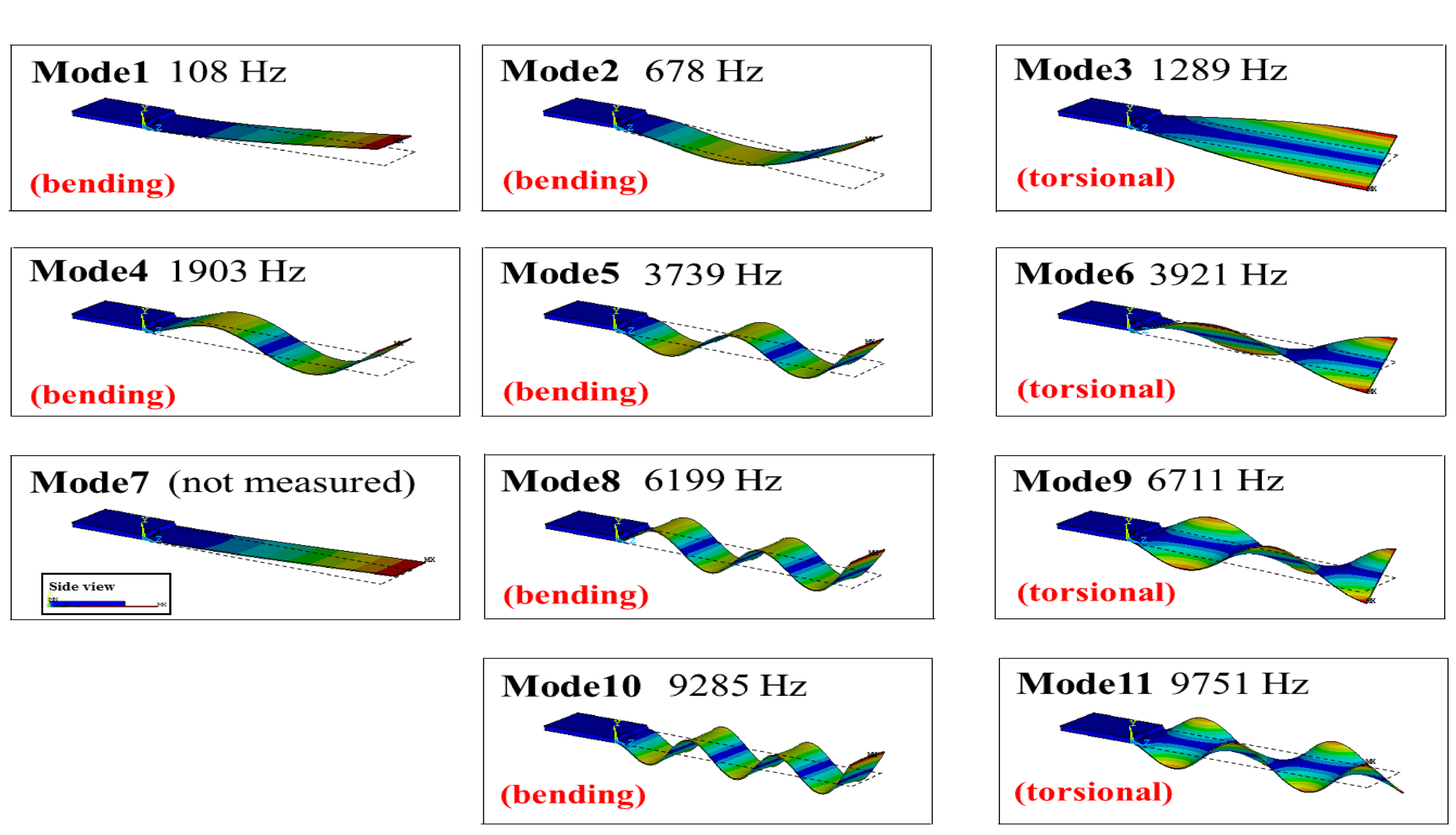

Fig. 2 Mode shapes and frequencies of the cantilever.

There are two major types of cantilever modes, bending modes and torsional modes. Mode 7 is a lateral mode that is hard to excite and is skipped from further study.

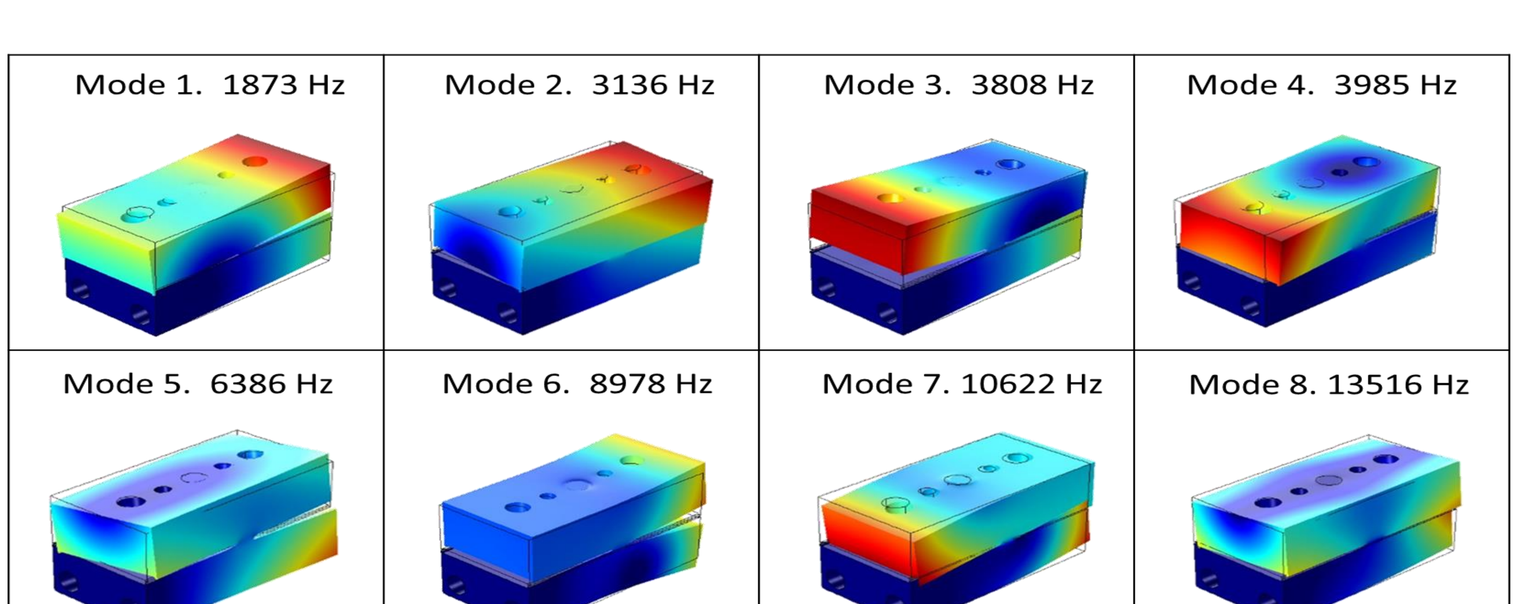

Fig.3 Mode shapes and frequencies of the clamp.

Since the screw is at the center, the vibration modes of the clamp are central symmetrical and open-end types. The lower left surface of the clamp was the fixed boundary in modal analysis.

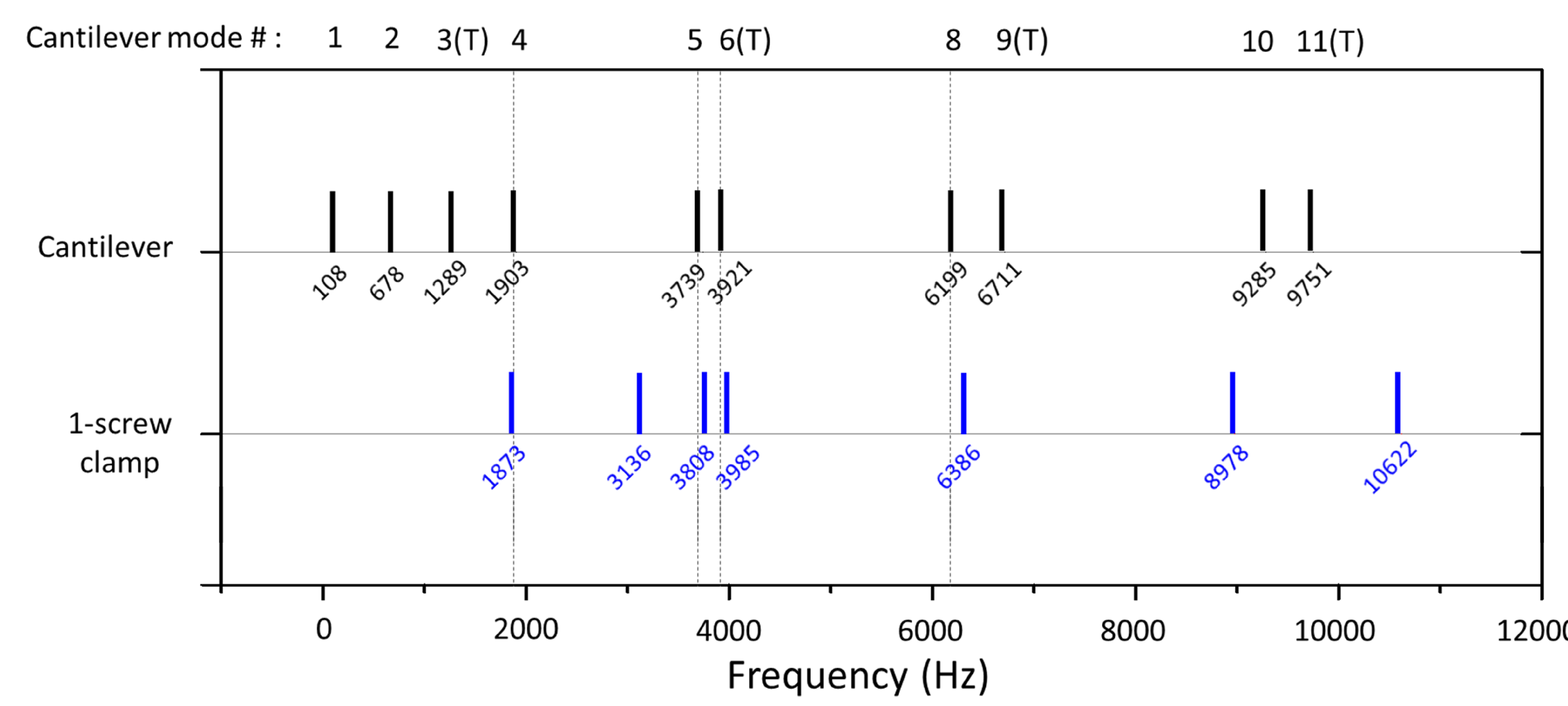

Fig.4 Mode frequencies of the cantilever (in black) and the clamp (in blue). The mode numbers are referred to the cantilever modes. T: torsional mode, others: bending mode. Fig.4 reveals that frequencies of cantilever mode 4,5,6,and 8 are close to that of some clamp modes.

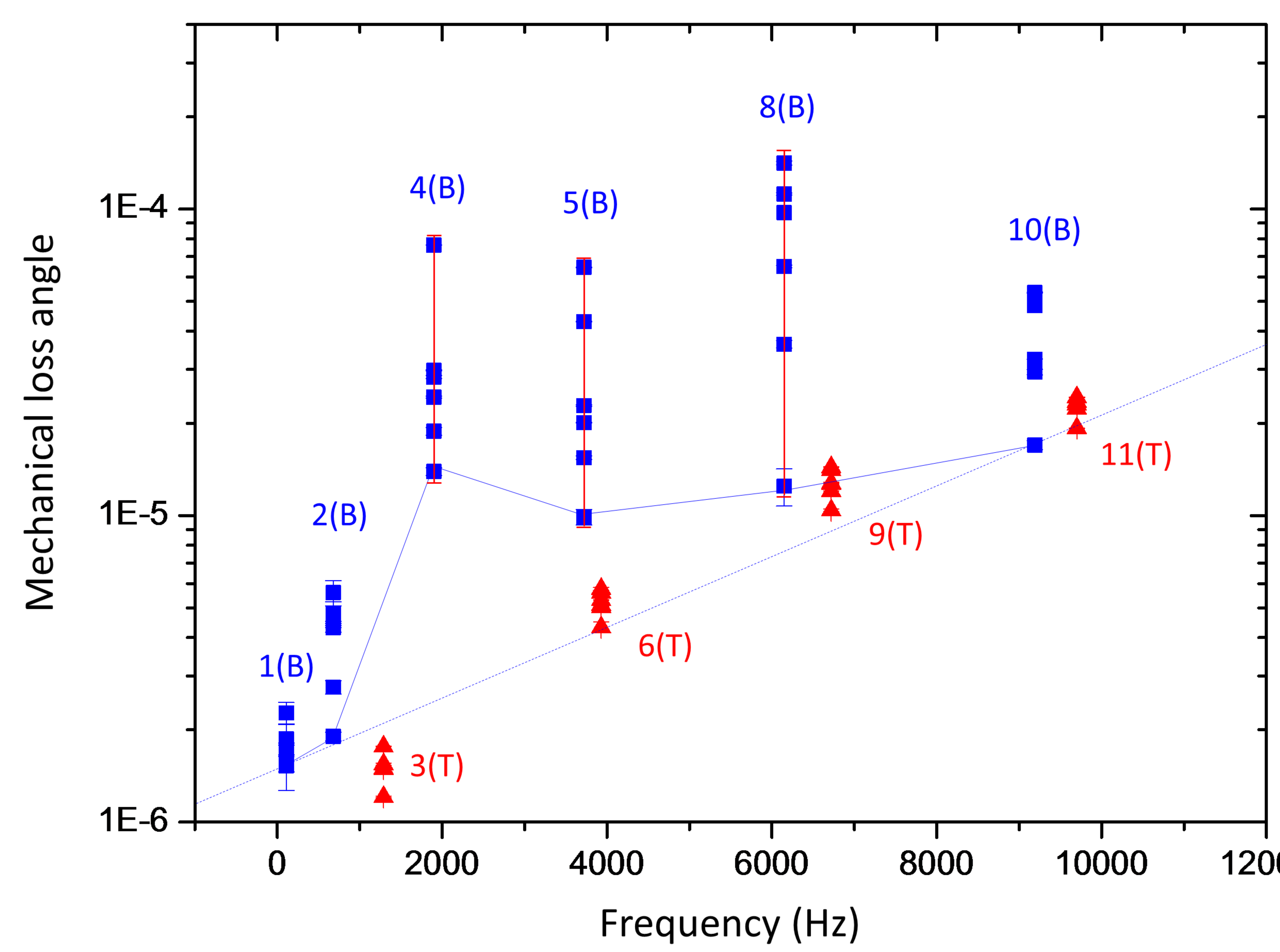

Fig.5 Experimental results of loss angle for silicon cantilever. The number referred to the mode number of the cantilever. T: torsional mode, B: bending mode. The spread data points were from 6 times of re-clamping. Thermo-elastic loss was subtracted for the bending modes.

Fig.5 reveals experimentally, that bending modes 4,5, 8 have particularly large uncertainty upon re-clamping that correlates with the results of Fig.4, which indicates that loss angle measurement of these modes are sensitive to mis-alignment upon re-clamping. In addition, Fig.5 shows that base-line loss angle, i.e. the lowest measured loss angle among the 6 times re-clamping, of bending mode 4,5,8 are larger than that for other modes, indicating that for these modes there are large energy coupling to the clamp when the cantilever is excited at these modes. Although frequency of torsional mode 6 also close to a clamp mode, but the uncertainty and deviation seemed to be less than the bending mode 4,5 and 8. It is possible that torsional modes are less susceptible to energy coupling. Moreover, fig.5 shows that the base-line loss increases with frequency, indicating that there might be a loss mechanism either from clamp or from silicon cantilever with Debye peak at high frequency.

Conclusion

The preliminary results showed that when the mode frequencies of the cantilever and the clamp are close, strain energy of the cantilever is easily coupled to the clamp, and the coupling is sensitive to the clamp-cantilever alignment. When this happens, particular caution is required on data deduction for the loss angle of the coatings due to error propagation in the data deduction scheme. It seemed that torsional mode is less susceptible to these problems than the bending modes.

It is possible to calculate the amount of strain energy coupling by using finite element analysis tool such as COMSOL to further analyze the contribution of the loss angle of the clamp to the nominal measured loss angle of the cantilever. This work is currently on-going.

Reference: [1]S. Chao, et al. "Mechanical loss of silicon cantilever coated with a high-stress SiNx film", LVC meeting, Stanford University, Aug. 25th ,2014, LIGO--G1400851. [2] S. Chao, et al, "Progress of coating development at NTHU", LVC meeting , Rome, Italy, Sep. 10th ,2012. LIGO-G1200849. [3] S. Reid, et al, "Mechanical dissipation in silicon flexures", Physics Letters A 351, 2006, p.205–211