Measurement of *Q*-factors of silicon wafers vibrational modes at low temperatures

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Motivation

Silicon test masses and silicon suspensions are considered as prospective candidates for the third generation of GW detectors due to very low mechanical loss in crystalline silicon and its other excellent properties [1]. They will operate at the low temperature of about 120 K in order to reduce significantly thermoelastic loss in silicon and associated thermal noise. Internal mechanical losses of silicon single-crystals allowed one to obtain $Q > 10^7$ for the silicon ribbons at these temperatures [2]. The main problem is surface losses because silicon fibers or silicon ribbons have large ratio of the surface to volume, so the losses in their surface layers dominate. It is necessary to realize a technique for silicon ribbons/fibers fabrication and subsequent their treatment which provide low surface losses. It is possible to fabricate silicon ribbons from standard silicon wafers. There are several techniques of etching of silicon used for fabrication of micromechanical structures. Wet or dry etching is likely the most appropriate, because allows obtaining of the smooth surface without defects. Anisotropy of etching allows one to fabricate ribbons from silicon wafer making slots in a wafer with vertical walls.

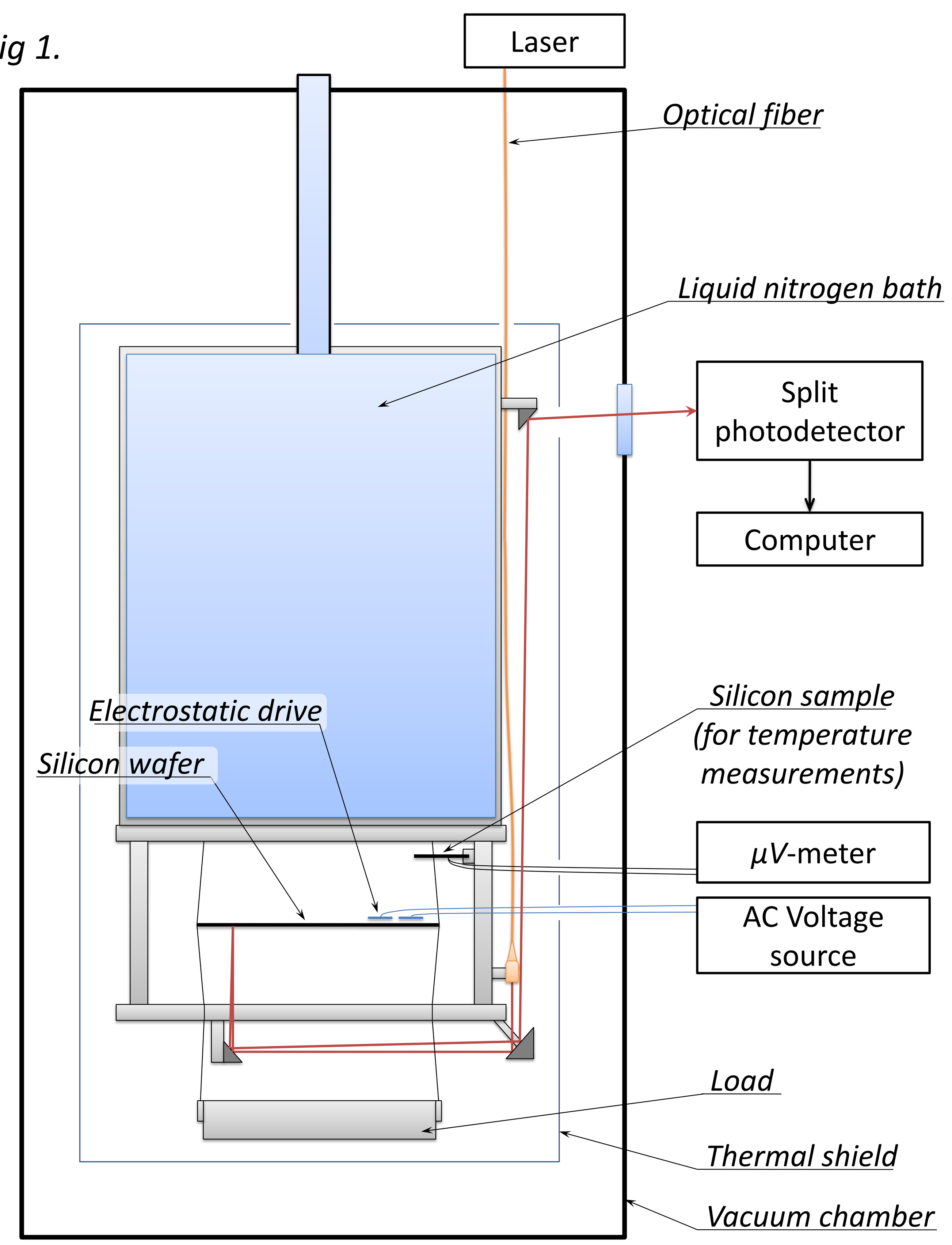
The losses in silicon ribbons can be determined by measuring the *Q*-factors of mechanical oscillators formed on the base of the ribbons. It is necessary to clamp the oscillator so that the clamping losses are negligible. In work [3] the thicker block at one end of the thin flexure was fabricated in order to reduce clamping losses of thin silicon flexure. We suppose to test other versions of clamping structure in order to measure dissipation in silicon ribbons which is not associated with clamping losses. It is proposed to fabricate the mechanical oscillator in the silicon wafer by means of etching and to clamp the wafer with the fabricated oscillator attaining the minimal clamping losses.

In this work we investigate mechanical losses of vibrational modes of silicon wafers suspended by wires at temperatures 100K – 300K.

Experimental setup.

Schematic of the setup is shown in Fig.1. The dewar with liquid nitrogen is mounted inside the vacuum chamber. The silicon wafer is suspended inside a special frame which is attached to the dewar bottom. We use 100 µm diameter nichrome wire for the wafer suspension. In order to provide the constant wire tension in the process of cooling the weight is hung on the wire end. The additional piece of silicon wafer with attached thermocouple is used to measure the temperature. Resonant excitation of the wafer vibrational modes is realized by the electrostatic drive. Optical sensor is used to monitor the vibration amplitude of the wafer modes. Local bending of the wafer produced by its vibration results in deflection of the laser beam reflected from the silicon wafer which passes through the mirror system and is detected by a split photodiode set outside the vacuum chamber. *Q*-factor of the mode is determined measuring the decay time of the mode free vibration.

Fig 1.



Results of measurements

The main measurements were carried out for 3 inch diameter 320 µm thickness double side polished commercial *n*-type single-crystal silicon <111> wafer doped with antimony (the electrical resistivity is 0.02 Ohm·cm). Several vibrational modes are measured. The temperature dependence of the relative variations of the modes frequencies is shown in Fig. 2.

We use two regimes of measurement of temperature dependence of the mode's *Q*-factor. In the first one the *Q*-factor is measured in process of cooling of the wafer after the dewar was filled with liquid nitrogen. The cooling of the wafer is realized by radiative heat transfer at the pressure of about $3x10^{-6}$ Torr in the vacuum chamber. In the second regime the *Q*-factor is measured in process of heating of the wafer which was cooled preliminary by means of exchange gas-nitrogen at the pressure of about $3x10^{-3}$ Torr in the vacuum chamber.

The temperature dependence of loss for two vibrational modes of the silicon wafer is shown in Fig.3. The dependences were measured in process of heating of the wafer.

Estimates of thermoelastic loss were made using calculations for silicon beam with rectangular cross section and the same thickness as the thickness of the wafer used in our measurements

Fig 2.

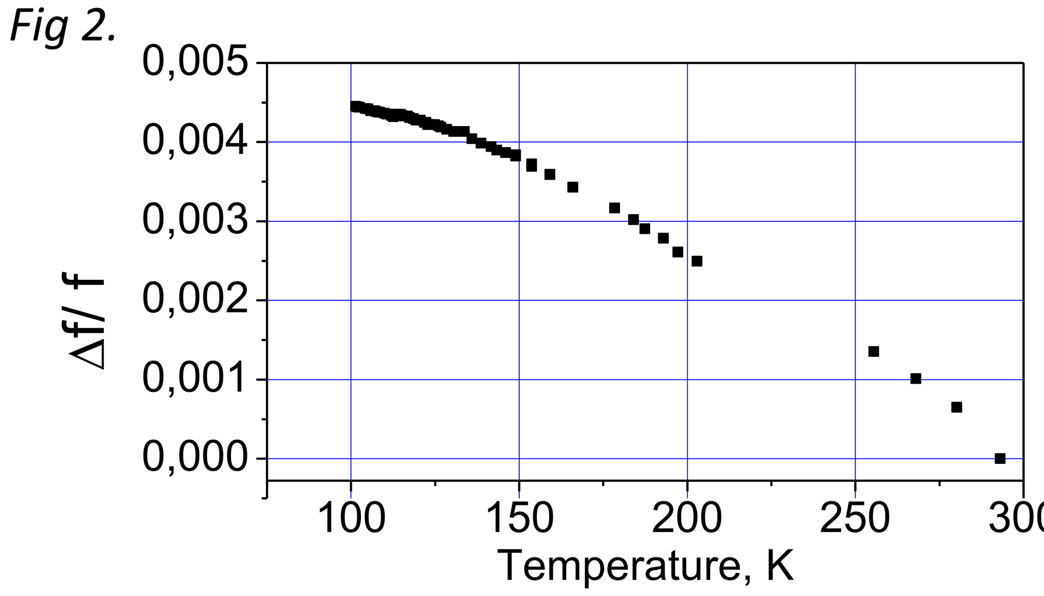
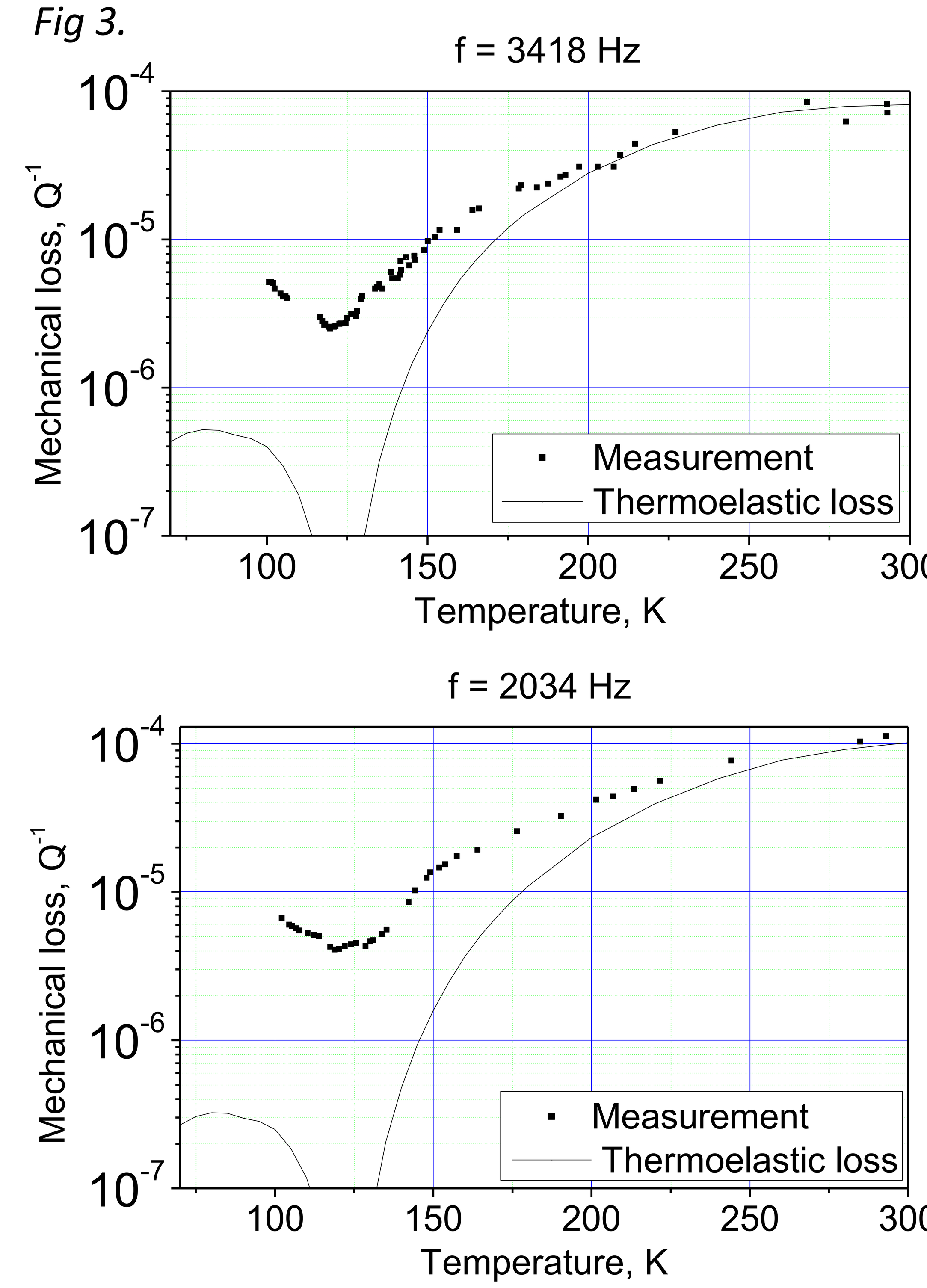


Fig 3.



Summary and future work

The mechanical dissipation in silicon wafer which we measure at the temperature range near 120 K is mainly associated with clamping losses. We plan to improve the wafer suspension and to measure the dissipation in silicon oscillators fabricated in the wafers.

Acknowledgements

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References:

1. R. Adhikari, K. Arai, S. Ballmer, E. Gustafson, S. Hild, LIGO-T1200031 (2012).
2. V. P. Mitrofanov, LIGO -T1200178 (2012).
3. R. Nawrodt et al., submitted to Class. Quantum. Grav.