Selectively-Method to Evaluate the Influence of Surface Loss on Micro-Cantilever

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Abstract

Keywords: Micro-Cantilever, Quality Factor, Surface Loss

◆ We propose a selectively-method to evaluate the effect of surface loss on the silicon micro-cantilever from the another energy loss mechanism that is several different energy loss due to thermo-elastic damping, air (viscous) damping, support loss, and surface loss. We can appraise indirectly the surface contamination quantity and the internal defects, by measuring the surface loss in this method.

INTRODUCTION & THEORY

§ Micro cantilever is expected to be applied to various devices such as SPMs (scanning probe microscopes), AFMs (atomic force microscopes), memory application and material physicality analysis. Quality factor (Q), that decide sensitivity and indicate energy losses, is one of the most important characteristic in almost cantilever-devices.

§ The cantilever with less damping have a larger Q factor and a sharper resonance peak, On the other hand, more damping have a smaller Q factor and lower the resonance peak. The Q factor can be expressed as following equation by considering several different energy losses.

$$Q_{total}^{-1} = Q_{Air}^{-1} + Q_{TED}^{-1} + Q_{clamp}^{-1} + Q_{surface}^{-1}$$

Where, air damping, thermo elastic damping, support loss and surface lose denote the quality factors due to air damping, thermo-elastic damping, support loss, and surface loss, respectively. In this study, we ignore any other losses.

About air damping.

$$Q_{Air} = \frac{2}{3}\frac{l_1}{p}\left(\frac{r_b^3}{3r_a^2 h^2}\right)^{0.25} H^{1.5}/L$$

The Q factor of air damping is able to negligible, in the case of less than 10E-2[Pa] vacuum condition in analytically.

About TED.

$$Q_{TED} = \frac{r_b C_p}{E\mathrm{A}^2 T_0}\frac{1+\left(w_1 t_z H^2\right)^2}{w_1 t_z H^2}$$

Where, $t_z = \frac{r_b C_p}{p^2 k_{th}}$

An equation to calculate thermo elastic damping was derived by Zener. According to this equation, this damping is on the order of 106 or more for a sufficiently thin micro-cantilever with a thickness of 1-2um. Therefore, this damping negligibly small in this study.

About support loss.

$$Q_{clamp} = k\left(L/H\right)^3$$

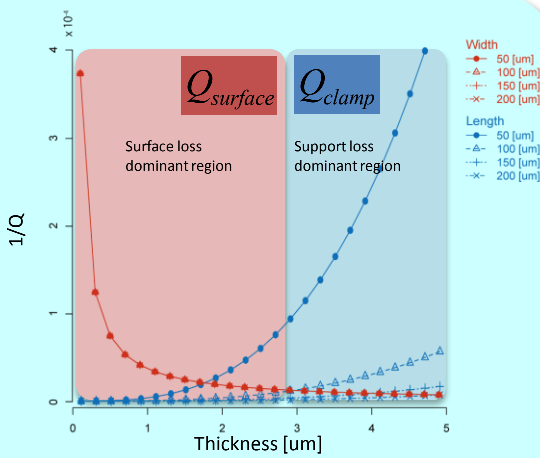
Support loss is the loss due to the vibrating moment under high-vacuum conditions when the air damping is negligible.

About surface loss.

$$Q_{surface} = \frac{WH}{2(3W+H)}E/dE_{ds}$$

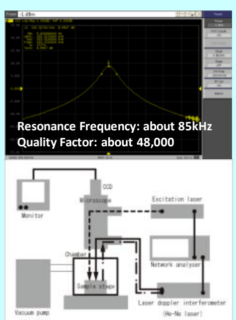
Surface loss is the energy loss due to contamination or defects on the surface, becomes dominant as the micro cantilever under the thickness of less than 3um as shown in right hand figure.

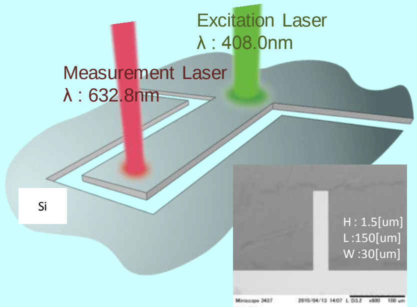
Symbol	Quantity	Symbol Value
ρ_a	Air Density[kg m⁻³]	1.18
η	Air Dynamic viscosity[Pa s]	1.86 x10⁻⁶
T_0	Temperature[K]	300
α	Linear thermal expansion coefficient[K⁻¹]	2.60 x10⁻⁶
ρ_b	Silicon density [kg m⁻³]	2.33 x10³
C_p	Silicon specific heat capacity[J kg⁻¹ K⁻¹]	700
λ_1	Flexural mode (first-order) identifier constant	1.87
E	Silicon modulus of elasticity ⟨110⟩[Gpa]	169
δE_{ds}	Thickness of complex Young's modulus[Pa m]	
κ	Coefficient calculated	2.08
κ_{th}	Thermal conductivity[W m⁻¹ K⁻¹]	156

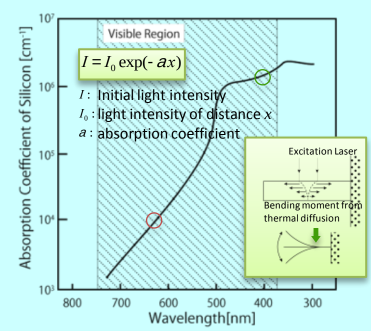


MESURE

§ This section shows a schematic diagram of an equipment to measure frequency response characteristics of the micro-cantilevers. The equipment is composed of a laser Doppler interferometer and a violet 408 [nm] laser diode LD for photo-thermal excitation. The laser Doppler interferometer is suitable for measuring high frequency vibration with small amplitude because velocity for a given amplitude of oscillation increases with frequency. The photo thermal excitation method was used to vibrate the cantilever rather than the piezoelectric PZT actuator excitation because the PZT excites many mechanical components simultaneously; hence, the detected vibration signal contains many spurious resonances originated from vibrating the components such as the cantilever holder and the cantilever substrate. On the other hand, photo thermal excitation does not require any mechanical elements, it excites only the resonance modes of the cantilever.







How to measure?

Resonance frequency and quality factor of the cantilever are detected by laser Doppler interferometer system.

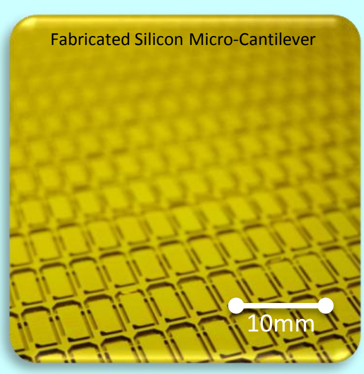
How to oscillated?

The cantilever oscillation is caused by bending moment form thermal diffusion which gives by excitation laser.

CONCLUSION

§ In this study, we propose a selectively-method to evaluate the surface loss in the micro-cantilever by theoretical study. As a result, surface loss is able to realized that assess the quality factor in resonance frequency under the thickness of 1-2um, the length of 100-200um and the high-vacuum conditions.

The measurement system which examine quality factor in resonance frequency is consist of the photo thermal excitation laser with 408[nm] wavelength and the laser Doppler interferometer. We can evaluate the surface contamination quantity and the internal defects, by measuring the surface loss.



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