Improvement of FM-AFM Performance in Liquid using Small Cantilevers with Megahertz-order Resonance Frequency

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The minimum detectable force ($F_{\min}$) required for true atomic-resolution imaging typically falls in the range of 10-100 pN. While this condition is easily satisfied in vacuum, it can barely be satisfied in liquid due to the low Q factor (Q) of the cantilever resonance. Such a narrow margin leads to low reproducibility of the experiments and practically limits the application range. In this study, we have improved $F_{\min}$ using small cantilevers (USC, Nanoworld) with a resonance frequency (f_0) of 3-4 MHz in liquid. This is more than 20 times higher than that of a standard one (NCH, Nanoworld). In addition, the spring constant (k) and Q of USC are comparable to those of NCH. While the merit of using a small cantilever is evident, it imposes stringent requirements on the instrumentation. To satisfy these requirements, we have developed a wideband (> 10 MHz) and low noise (< 5 fm/√Hz) deflection sensor combined with high magnification optics; and a wide band (> 300 MHz) photothermal excitation system with extremely high stability.

To confirm the improved $F_{\min}$, we have measured oscillatory hydration force using NCH and USC. The Δf curve obtained by USC shows 50 times higher magnitude than the one obtained by NCH. On the contrary, the converted force curves show almost the same magnitude. These results show that the force sensitivity is improved by 43.4 times by using USC. We also estimated the noise contained in the Δf curves and found that the noise is 5.86 times increased by using USC. Consequently, $F_{\min}$ at B = 100 Hz is improved from 10.7 pN to 1.44 pN by using USC. Owing to this seven-fold improvement in $F_{\min}$, the Δf curve obtained by USC shows much lower noise and hence reveals the existence of the third hydration layer, which is hardly visible in the curve obtained by NCH.

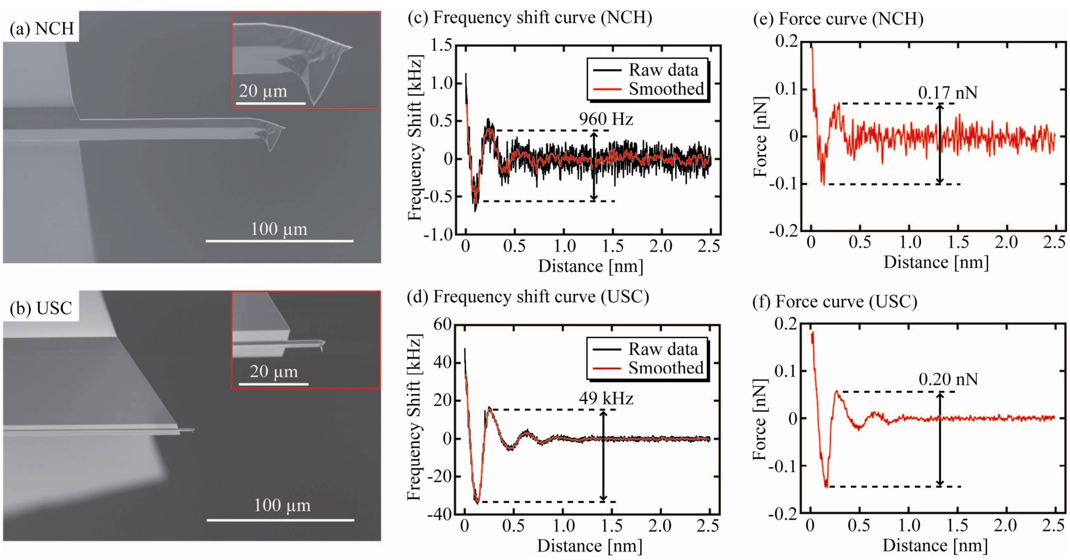

Fig. 1: Comparison between a standard (NCH, f_0 = 150 kHz, Q = 8.8, k = 52 N/m) and a small (USC, f_0 = 3.1 MHz, Q = 6.3, k = 24 N/m) cantilever. (a), (b) SEM Images. (c), (d) Δf curves measured on mica in phosphate buffer saline solution (B = 100 Hz). (e), (f) Force curves obtained from (c) and (d).

References

[1] T. Fukuma et al., Nanotechnology, 23 (2012) 135706