High Resolution Imaging by Frequency Modulation Atomic Force Microscopy Using Quartz Length-Extension Resonator

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In non-contact atomic force microscopy (nc-AFM), small oscillation amplitude is desirable for a detection of short-range components, which contributes to the atomic resolution [1]. When the oscillation amplitude is reduced using a conventional cantilever (CL), however, this causes snapping the CL into sample to damage the surface and tip ("jump to contact"). Using a quartz tuning fork (qPlus sensor) which has higher stiffness than the normal CL, Giessibl have shown atomically resolved nc–AFM imaging with the oscillation amplitude below 1 nm without the "jump to contact" [1]. Using a quartz length-extension resonator (LER), Heike and Hashizume also reported atomically resolved imaging in phase detection method [2]. In this study, we carried out frequency modulation (FM) nc-AFM observation using a LER whose spring constant and resonant frequency f_0 are ~400 000 N/m and 1 MHz, respectively (Fig. 1(a)). While in the phase detection method the band width of the force detection is restricted by a time constant of the amplitude response to a finite change in f_0 ($Q/\pi f_0$), such restriction does not occur in the FM method, enabling us stable scanning of nc-AFM in ultra high vacuum.

A tungsten (W) tip was attached on the apex of the front rod of the LER (Fig. 1(b)), and was fabricated in the focused ion beam method as a tip of AFM probe [4]. Prior to the nc-AFM experiment, field ion microscopy observation was performed *in-situ* on the W tip to remove oxide layer covering the W tip (Fig. 1(c)). Then, highly resolved nc-AFM topographic imaging of the Si(111) 7×7 surface was achieved (Fig. 1(d)).

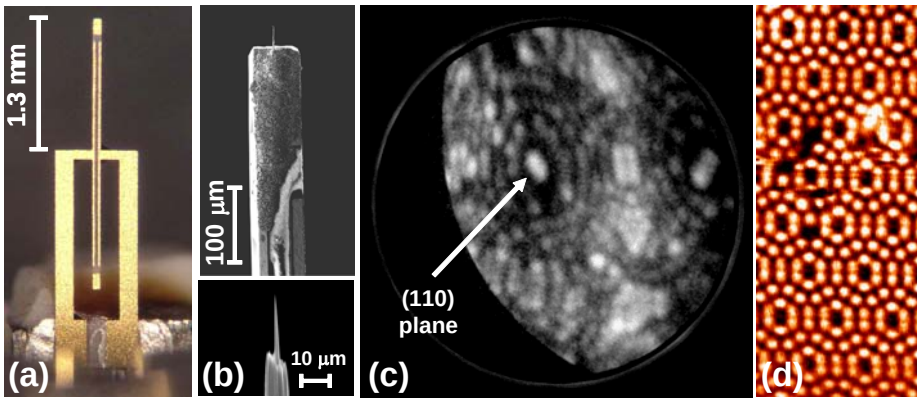

Fig. 1, (a) a quartz LER. (b) a scanning electron microscopy (SEM) image of the front rod with a W tip, and a zoomed SEM image of the W tip fabricated by focused ion beam. (c) field ion microscope image on the W tip after removal of the oxide layer. (d) a nc-AFM image of the Si(111) 7×7 surface. The observed area is 9 nm × 19 nm, f_0 = 997406 Hz, Δf = -0.37 Hz, oscillation amplitude A_0 = 0.75 nm, sample bias V = + 0.5 V.

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