Mechanical characteristics of the ultra-long horizontal free-space-nanowire grown by real-time feedback control on focused-ion-beam chemical vapor deposition

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Focused-ion-beam chemical vapor deposition (FIB-CVD) [1] has become a key technology for the fabrication of three-dimensional (3D) nano- and microstructure. Especially, various nanomechanical devices such as nano-resonantor can be fabricated. However, due to the change of growth characteristics, it's difficult to fabricate horizontal free-space-nanostructure with an overhang length of a few 10 μm, which is sometime demanded by the nano-resonator. Therefore, real-time feedback control on FIB-CVD [2] was proposed and demonstrated to be enabling the fabrication of horizontal free-space-nanowire with a length more than 30 μm. However, the mechanical properties such as Young's modulus keep unknown, which is always needed for the design of nanomechanical devices. Therefore, the mechanical characteristics of free-space-nanowire grown by real-time feedback control on FIB-CVD, were investigated.

Ultra-long free-space-nanowire was fabricated by using real-time feedback control of the scanning speed on FIB-CVD, as shown in Fig. 1(a). A commercially available FIB system with a Ga^+ ion beam having an acceleration voltage of 30 kV was used. Phenanthrene ($C_{14}H_{10}$) was used as the gas source to deposit diamond-like carbon (DLC). The scanning of FIB was controlled by using a function generator. The substrate current was monitored by using an electrometer during nanowire growth. Moreover, unique programs on the computer were used to perform real-time feedback control. A 30 μm long horizontal free-space-nanowire as shown in Fig. 1(b), was grown with a beam current 0.50 pA and controlled with a start scanning speed 80 nm/s and a range of substrate current 1.10 ± 0.1 pA. In order to obtain the Young's modulus of the free-space-nanowire, a nanopillar with a height of 20 μm was grown on the probe and used to bend the 15 μm long free-space-nanowire. According to the Hooke's law, the multiplication products of the spring constant and the displacement of nanopillar and free-space-nanowire are the same. By using the previously reported Young's modulus of nanopillar, [3] the spring constant and Young's modulus of nanowire were measured as 1.21×10^{-3} N/m and 101 GPa, respectively. Furthermore, by using an electron beam vibrometer, resonant frequency of the nanowire was measured as 460 kHz. Therefore, the average density of the nanowire could be calculated as 4.7×10^3 kg/m^3. This was higher than the density of DLC nanopillar that was reported as 3.8×10^3 kg/m^3 [3]. The reason could be, the dose for the fabrication of free-space-nanowire was higher than that of nanopillar and it allowed more Ga ions to be incorporated into the nanowire. More details regarding the mechanical characteristics of free-space-nanowires with different lengths are scheduled to be present.

[1] S. Matsui *et al*, J. Vac. Sci. Technol. B **18**, 3181-3184 (2000).
[2] D. Guo *et al.*, MNE2012 abstract, Nanofab3-049 (2012).
[3] J. Igaki *et al*, J. Vac. Sci. Technol. B **24**, 2911-2914 (2006).

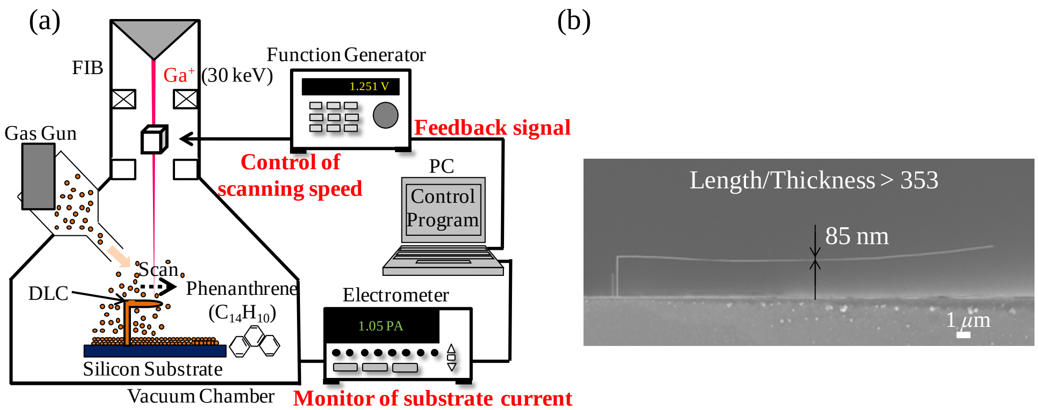

Figure 1: Real-time feedback control on FIB-CVD: (a) Experiment schematic and (b) 30 μm long horizontal free-space-nanowire.

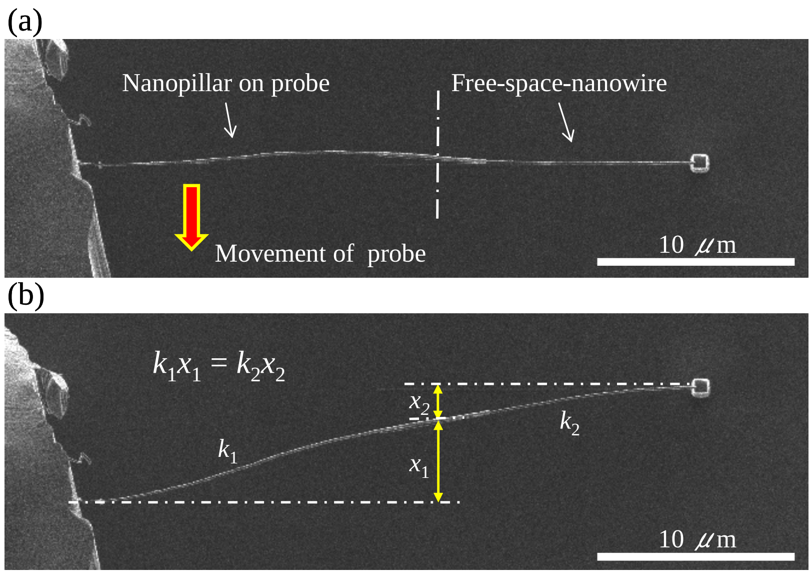

Figure 2: Measurement of Young's modulus of free-space-nanowire: (a) top view of before bending and (b) top view of after bending.

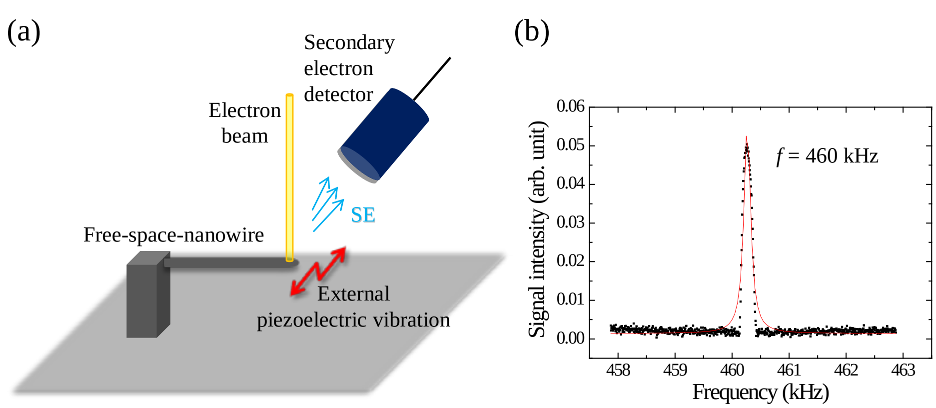

Figure 3: Measurement of resonant frequency of free-space-nanowire for density measurement: (a) experiment schematic of electron beam vibrometer and (b) resonant spectrum of 15 μm long free-space-nanowire.