Mechanical characteristics of nanostructures fabricated by nanoimprint

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Nanoimprint lithography (NIL) is a very useful technique to replicate nanostructure with low cost and high throughput. This technique has been demonstrated for making magnetic devices and optical devices. In order to design the devices using imprinted structure, the mechanical data were required. However, it is difficult to measure Young's modulus of nanostructures by the conventional macroscale method such as a nanoindenter. In this work, we evaluated the Young's modulus of imprinted nanopillars by using an atomic force microscopes (AFM) cantilever manipulated with a three-axis actuator1).

Figure 1 shows the process for measuring the spring constant of imprinted pillars. The process is as follows. (1) The diamondlike carbon (DLC) nanopillars were fabricated on a Si substrate by focused-ion-chemical vapor deposition (FIB-CVD) using phenanthrene ($C_{14}H_{10}$) gas source2). (2) The FIB-CVD mold was treated by a fluorinated anti-sticking agent3). (3) Poly(dimethylsiloxane) (PDMS) prepolymer was spin-coating on a FIB-CVD mold. (4) PDMS coated substrate was baked at 80 °C for 30 min to cure the PDMS. After curing of PDMS, PDMS copy mold was de-molded from the FIB-CVD mold. (5) SU-8 (Kayaku Microchem Co., SU-8-5) was spin-coated on a Si substrate. (6) The nanoimprinting was carried out. The imprinting pressure was 0.3 MPa and the UV dose was 50 mJ/cm^2. Then, the Si substrate was heated at 80 °C for 2 min to solidify the polymer. (7) The PDMS mold was removed from the Si substrate, and the structures were completely replicated on the substrate. (8) The Si cantilever was fixed and the Si substrate with imprinted pillars was manipulated by using three-axis actuators mounted in the vacuum chamber of the FIB system. (9) The tips of the Si cantilever and the SU-8 pillar were squeezed together. The displacements of both the Si cantilever and the imprinted pillar were measured by scanning ion microscopy (SIM), as shown in Fig. 2.

As the spring constant k_2 of the Si cantilever is known, the spring constant k_1 of the SU-8 pillar was obtained from

$$k_1 x_1 = k_2 x_2, \qquad (1)$$

where x_1 and x_2 are the transverse displacements of the SU-8 pillar and Si cantilevers, respectively. The spring constant and Young's modulus for these pillars to obtain based on the following equation:

$$k = \frac{3EI}{L^3}, \qquad (2)$$

where E is Young's modulus, I is the area moment inertia, L is the length. For the rectangular cross section of the SU-8 pillars,

$$I = \frac{\pi d^4}{64}, \qquad (3)$$

where d is the diameter. Eq. (2) and (3) give as follows Eq. (4),

$$k = \frac{3\pi E d^4}{64 L^3}. \qquad (4)$$

Figure 3 shows the imprinted structure of the d^4/L^3 dependency of the spring constant of the imprinted pillar. The data points formed a linear plot as expected from Eq. (4). The Young's modulus of imprinted SU-8 pillar was calculated as 4.8 ± 1.1 GPa. The value is nearly the same as that (4 GPa) of the polymerized film[4).

In the presentation, we will discuss more details about size dependences of Young's modulus of imprinted nanopillars.

Reference

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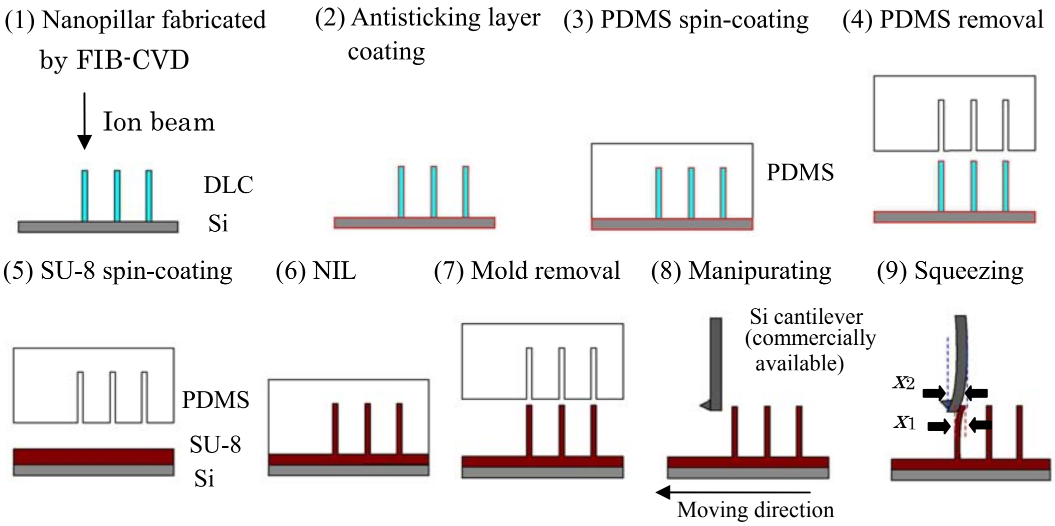
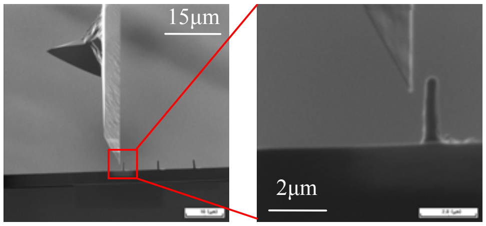
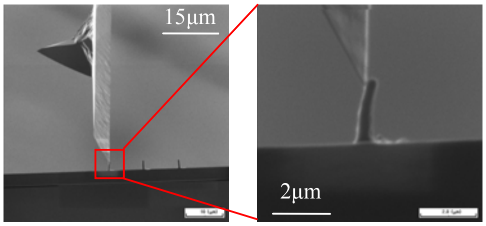


Fig.1. Schematic of the cantilever and imprinted pillar.



(a) Before squeezing



(b) After squeezing

Fig.2. Direct bending measurement of the pillar imprinted using SU-8. The diameter was 400 nm and the height was 2400 nm.

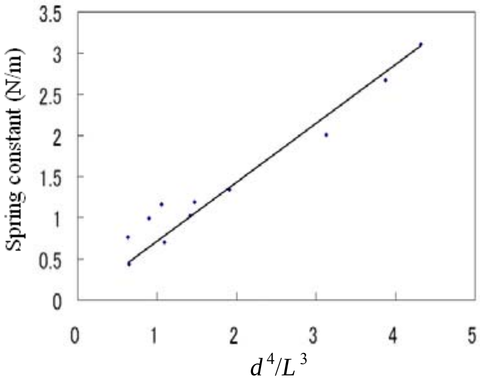


Fig.3. Spring constant of the imprinted pillar dependence of d^4/L^3.