# Characteristics of mechanical vibration in imprinted nanostructures


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Nanoimprint lithography (NIL) is a very useful technique to replicate nanostructure with low cost and high throughput.[1)] This technique has been demonstrated for making magnetic devices and optical devices. To design devices to be fabricated by NIL, it is important to understand the properties of the product. Previously, we determined the Young's modulus of the imprinted pillar by measuring spring constant using Si cantilever manipulated with a three-axis actuator.[2)] In this work, we present evaluation of density of the imprinted pillar. The density can be calculated by measuring resonant frequency. So far, Guillon *et al.* previously reported a technique for measuring the resonant frequency of nanostructure by alternating current (AC) electrostatic force.[3)] Therefore, the resonant frequency of the imprinted pillar were characterized by AC electrostatic force

In this experiment, SU-8 (SU-8-5, Kayaku Microchem Co., Ltd.) was used as a replica material. Figure 1 shows SEM images of imprinted pillars. The diameter was fixed for 500 nm and the heights were 4 μm, 5.3 μm, 6.4 μm, 8.5 μm, and 11 μm, respectively.

As shown in Fig. 2(a), the three-axis manipulator was used to bring the imprinted pillar to few tens of nanometers from the excitation Si cantilever. SEM images of the imprinted pillar before and after resonance are shown in Figs. 2(b) and 2(c). The height plotted against the resonant frequency on a log-log scale is shown in Fig. 3. The height increased as the resonant frequency decreased, with a liner relationship between the height and the resonant frequency. The slope of −1.94 was estimated from the approximate plots from imprinted pillar.

For a pillar that is fixed at one end, the mechanical resonant frequency is

$$f_n = \frac{d\beta_n^2}{8\pi L^2}\sqrt{\frac{E}{\rho}}, \qquad (1)$$

where $f$ is the resonant frequency, $d$ is the diameter, the $L$ is the length, $E$ is the Young's modulus, $\rho$ is the density, and $\beta$ is a constant that depends on the vibration mode (for the fundamental mode, $\beta_0$=1.875). If the diameter is fixed, Eq. (1) becomes

$$\log f = -2\log L + C, \qquad (2)$$

and $\log f$ is proportional to $-2 \log L$. The experimental results show good agreement with the theoretical value of −2. The density of imprinted pillar was calculated from the resonant frequency using Eq. (1). The density value of imprinted pillar was calculated as 0.96 ± 0.20 g/cm$^3$. The density value of imprinted pillar was lower than the 1.19 of the bulk.[4)]

In the presentation, we will discuss more details about size dependences of density of imprinted nanopillars.

**References**

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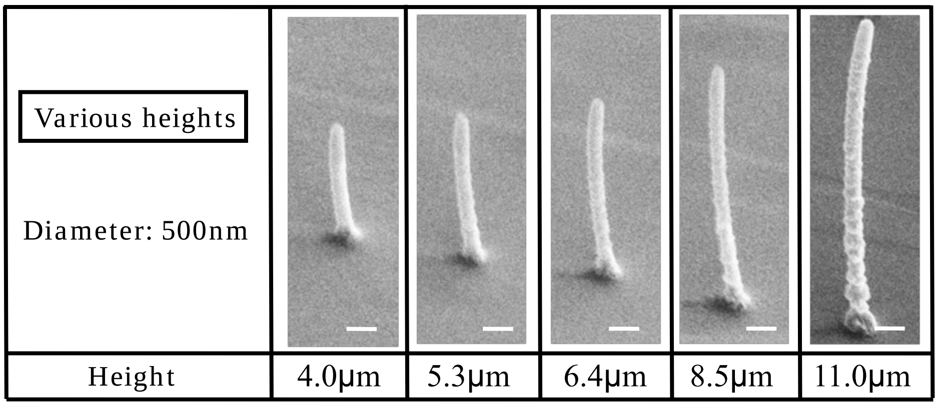


Fig.1. SEM images of imprinted SU-8 pillar. The white bar is 1 μm.

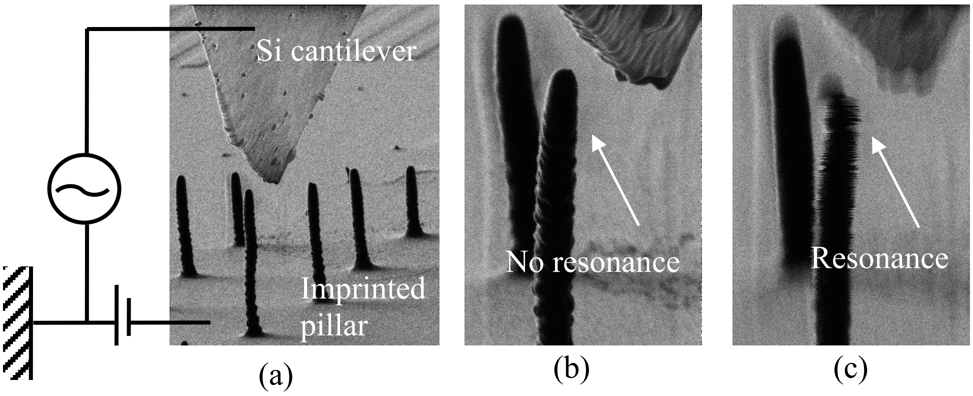


Fig.2. SEM images: (a) relative positioning of the Si cantilever and the imprinted pillar. (b) and (c) are the imprinted pillar before and after resonance.

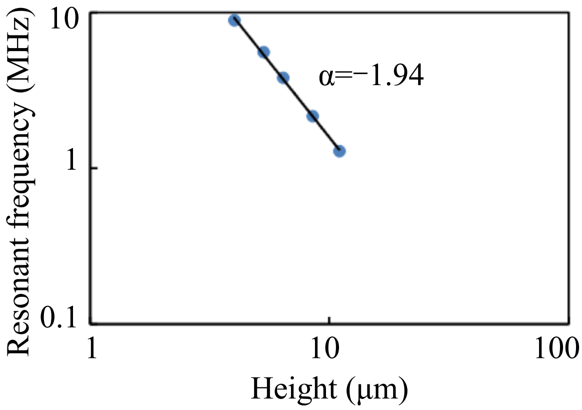


Fig.3. Resonant frequency dependence of the pillar height on a log-log scale.