Young's Modulus of Single-Nano-Scale Gold Nanowires Estimated by TEM-AFM

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It is important to understand the mechanical properties of nano- or atomic scale materials because of miniaturization of electronic devices or machines. Theoretically, Young's modulus has been expected to change from the bulk value when the size becomes 10 nm below [1,2]. However, such size effect has still remained uncertain because of lack of experimental results. In this study, we investigated the size dependency of Young's modulus of gold nanowires by developing a TEM holder with the force sensor utilizing frequency modulation atomic force microscopy (FM-AFM) method. Application of FM-AFM method to elasticity measurement is a challenging attempt. Therefore length extension resonator (LER) with high rigidity (7.5×10^5 N/m) was used as the force sensor. Our experiment was carried out under ultra-high vacuum in order to remove surface contamination.

Fig. 1 shows the configuration of LER, gold contact, and electrodes in our developed TEM holder. The gold nano-contact was formed between two gold wires. One of the wires is fixed to the edge of LER and another, to the conductive substrate. The LER vibrates along the longitudinal direction with the resonant frequency of 1MHz when the gold contact is not formed. Its frequency shifts when the gold contact forms since the gold bridge between the LER and the conductive substrate acts as spring. In FM-AFM method, the frequency shift correspond to the spring constant of the gold bridge as expressed by $k = 4k_{LER}\Delta f/f_0$ (k : the spring constant of the gold bridge, k_{LER} : the spring constant of LER, Δf : the resonant frequency shift from f_0, f_0 : the original resonant frequency of LER.)

Fig. 2 shows TEM images of the gold contacts and the measured spring constants, which are taken from the stretching process. It can be easily seen that the spring constant of the gold contact decreases as it becomes thinner. The measured spring constants correspond to the gold bridges between the LER and the conductive substrate. In order to clarify the size dependence of Young's modulus, a specific analysis method is required. We found such method, in which the gold contact is approximated to consist of disks with different diameters as shown in Fig. 3. For each disk, assuming Young's modulus depends on disk diameter. In the experiment, the spring constant changed when the gold contact was deformed plastically. Such a plastic deformation correspond to change of a set of disks with different diameters. By comparing the change of the spring constant and the change of the disk set, we could estimate Young's modulus of each disk.

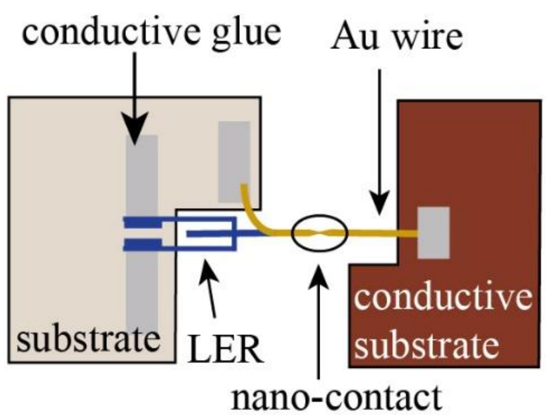

Fig. 1. The schematic view of measurement configuration incorporated in our TEM holder. Nano-contacts were constructed between the two gold wires. The conductive glue on the insulating substrate side serves as electrodes for connecting the terminals.

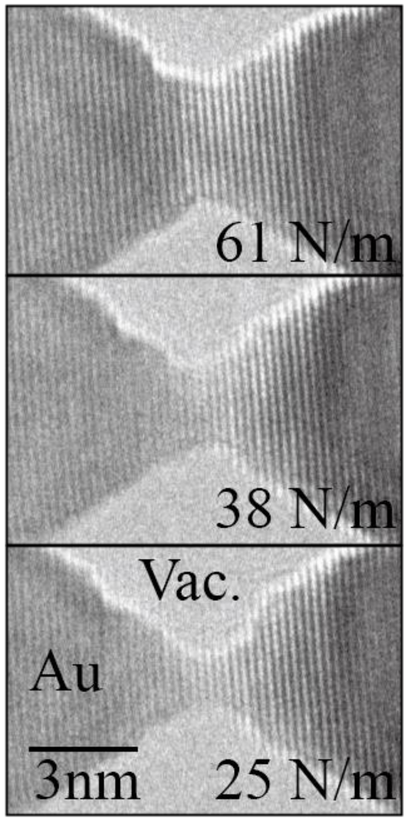

Fig. 2. TEM images and corresponding measured spring constants. Nano-contacts were deformed by displacing the substrate.

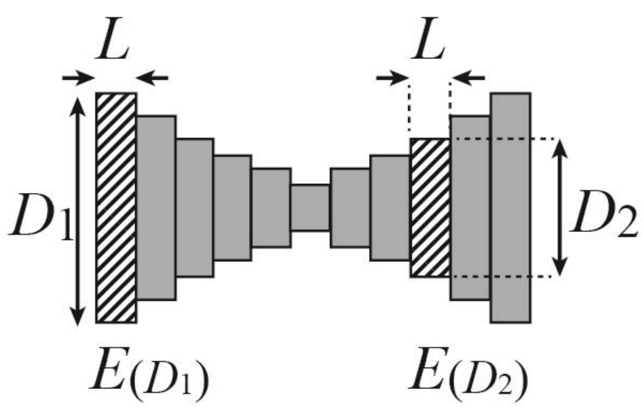

Fig. 3. The model of nano-contact by disks. L and D is represent the thickness and diameter of the disk, respectively. E is Young's modulus, as the function of the diameter. The measured spring constant is considered to be the series connection of such disk springs.

Acknowledgements
This work was supported by Grant-in-Aid for Scientific Research(B) 15H03522.

References
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