Mechanical properties of Pt atomic chains measured by in-situ TEM technique

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One- and two-dimensional materials have different bonding states from bulk counterparts, so the bond stiffness is expected to be different for such low dimensional materials. The bond stiffness is important for understanding the mechanical response, but it is difficult to measure because of local information. To solve this problem, we developed an in-situ TEM holder equipped with a quartz resonator as force sensor (Fig. 1a) [1,2]. By using this in-situ TEM holder, we observed platinum monatomic chains at atomic scale simultaneously with measuring the equivalent spring constant based on frequency modulation (FM) method.

A quartz length-extension resonator (LER) was used to measure the stiffness of Pt monatomic chains from its frequency shift. The stiffness of the atomic chain suspended between the edge of LER and the fixed counter base can be measure precisely with very small oscillation amplitude (about 30 pm). The atomic resolution TEM images (Fig. 1b) were captured simultaneously with measuring the conductance and stiffness.

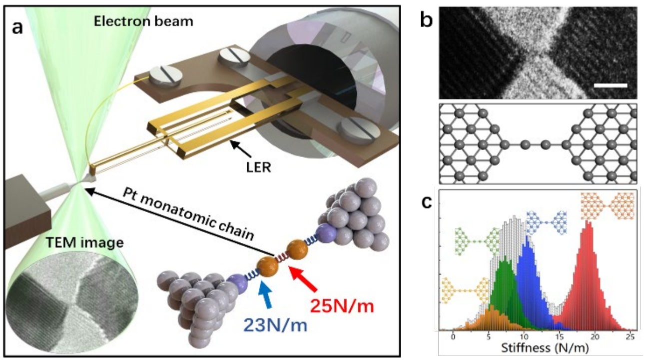

Fig. 1. (a) Schematic illustration of the experimental setup. (b) TEM image of at atomic chain with 4 atoms and corresponding atomic configurations of the chain. (c) Stiffness histograms of the Pt monatomic chains.

The stiffness of atomic chains with 2-5 atoms were obtained (Fig. 1c). By subtracting the stiffness of the electrodes supporting the monatomic chain from the measured stiffness, we found that the stiffness of a Pt monatomic chain varied with the number of the constitute atoms in the chain. We investigated the stiffness of about 150 Pt monatomic chains for reproducibility and confirmed that the middle bond stiffness (25N/m) in the chain was slightly higher than that of the bond connect to the suspending tip (23N/m). In addition, the maximum elastic strain of individual bond in the chain was as large as 24% [3].

Our developed method also enabled us to measure the critical shear stress of gold (Au) nanocontact by measuring the energy dissipation. We measured it for Au nanocontact with the axis of the [111] and [110] direction and found that the critical shear stress was 0.94 ± 0.1 GPa, which corresponds to the slip along the [112] direction on the (111) plane [4].

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[3] J. Zhang et al, Nano letters. 21 (2021) 3922-3928.

[4] J. Liu et al, Appl. Phys. Express 14 (2021) 075006.