Multiscale superlubricity using nanopillar array

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Friction, the force resisting the relative motion of two objects, is one of the most fundamental forces in physics. But the friction at the nanoscale is quite different from that at the macroscale, and the unique phenomena have been reported for decades. The source of the unique phenomena originated from an interactive force acting between a nanotip and a surface with a velocity of microns per second, although the frictional force at the macroscale comes from contact with multiple asperities at an interface at a higher velocity.

Frictional forces at the nanoscale in general materials provide nanonewton order, but frictional forces at the nanoscale in the two-dimensional layered materials such as graphite and MoS_2 decrease rapidly down to piconewton order when there is structural incommensuration between crystalline solid surfaces. Structural superlubricity, a phenomenon first proposed by Hirano *et al.*[1)] has been researched for the past decades. To date, all experimental evidence of structural superlubricity was obtained at the nanoscale. Liu *et al.*[2)] have demonstrated direct evidence for reproducible structural superlubricity at the micron scale and even under ambient conditions, which provides a platform to study superlubricity in a size scale from nm^2 to hundreds of μm^2. However, the structural superlubricity has been realized at the nanoscale but not yet at the macroscale[3)]. This is the reason why friction is a hierarchical phenomenon and structures that do not appear at the nanoscale, such as cracks and strains, and vice versa, have a significant effect at the macroscale. Thus, it is necessary to know what the factor that controls fiction at the macroscopic scale is and to build the theory needed to bridge between nano to macro scale. Recently, Miura[4)] has reported that novel superlubricity appears at the MoS_2 island smaller than a micrometer, which is quite different the structural superlubricity and gives the key to bridge between nano to macro scale. Here, a frictional force microscopy (FFM) and a tribometer were used to bridge the gap between nano and macro scale.

Figure 1 shows the frictional force and frictional force loop obtained using an FFM from a single pillar surface plotted against the pillar diameter φ. The scan velocity was 64 nm/s. The frictional force loops in the insets of Fig. 1 from the pillar surface indicate a nonperiodic lattice. As the pillar diameter φ decreased to 300nm, it was unexpectedly found that the frictional force

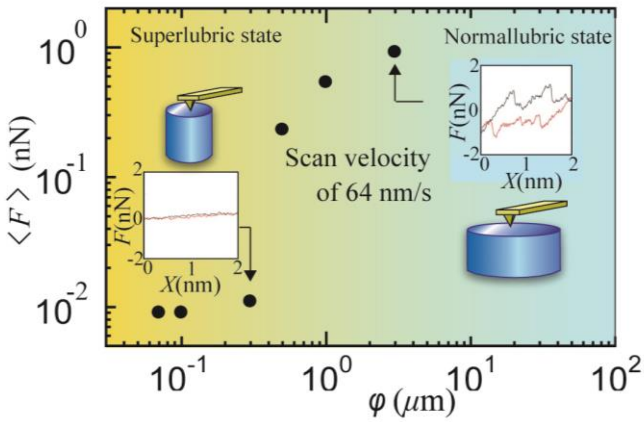

Fig. 1. The frictional force <*F*> was evaluated from the frictional force loop *F* where the black and red lines indicate one direction and the opposite direction, respectively.

decreases rapidly down to piconewton order, which is close to the detection limit of the magnitude of forces, originating from thermal fluctuations. In conclusion, the superlubricity of piconewtons appears at silicon nanopillars with a diameter of less than 200 nm, which is quite different from the structural superlubricity**.**

Furthermore, I demonstrate the macroscopic superlubricity is realized using a superlubric pillar array. The conditions at which the macroscopic superlubricity appears are summarized using the friction coefficient and the viscous friction coefficient.

References

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