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Structure and superlubricity of MoS_2 on Au(111) revealed by ultrahigh vacuum atomic force microscopy

Yiming Song, Antoine Hinaut, Sebastian Scherb, Yves Pellmont, Rémy Pawlak, Zhao Liu, Thilo Glatzel* and Ernst Meyer*

Department of Physics, University of Basel, Basel, Switzerland.
*Corresponding author: Thilo.Glatzel@unibas.ch, Ernst.Meyer@unibas.ch

The structural and superlubric properties of single layer MoS_2 on Au(111) forming moiré structures has been investigated by means of ultrahigh vacuum atomic force microscopy with bimodal and contact modes. Friction force microscopy measurements at the atomic scale indicate a superlubric regime between the tip apex and the MoS_2 surface in which the friction force remains at an ultralow value and is independent from normal load. On the basis of the Prandtl-Tomlinson model, our calculation reveals that superlubricity is indeed induced by the moiré superlattice modulation originating from the natural misfit between MoS_2 and the Au(111) substrate.

Keywords: molybdenum disulfide, superlubricity, UHV AFM, nanotribology, two-dimensional materials

1. Introduction

Molybdenum disulfide (MoS_2), a single layer of Mo atoms sandwiched in between two layers of S atoms, shows a wide range of potential applications in the fields of electronics, optoelectronics and micro and nanomechanical systems requiring ultralow friction[1, 2]. In previous research, the normal load dependence of friction between AFM tip and MoS_2 surface always shows a linear or logarithmic trend[3]. In this paper, the superlubricity of MoS_2 has been revealed by means of the MoS_2 preparation and friction measurement under UHV conditions.

2. Methods

We investigate the structure and frictional behavior of MoS_2 on an Au(111) substrate and report the superlubricity between a bare Si AFM tip and MoS_2 .

2.1. MoS_2 preparation under UHV
The monolayer MoS_2 flakes of well controlled size are prepared under UHV conditions upon sputtering Mo atoms on a clean Au(111) surface in H_2S atmosphere followed by post annealing.

2.2. Load dependence of MoS_2
Frictional force measurements are acquired in the same UHV AFM system using soft cantilevers in contact mode. The investigation of the load dependence of the friction shows an independent correlation, in particular the absolute friction value is very low compared to previous results.

2.3. P-T model simulation
The mechanism of superlubricity between the tip and MoS_2 is revealed using the Prandtl-Tomlinson (PT) model.

$$V(x,y) = V_{tip-atom} + V_{tip-moire} + V_{spring}, \qquad (1)$$

All the parameters used in the PT model simulations are chosen based on the experimental parameters, which lead to an excellent agreement that the simulation well repeats the friction measurements.

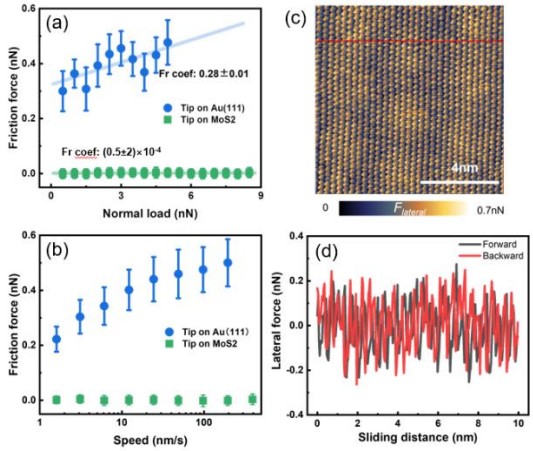

Figure 1: Friction characterizations of MoS2 and Au(111) surfaces.

3. Discussion

The existence of the superlubric state between AFM tip and MoS_2 is affected by two opposing effects concerned with the strong interaction of MoS_2 and Au(111) and the extra potential provided by the long-range superlattice structure. Au is known to have a strong affinity for sulfur, therefore, the local out-of-plane deformation is suppressed when the layer is slightly moved by the AFM tip. The superstructure provides an additional corrugated potential which results in the corresponding variation in friction. However, the lateral force trace and retrace are tunned consistently leading to the result that there is almost no variation of the energy dissipation due to the lower amplitude of potential and larger periodicity of long-range superstructure in our results.

4. References

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