O 27: Tribology

Time: Tuesday 10:30–12:30 Location: MA 144

O 27.1 Tue 10:30 MA 144

Anisotropic Friction of Snake Scales Analyzed by Atomic Force Microscopy - From Fundamentals to Applications — Weibin Wu[1,2], K. M. Samaun Reza[1], Patrick Weiser[1], Cornelia Friederike Pichler[1], Richard Thelen[1], and •Hendrik Hölscher[1] — [1]Karlsruhe Institute of Technology, Kalsruhe, Germany — [2]now at: Institute of Noise and Vibration, Naval University of Engineering, Wuhan, P.R. China

As snakes are limbless, they have to locomote in direct contact with the ground. Therefore, the ventral scales of many snake species are equipped with nano-step structures to achieve anisotropic friction for efficient locomotion. Here, we present our study of this structural frictional anisotropy by atomic force microscopy showing that the frictional anisotropy correlates with the height of the nanosteps. The frictional anisotropy of the nano-stepped surface can be employed for the unidirectional transport of microscale particles through small random vibrations. Due to the frictional anisotropy, the micro-particles drift in the direction of lower friction. This feature can be employed for the dry self-cleaning of surfaces like photovoltaic modules in sunny but dry areas where soiling is an issue.

O 27.2 Tue 10:45 MA 144

Dynamic Friction Unraveled by Observing an Unexpected Intermediate State in Controlled Molecular Manipulation — Norio Okabayashi[1], Thomas Frederiksen[2,3], Alexander Liebig[4], and •Franz J. Giessibl[4] — [1]Graduate School of Natural Science and Technology, Kanazawa University, Ishikawa 920-1192, Japan — [2]Donostia International Physics Center (DIPC), San Sebastián 20018, Spain — [3]IKERBASQUE, Basque Foundation for Science, Bilbao 48013, Spain — [4]Institute of Experimental and Applied Physics, University of Regensburg, Regensburg D-93053, Germany

The pervasive phenomenon of friction has been studied at the nanoscale via a controlled manipulation of single atoms and molecules with a metallic tip, which enabled a precise determination of the static friction force necessary to initiate motion. However, little is known about the atomic dynamics during manipulation. Here, we reveal the complete manipulation process of a CO molecule on a Cu(110) surface at low temperatures using a combination of noncontact atomic force microscopy and density functional theory simulations. We found that an intermediate state, inaccessible for the far-tip position, is enabled in the reaction pathway for the close-tip position, which is crucial to understanding the manipulation process, including dynamic friction. Our results show how friction forces can be controlled and optimized, facilitating new fundamental insights for tribology [1].

[1] N. Okabayashi, Th. Frederiksen, A. Liebig, F.J. Giessibl, Phys. Rev. Lett. 131, 148001 (2023).

O 27.3 Tue 11:00 MA 144

Atomic Friction on 1T-TaS2 over a Phase Transition — •Yiming Song, Dirk Dietzel, and Andre Schirmeisen — Institute of Applied Physics (IAP), Justus-Liebig-Universität Gießen, 35392 Gießen, Germany

Friction force microscopy experiments were performed on 1T phase tantalum disulfide (1T-TaS2) surfaces as a function of temperature over the phase transition from nearly commensurate charge density wave (CDW) phase to commensurate CDW phase. While the superstructure can be revealed both in friction and in topography images, friction variation between these two phases is negligible, which is supported by detailed investigation on atomic stick-slip motion of the single asperity AFM tip sliding over 1T-TaS2. Besides, the load and velocity dependence of atomic friction on 1T-TaS2 surface in CCDW and NCCDW phases have been revealed. Using conductive atomic force microscopy, we were able to show the local electric conductivity on NCCDW surface with atomic resolution.

O 27.4 Tue 11:15 MA 144

Tribological properties of 2D materials — •Oscar Javier Gutiérrez Varela and José Guilherme Vilhena Albuquerque D Orey — Departamento de Física Teórica de la Materia Condensada, Facultad de Ciencias, Universidad Autónoma de Madrid, Madrid, España

2D materials are pivotal in diverse technological areas, necessitating a thorough examination of their physical properties in order to guarantee practical applications and to gain insights into their exhibited intriguing phenomena. We delved into the tribological properties of 2D materials, specifically graphene and MoS2. Using fully atomistic Molecular Dynamics (MD) simulations to mimic Friction Force Microscopy (FFM) experiments, we examine different tribological properties. Scenarios include suspended and substrate placements of monolayers or multiple layers, with analyses of pristine and defective 2D material presentations to discern different types of vacancies through FFM. We also explore various scanning directions and the impact of thermophoresis. Preliminary results confirm known characteristics, such as higher frictional forces in suspended graphene than on a substrate. Variations in lateral force patterns are observed in MoS2 with vacancies, hinting at the potential to distinguish defects using FFM. Additionally, scanning graphene and MoS2 against the direction of thermal flow increased hysteresis and lateral force, associated with higher friction. This comprehensive analysis allows for comparisons with experimental groups, contributing to a deeper understanding of the tribological properties of 2D materials.

O 27.5 Tue 11:30 MA 144

Friction Force Microscopy of Graphene on a Platinum Surface — •Thilo Glatzel[1], Zhao Liu[2], Guilherme Vilhena[3], Antoine Hinaut[1], Sebastian Scherb[4], Enrico Gnecco[5], and Ernst Meyer[1] — [1]University of Basel, Dep. of Physics, Klingelbergstr. 82, 4056 Basel, Switzerland — [2]Nankai University, School of Materials Science and Engineering, 300350 Tianjin, China — [3]Universidad Autónoma de Madrid, Dep. of Theoretical Condensed Matter Physics, 28049 Madrid, Spain — [4]Institute for Molecules and Materials, Radboud University, 6525 AJ Nijmegen, Netherlands — [5]M. Smoluchowksi Institute of Physics, Jagiellonian University in Krakow, 30-348 Krakow, Poland

Friction control and technological advancement are deeply connected. Two dimensional materials play a significant role in achieving near-frictionless contacts. However, there is a challenge in adjusting the sliding of superlubric materials. Taking inspiration from twistronics, we studied the control of superlubricity through moiré patterning. Through friction force microscopy and molecular dynamics simulations, we demonstrated that different twist angles of graphene moirés on a Pt(111) surface lead to a transition from superlubric to dissipative sliding regimes under various normal forces. This is due to a new mechanism at the superlattice level, where moiré tiles undergo a highly dissipative shear process connected to the twist angle beyond a critical load. Importantly, the atomic-level dissipation associated with moiré tile manipulation allows bridging different sliding regimes in a reversible manner, offering a way to subtly control superlubricity.

O 27.6 Tue 11:45 MA 144

Analyzing the tribological combination of microstructure and lubricant in beetle joints — •Cornelia Friederike Pichler[1], Richard Thelen[1], Matthias Mail[2], Thomas van de Kamp[3], and Hendrik Hölscher[1] — [1]Institute of Microstructure Technology, Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Institute of Nanotechnology, Karlsruhe Institute of Technology, Karlsruhe, Germany — [3]Institute for Photon Science and Synchrotron Radiation, Karlsruhe Institute of Technology, Karlsruhe, Germany

In order to gain inspiration for the development of environmentally friendly lubricants, we characterize the sophisticated friction-reducing system found in the joints of beetles. By combining microstructures with a lubricating substance, beetles optimize friction in their joints. We aim to research both the lubricant and the microstructure of the joints to gain inspiration for a degradable (and hopefully superior) alternative to mineral-oil-based lubricants. However, restrained by the tiny quantities of the beetle's lubricant and the compactness of their joints, the analysis is challenging. We, therefore, apply atomic force microscopy (AFM) to image topographical features of the joints and the frictional properties of the lubricating substance. Furthermore, we develop an artificial surface mimicking the beetle's microstructures and determine its frictional properties utilizing colloidal probes. Finally, we discovered the origin of the lubricant leaking through pores into the beetle's joint with focused ion beam (FIB) tomography.

O 27.7 Tue 12:00 MA 144

Superfluidity meets the solid-state: frictionless mass-transport through a (5,5) carbon-nanotube — •Alberto Ambrosetti, Pier Luigi Silvestrelli, and Luca Salasnich — Università degli Studi di Padova (Italy)

Superfluidity is a well-characterized quantum phenomenon which entails frictionless-motion of mesoscopic particles through a superfluid, such as ^{4}He or dilute atomic-gases at very low temperatures. As shown by Landau, the incompatibility between energy- and momentum-conservation, which ultimately stems from the spectrum of the elementary excitations of the superfluid, forbids quantum-scattering between the superfluid and the moving mesoscopic particle, below a critical speed-threshold. Here we predict that frictionless-motion can also occur in the absence of a standard superfluid, i.e. when a He atom travels through a narrow (5,5) carbon-nanotube (CNT). Due to the quasi-linear dispersion of the plasmon and phonon modes that could interact with He, the (5,5) CNT embodies a solid-state analog of the superfluid, thereby enabling straightforward transfer of Landau's criterion of superfluidity. As a result, Landau's equations acquire broader generality, and may be applicable to other nanoscale friction phenomena, whose description has been so far purely classical.

O 27.8 Tue 12:15 MA 144

Effect of Amorphous-Crystalline Phase Transition on Superlubric Sliding — Ebru Cihan[1,2], •Dirk Dietzel[1], Benedykt Jany[3], and Andre Schirmeisen[1] — [1]Institute of Applied Physics, Justus-Liebig-Universität Giessen, Germany — [2]Institute for Materials Science and Max Bergmann Center for Biomaterials, TU Dresden, Germany — [3]Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland

'Structural superlubricity' describes a state of ultralow friction, that can be attributed to the lattice mismatch between two incommensurate surfaces in sliding motion. It is commonly anticipated that structural superlubricity is most effective for crystalline surfaces, while the irregular structure of amorphous surfaces leads to less efficient lateral force cancellations and thus higher friction. To verify this fundamental assumption, we analyzed friction of antimony nanoparticles sliding on HOPG for temperatures between 300 and 750K[1] under UHV conditions. At about 420K a distinct and irreversible decrease in friction was observed. Based on complementary EBSD-analysis, this decrease was linked to a phase transition from amorphous to crystalline structure of the nanoparticles. More quantitatively, the results are described based on the Prandtl-Thomlinson model, where the relative changes of the effective energy barrier are correlated to a characteristic scaling factor γ that represents a measure for the crystalline state of the interface. γ is found to decrease by 20% and thereby also corroborates the influence of the phase transition on structural superlubricity.

[1]Cihan et al., PRL 130, 126205 (2023)