Nanotribology

Prof. Dr. Roland Bennewitz INM – Leibniz Insitute for New Materials and Physics Department, Saarland University

Content of the two lectures

- November 30, 2018:
- Introduction to tribology
- Atomic force microscopy
- December 12, 2018:
- Recapitulation
- Materials and recent experiments in nanotribology

Shearing, plastic deformation, and friction



Shearing, elastic deformation, and friction



$$F_{l} = \tau \cdot A$$

contact mechanics







Normal and lateral force measurement



Meyer, Bennewitz, Hug: Scanning Probe Microscopy, Springer-Verlag 2003

High-bandwidth friction force microscope



- Measurement of forces with 3 MHz bandwidth
- Superluminescent diode for high spatial stability.

Graphene – Superstar material





picture from http://graphene-flagship.eu/

Graphite is a great solid lubricant (except in vacuum), what about graphene?

Epitaxial graphene on SiC(0001)



- Graphene grown by thermal decomposition in Argon atmosphere
- Top layer of graphene covers substrate steps like a carpet
- Atomic friction reveals structure of the glide plane





Friction on graphene vs. graphite

- Huge decrease of friction compared to (contaminated) interface layer.
- Factor of two in friction between single and bilayer graphene.
- Bilayer outperforms graphite as solid lubricant due to lower adhesion.





Multi-scale tester MuScaT





Microtribometer experiments



- 500 μm ruby sphere in reciprocal sliding over 400 μm.
- Very low initial friction.
- Steady-state friction coefficient still lower than on SiC.
- Poor reproducibility between experiments is caused by variations in the sphere, not the surface.





Friction force microscopy of track





Histogram of friction forces confirms that surface exposed in the sliding track is the carbon-rich interface layer.

- Friction force microscopy reveals contrast between single and bilayer graphene.
- Sliding track exhibits higher constant friction, except for low-friction patches.
- Substrate steps not affected.





15 N. Chan et al., Carbon 113 (2017) 132.

Friction on graphene/Pt(111)

- Ultrahigh-vacuum atomic force microscopy
- Modulation of lateral force.
- Friction follows Moiré pattern.







- Force microscopy in aqueous solution.
- Very soft biomaterials (4-40 kPa).
- Friction and adhesion are scale dependent (persistence length vs. mesh size vs. sample size).

Dr. Johanna Blass



www.inm-gmbh.de

Au(100) in 0.01 M HClO₄

-0.3

Friction increases upon oxidation.

- Friction decreases upon reduction.
- Oxidized surface is roughened, atomic stick-slip reestablished after reduction.

friction friction force (nN) 0.6 current 0.4 0.2 0.9 È 0.0 current 0.3 0.0 0.8 1.0 1.2 1.4 0.0 0.2 0.4 0.6 potential (V)





Haptics and Friction



- Measure friction between a fingertip and various materials.
- Question: Can we relate the perception of similarity in touch to material properties?

dimension 1







www.inm-gmbh.de