Novel Friction Properties of Confined Water underneath Two-dimensional Atomic Sheets

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The material properties of large-scale synthesized graphene and other two-dimensional atomic sheets are greatly influenced by atomic-scale defects, mechanical deformation, and microstructures. For graphene-based applications, it is, therefore, essential to uncover the role of atomic-scale defects and domain structures of two-dimensional layers. In this talk, I will discuss friction and nanomechanical properties of graphene, addressing the role of chemical modification and water intercalation. Because of intrinsic structural differences, two-dimensional atomic sheets give rise to unique nanomechanical properties (e.g., thickness dependence, changes after chemical modification) that are in contrast to the three-dimensional continuum medium. The lubricating properties of water have been discussed extensively for millennia, where everyday phenomena show that water films exhibit high friction in the form of cold ice, or act as lubricants in skating and skiing when liquid.

Here, I describe the remarkable enhancement of friction caused by water when intercalated between graphene and mica. Atomic force microscopy showed that while the hydrophilic substrates determine the structure of the water near its surface, graphene guides its diffusion, favoring growth of intercalated water domains along the C-C bond zigzag direction. To gain a fundamental understanding of these phenomena and to resolve long-standing issues of energy dissipation in friction, we chose a system consisting of graphene flakes deposited on mica, where it is known that water intercalates at high humidity and forms ordered structures. Using atomic force microscopy, we show that intercalated water increases the friction force ~3 fold relative to “dry” graphene over mica, an unexpectedly large increase. We explain this by the softening of the flexural modes of graphene and by stronger phonon coupling between graphene and mica that facilitates “drainage” of the interfacial atomic vibrations to the bath sink of the substrate.