Nanolithography-Induced Exfoliation of Multilayered Materials

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We present a comparative study of nanoexfoliation on bulk, layered materials (MoS2, WSe2, HOPG, and mica) conducted via atomic force microscopy (AFM). The samples were scratched by single crystal diamond probes with varying scan velocities and normal forces. Friction forces measured during the scratch tests and post-mortem topography images allow a detailed investigation of nanoexfoliation mechanisms. In particular, while MoS2, WSe2, and HOPG undergo nanoexfoliation that is characterized by the peeling of flakes from the surface and crack propagation off the main scratch direction, mica is devoid of such effects, instead forming well-defined wear tracks that involve layer-by-layer exfoliation of terraces separated by monoatomic steps. A comparison of material properties (bending stiffness, interlayer adhesion, and tensile strength) mechanistically explains the differences in nanoexfoliation behavior. Moreover, the velocity dependence of lateral contact stiffnesses is studied to infer the influence of capillary-adhesion-mediated contact aging on nanoexfoliation, revealing a connection to the degree of surface hydrophobicity. Our results contribute to the formation of a physical understanding of the elementary steps involved in wear of layered materials, and hint at the possibility of precise, controlled nanoexfoliation by a careful selection of operational and environmental parameters.

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