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Giant and Tunable Anisotropy of Nanoscale Friction in Graphene

RODRIGO CAPAZ, MARCOS MENEZES, Univ Fed Rio de Janeiro, Brazil, CLARA ALMEIDA, MARCELO DE CICCO, CARLOS ACHETE, INMETRO, Brazil, BENJAMIN FRAGNEAUD, Univ Fed Juiz de Fora, Brazil, LUIZ GUSTAVO CANÇADO, Univ Fed Minas Gerais, Brazil, RICARDO PAUPITZ, DOUGLAS GALVÃO, Unicamp, Brazil, RODRIGO PRIOLI, PUC-RJ, Brazil — The nanoscale friction between an atomic force microscopy tip and graphene is investigated using friction force microscopy (FFM). During the tip movement, friction forces are observed to increase and then saturate in a highly anisotropic manner. As a result, the friction coefficient of graphene is highly dependent on the scanning direction: Under some conditions, the energy dissipated along the armchair direction can be 80% higher than along the zigzag direction. In comparison, for highly-oriented pyrolitic graphite (HOPG), the friction anisotropy between armchair and zigzag directions is only 15%. This giant friction anisotropy in graphene results from anisotropies in the amplitudes of flexural deformations of the graphene sheet driven by the tip movement, not present in HOPG. The effect can be seen as a novel manifestation of the classical phenomenon of Euler buckling at the nanoscale, which provides the non-linear ingredients that amplify friction anisotropy. Simulations based on a novel version of the 2D Tomlinson model (modified to include the effects of flexural deformations), as well as fully atomistic molecular dynamics simulations and first-principles density-functional theory (DFT) calculations, are able to reproduce and explain the experimental observations.

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