Highlights

RESEARCH AREA 2 - Functional and Complex Materials for Innovative Electronics and Sensing - 2023

Dissipation Mechanisms and Superlubricity in Solid Lubrication by Wet-Transferred Solution-Processed Graphene Flakes: Implications for Micro Electromechanical Devices

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Solution-processed few-layer graphene flakes, dispensed to rotating and sliding contacts via liquid dispersions, are gaining increasing attention as friction modifiers to achieve low friction and wear at technologically relevant interfaces. Vanishing friction states, i.e. superlubricity, have been documented for nearly-ideal nanoscale contacts lubricated by individual graphene flakes. However, there is no clear understanding if superlubricity might persist for larger and morphologically disordered contacts, as those typically obtained by incorporating wet-transferred solution-processed flakes into realistic microscale junctions. Here, we address the friction performance of solution-processed graphene flakes by means of colloidal probe Atomic Force Microscopy (AFM). We use a state-of-the-art additive-free aqueous dispersion to coat micrometric silica beads, which are then sled under ambient conditions against prototypical material substrates, namely, graphite and the transition metal dichalcogenides (TMDs) MoS_2 and WS_2. High resolution microscopy proves that the random assembly of the wet-transferred flakes over the silica probes results into an inhomogeneous coating, formed by graphene patches that control contact mechanics through tens-of-nanometers tall protrusions. Atomic-scale friction force spectroscopy reveals that dissipation proceeds via stick–slip instabilities. Load-controlled transitions from dissipative stick–slip to superlubric continuous sliding may occur for the graphene–graphite homojunctions, whereas single- and multiple-slips dissipative dynamics characterizes the graphene–TMD heterojunctions. Numerical simulations demonstrate that the thermally activated single-asperity Prandtl–Tomlinson (PT) model comprehensively describes friction experiments involving different graphene-coated colloidal probes, material substrates, and sliding regimes. Our work establishes experimental procedures and key concepts that enable mesoscale superlubricity by wet-transferred liquid-processed graphene flakes. Together with the rise of scalable material printing techniques, our findings support the use of such nanomaterials to approach superlubricity in micro electromechanical systems.

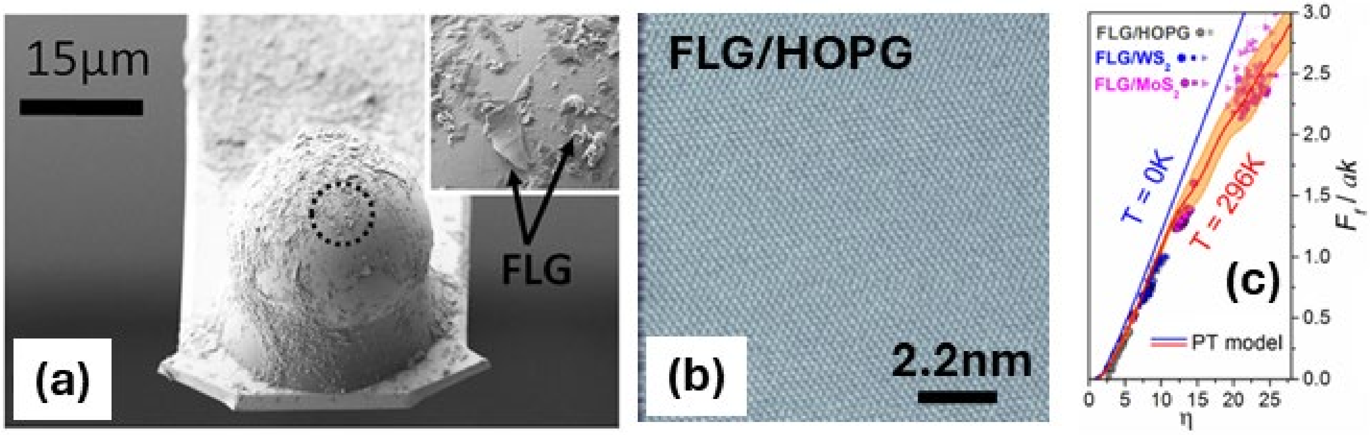

Fig. 1 (a) SEM micrograph of a graphene-coated colloidal AFM probe. At higher magnification, the silica surface appears partially covered by FLG flakes (inset). (b) Atomic-scale lateral force map acquired on HOPG by means of a graphene-coated probe. (c) Comparison of experimental friction data with predictions from the PT model, for graphene-coated probes sled against HOPG, WS_2 and MoS_2. Superlubricity takes place only for the FLG/HOPG interface and for the PT parameter values $\eta \lesssim 2$. Pinning effects dominate the friction response of Van der Waals interfaces involving TMDs.

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