Nanotribology of inkjet printed graphene flakes

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Layered materials such as graphite and MoS_2 have long been recognized as effective surface lubricants and they have been used to control friction and wear in a number of applications [1]. In fact, their use reduces friction because they offer interlayer sliding interfaces with low interfacial shear strength. The ability to isolate single atomic layers and few-layer sheets has recently promoted research into the frictional properties of two-dimensional lubricant materials [2]. In this context, graphene is rapidly evolving from a material with fascinating properties [3-5] to one with practical tribological applicability [6]. Nowadays, the majority of the fundamental studies on graphene friction have been carried out in single-asperity regime by Atomic Force Microscopy (AFM), using almost exclusively the micrometric flakes prepared by mechanical exfoliation of pristine graphite [6,7].

Here, we exploit AFM to address the friction response of few-layer graphene nanoflakes obtained from the liquid phase exfoliation of graphite [8,9,10]. To this purpose we print state-of-the-art graphene inks [9] on bare and hexamethyldisilazane-terminated SiO_2. We characterize the printed stripes by optical microscopy (Fig. (a)), electron microscopy, AFM imaging and lateral force microscopy/spectroscopy (Fig.(b),(c)). We find that large, atomically-flat portions of the printed stripes show friction response comparable with that typically reported for bulk graphite. Local friction excess is observed at the surface roughness originated by the flakes self-assembling process. Overall, our work demonstrates that printable inks are suitable for exploring and quantifying graphene and few-layer graphene nanoflakes friction by means of AFM.

References

[1] A. Erdemir in *Handbook of Modern Tribology*, (Ed. B. Bhushan) CRC Press 2001, 787-818.
[2] J. C. Spear, B. W. Ewers and J. D. Batteas, *Nano Today*, 2015, **10**, 301–314.
[3] A. C. Ferrari et al., *Nanoscale* 2015, **7**, 4598-4810.
[4] G. Fiori et al., *Nature Nanotech*. 2014, **9**, 768-779.
[5] F. Bonaccorso et al., *Science* 2015, **347**, 1246501.
[6] D. Berman, A. Erdemir and A. V. Sumant, *Mater. Today*, 2014, **17**, 31–42.
[7] J. C. Spear, J. P. Custer, J. D. Batteas, *Nanoscale* 2015, **7**, 10021.
[8] O. M. Maragò, et al ACS Nano 2010, **4**, 7515-7523.
[9] T. Hasan, F. Torrisi, Z. Sun, D. Popa, V. Nicolosi, G. Privitera, F. Bonaccorso and A.C. Ferrari, *Phys. Status Solidi*, 2010, **247**, 2953–2957.
[10] A. C. Capasso, et al. Solid State Comm. 2015, **224**, 53-63.