Large-scale Manufacturing of Graphene and Related Materials Inks for Flexible (Opto)electronics

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Graphene and related materials (GRMs) hold great potential for flexible (opto)electronics for their novel electrical, optical and mechanical properties. The road to realistic applications and commercialization of GRMs requires the assessment of three key factors: cost/performance, mass-production and manufacturability with respect to commercially available alternative solutions. For example, transparent conducting oxides used in displays are brittle, printable metal nanoparticles for interconnects are not cost-effective and have demanding processing requirements, while organic polymers are expensive and have limited stability. Low temperature production and deposition of GRM-based inks is thus an attractive alternative for large-area printable, flexible (opto)electronics. GRM inks enable a large range of device fabrication and integration options, such as digital and lithographic printing, roll-to-roll coating, as well as being ideal for embedding into polymer composites or other nanomaterials. Liquid Phase Exfoliation (LPE) of bulk precursor layered materials (such as graphite, MoS_2 crystals, etc.) is a scalable approach ideally suited to produce inks. However, currently LPE has low yield, resulting in a low concentration of dispersed GRMs. I will give a brief overview about the development of high-yield, cost-effective and large-scale production techniques for GRM-based inks, and the portfolio of reproducible manufacturability processes enabling future GRM-based printable and flexible (opto)electronic devices and composites. I will demonstrate cost-effective, up-scalable production of high concentration graphene inks with tailored properties (on-demand size, shape, number of layers and concentration) [1]. By combining LPE with ultra-centrifugation, I will show pilot-scales to produce stable GRM inks through engineered exfoliation and chemical treatment protocols. Fine tuning of the size and shape of the flakes enables the formulation of inks, tailored for various printing and coating methods, such as inkjet, flexographic and screen printing, spray and rod coating. Their distribution of the GRM flakes and their interaction with the substrate controls the final (opto)electronic properties of the printed devices. I will discuss realistic pathways to commercialization of GRM inks and demonstrate prototypes such as: flexible printed graphene thin-film transistors [3], smart textiles [4], flexible transparent touch pads and photodetectors. Finally, I will present my vision on manufacturability of flexible and wearable electronic and optoelectronic devices embedding the optical, electronic, mechanical and thermal functionalities of graphene, 2d crystals and their hybrid hetero-structures.

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[2] F. Torrisi *et al.* "Electrifying graphene inks" Nat. Photon. (2014)
[3] F. Torrisi, *et al.* "Ink-Jet Printed Graphene Electronics" ACS Nano, 6, 2992 (2012).
[4] J. Ren, *et al.* "Environmentally-friendly conductive cotton fabric as flexible strain sensor based on hot press reduced graphene oxide" Carbon, 111, 622, (2017)