

A Multifunctional Polymer-Graphene Thin-Film Transistor with Tunable Transport Regimes

T. Mosciatti¹, S. Haar¹, F. Liscio², A. Ciesielski¹, E. Orgiu¹, and P. Samori¹

¹ ISIS & icFRC, Université de Strasbourg & CNRS, 8 allée Gaspard Monge, 67000 Strasbourg, France

² Istituto per la Microelettronica e Microsistemi (IMM)- CNR, liscio@bo.imm.cnr.it

The modern electronics industry is continuously searching for novel materials and processing methods that could lead to devices based on new physical concepts, paving the way toward the exploitation of unprecedented properties. Among these novel materials, graphene has certainly garnered a great deal of attention. Graphene is constituted by a single layer of covalently tethered carbon atoms arranged in a honeycomb lattice; it is a zero band gap semiconductor exhibiting extraordinary electronic properties. To become a golden component for the electronic industry, two greatest challenges need to be addressed: (i) developing methods that can be up-scaled for mass production of high quality graphene, and (ii) opening a band gap to “switch off” graphene devices and thus make them suitable for logic application [1]. On the one hand, liquid-phase exfoliation of graphite into graphene is emerging as a suitable up-scalable method for the production of high quality graphene[2]. On the other hand, different strategies have been proposed in order to open a band gap in graphene such as the production of reduced graphene oxide [3] or graphene nanoribbons [4]. A different way of employing graphene for electronics relies on the use of hybrid solutions that combine graphene with suitable molecules to enable reciprocal modification of the component properties, e.g., via tailoring of interfaces or blending. Graphene/inorganic devices were proposed for different ferroelectric and semiconductor applications or as excellent option for radio frequency transistors that do not need high I_{on}/I_{off} ratio. Liquid-phase exfoliated graphene (LPE-G) in the presence of suitable molecules was successfully used as a bi-component graphene/organic hybrid active layer for tuning the transport in thin-film transistors[5]. A well explored way to address this approach relies on the use of a blend of graphene and an organic or polymeric semiconductor, although blends exhibit mayor downsides like phase segregation, graphene random aggregation, crystallinity loss in the semiconductor matrix and very poor control over graphene deposition.

Here we describe a novel strategy for fabricating a multifunctional polymeric-graphene thin-film transistor (PG-TFT) that relies on solution processing of semiconducting polymers on the top of solution processed graphene nanoscale patches having thermally tunable ionization energy (IE). This graphene's energy level engineering resulting in a broad range of IEs makes it possible to modulate the electronic interactions between the LPE-G and the semiconducting polymer. In this work, we focused our attention on two exemplary cases, i.e., LPE-G with an IE laying either inside or outside the band gap of either a p- or an n-type polymer active layer. When the IE is outside the polymer band gap one obtains tunable device's working regimes, which depend on the surface coverage. In particular, it was possible to adjust the transport in the bi-component film from semiconducting to truly conductive, i.e., exhibiting no gate modulation. The control over the IE of deposited LPE-G interacting with the polymer makes it possible also to operate the three-terminal device as a memory element without the need of depositing a further dielectric interlayer as previously reported in literature. Noteworthy, the approach has been tested with both n- and p-type polymer semiconductor demonstrating that this novel and general working mechanism is viable for both hole and electron transport [6-7].

References

[1] C. Sire et al., Nano Letters, 12 (2012) 1184; F. Schwierz. Nature Nanotechnology 5 (2010) 487.

[2]. A. Ciesielski, et al, Angewandte Chemie International Edition 53 (2014) 10355; A. Ciesielski, et al., Chemical Society Reviews, 43 (2014), 381; J. Coleman, Account Chemical Research, 46

(2012) 14; F. Bonaccorso, et al., *Material Today* 15 (2012) 564; H. Kim, H. et al, *Nanoscale* 5 (2013) 12365.

[3] Q. He et al., *ACS Nano* 5 (2011) 5038; C. Gómez-Navarro, et al., *Nano Letters* 7 (2007) 3499.

[4] D. Wei, et al., *Nature Communication*, 4 (2013) 1374 ; Q. Yan, et al. *Nano Letters* 7 (2007) 1469; X. Wang, et al., *Physical Review Letters*, 100 (2008) 206803; X. Li, et al., *Science*, 319 (2008).

[5] M. El Gemayel, et al., *Advanced Materials*, 26 (2014) 4814; N. Yang, et al., *ACS Nano*, 4 (2010) 887.

[6] T. Mosciatti et al. *ACS Nano*, 9 (2015) 2357.

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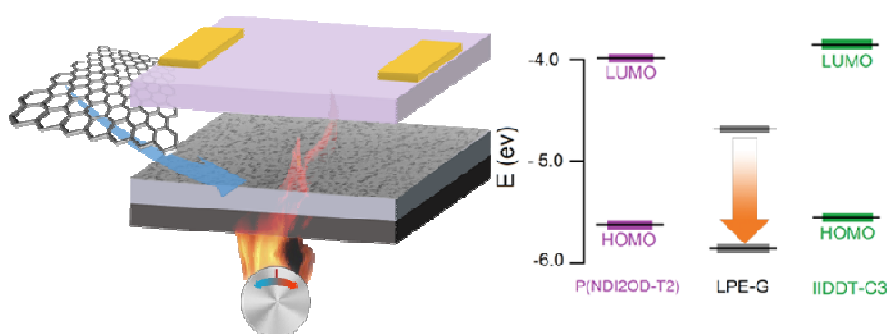


Figure 1: Scheme of the device geometry showing the polymer thin film deposited on the top of LPE-G lying on the SiO₂ dielectric surface, and the top gold electrodes (on the left). Effect of the thermal annealing on the corresponding energy scheme of LPE-G, with respect to the two polymeric semiconductors HOMO/LUMO levels as measured by ambient photoelectron spectroscopy (on the right).