Ink-Jet printed graphene electronics

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Ink-jet printing is one of the most promising techniques for inexpensive large area fabrication of flexible plastic electronics[1], due to its versatility, the limited number of process steps[2], the ease of mass fabrication[2]. Despite much progress, ink-jet printed organic Thin Film Transistor (TFT) still show poor air stability, limited lifetime, mobility ($\mu<0.5\ cm^2\ V^{-1}\ s^{-1}$) [3], and ON/OFF ratios($<10^5$). The use of carbon nanotubes (CNT) ink [4,5] allowed to increase μ by at least one order of magnitude[3,4].
Graphene is at the centre of an ever expanding research area [6]. Near-ballistic transport and high mobility make it an ideal material for nanoelectronics, especially for high frequency applications. Furthermore, its optical and mechanical properties are ideal for thin-film transistors and transparent and conductive electrodes[7]. Here we exploit the extraordinary properties of graphene to fabricate graphene-based ink-jet printed transparent and conductive electrodes and TFTs. Liquid phase exfoliation (LPE) is ideal to produce printable graphene-based inks.
High quality graphite flakes are dispersed in organic solvents by ultrasonication (~9 hours) followed by ultracentrifugation to remove large graphite fragments that are likely to clog the nozzle of the ink-jet printer. We investigate N,N-dimethylacetamide, Ethyl Acetate, 1-Methyl-2-pyrrolidone (NMP), Dimethylformamide as organic solvents. By Optical Absorption Spectroscopy (OAS), Transmission electron microscopy (TEM) and Raman spectroscopy we find that NMP gives the highest yield of monolayer graphene [8].
Graphene-ink stripes are then ink-jet printed on Si/SiO_2 modified by Self-Assembled Monolayers (SAM), which reduce the wettability of the substrate and allow uniform printing of graphene electrodes. AFM shows that a ~20 nm thick conductive stripe is obtained with a uniform distribution of graphene flakes. Its optical and electrical properties are studied respectively by OAS and electrical four-point probe measurements at room temperature. The ink-jet printed graphene-ink stripes are then utilized to fabricate graphene-based TFTs achieving mobility up to $95cm^2V^{-1}s^{-1}$ and ON/OFF ratio of $\sim10^4$-10^5. The electrical and optical performances observed in our devices, demonstrate the viability of graphene-ink to fabricate electronic devices, paving the way to graphene ink-jet printed electronics [9].

References

[1] H. Sirringhaus et al. Science, **290** (2000) 2123.
[2] B. J. DeGans et al. Adv. Mater. **16** (2004) 203.
[3] M. Singh et al. Adv. Mater. **22** (2010) 673.
[4] M. Ha et al. ACS Nano **4** (2010) 4388.
[5] P. Beecher et al. J. Appl. Phys. **102** (2007) 043710.
[6] A. K. Geim et al. Nat. Mater. **6** (2007) 183.
[7] F. Bonaccorso et al. Nat. Photon. **4** (2010) 611.
[8] Y. Hernandez et al. Nat. Nanotechnol. **3** (2008) 563
[9] F. Torrisi et al., submitted, (2011).

Figures

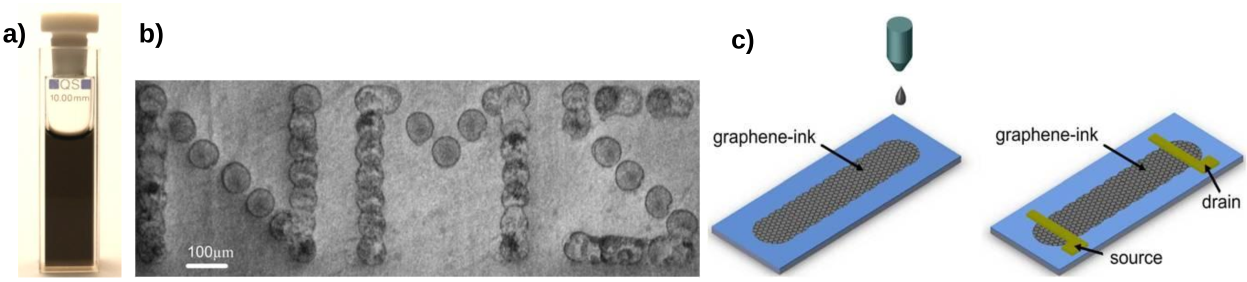

Figure: a) Graphene-ink. b) Example of graphene ink-jet printed pattern. c) Graphene TFT fabrication steps: graphene-ink is printed on Si/SiO_2 substrate, gold pads define source and drain.