

Synthesis of conducting transparent few-layer graphene directly on glass at 450 °C

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For the integration of graphene in microelectronics, it appears mandatory to be able to synthesize this material in a reproducible manner, and with a cost as low as possible. Early preparation routes, such as mechanical or chemical exfoliation of HOPG (highly ordered pyrolytic graphite) [1], or epitaxial growth by high temperature annealing of (0001) SiC [2] in ultra-high vacuum (UHV), fall short in terms of reproducibility or scalability.

In contrast, methods involving the catalytic crystallization of graphene on a metallic substrate have a potential of large-area fabrication and appear well adapted to meet the requirements for industrial applications. The carbon can be brought by (i) chemical vapor decomposition (CVD) [3] using gaseous (methane etc.) or liquid (ethanol etc.) sources [4, 5], possibly with laser-induced rapid growth of graphene pattern [6], (ii) a solid-state source (organic layers, amorphous carbon, diamond etc.) [7-11] or (iii) it can be implanted in the metallic substrate [12]. In all these methods, graphene is obtained during a hightemperature stage or during the sample cooling immediately following it. It is often of variable thickness ("few-layer graphene, FLG"). However, the substrate in these techniques is a conducting metal, such as nickel or copper; thus, after the graphene film is formed, further device fabrication requires its transfer on an insulating functional substrate; an operation that, in turn, introduces a variety of defects [13].

Post-growth transfer and high growth temperature are two major hurdles that research has to cross to get graphene out of research laboratories. Here, using a plasma-enhanced chemical vapour deposition process, we demonstrate the large-area formation of continuous transparent graphene layers at temperatures as low as 450 °C. Few-layer graphene grows at the interface between a pre-deposited 200-nm Ni catalytic film and an insulating glass substrate. After nickel etching, we are able to measure the optical transmittance of the layers without any transfer. We also measure their sheet resistance directly and after ink-jet printing of electrical contacts: it is locally as low as 500 Ω/sq. Finally the samples thus equipped appear to be efficient humidity sensors.

References

- [1] Novoselov K. S., Geim A. K., Morozov S. V. et al. *Science*, 306 (2004), 666-69
- [2] Berger C., Song Z. M., Li T. B., et al. *J. Phys. Chem. B*, 108 (2004), 19912-16
- [3] Reina A., Jia X. T., Ho J., et al. *Nano Lett.*, 9 (2009), 30-35
- [4] Miyata Y., Kamon K., Ohashi K. et al. *Appl. Phys. Lett.*, 96 (2012), 263105
- [5] Guermoune A., Chari T., Popescu F. et al. *Carbon*, 49 (2011), 4204-10
- [6] Park J. B., Xiong W., Gao Y. et al. *Appl. Phys. Lett.*, 98 (2011), 123109
- [7] Sun Z., Yan Z., Yao J., *Nature*, 468 (2010), 549-52
- [8] Zheng M., Takei K., Hsia B. et al. *Appl. Phys. Lett.*, 96 (2010), 063110
- [9] García J. M., He R., Jiang M. P. et al. *Carbon*, 49 (2011), 1006-12
- [10] Hofrichter J., Szafranek B. N., Otto M. et al. *Nano Lett.*, 10 (2009), 36-42
- [11] Rodriguez-Manzo J. A., Pham-Huu C. and Banhart F., *ACS Nano*, 5 (2011), 1529-34

[12] Baraton L., Cojocaru C. S., Pribat D. et al. Nanotechnology, 22 (2011), 085601

[13] Lin Y.-M., Valdes-Garcia A., Han S.-J. et al. Science, 332 (2011), 1294-97

Figures

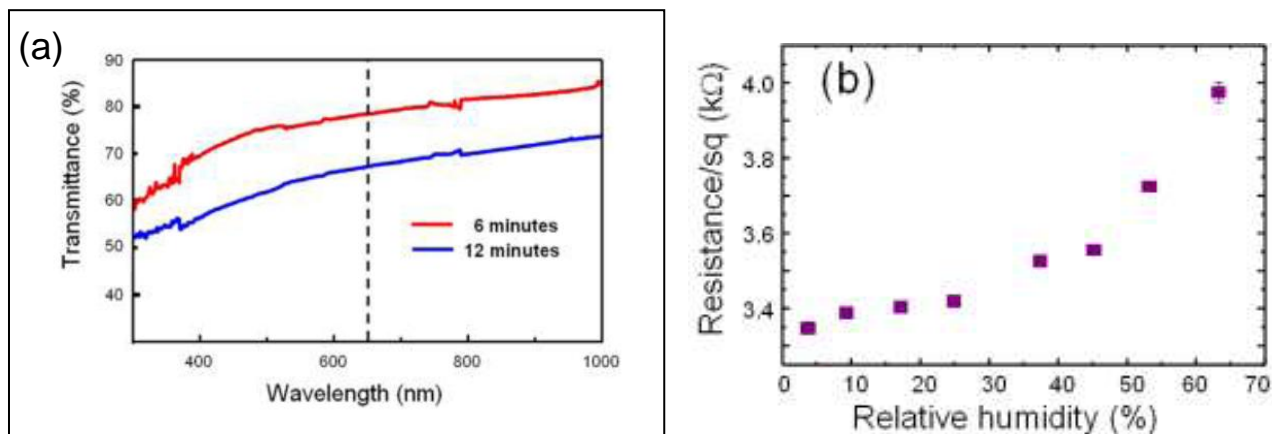


Figure caption

(a) Optical transmittance in the 300 to 1000-nm range, for two plasma exposure times. The vertical dotted line indicates the 650-nm wavelength

(b) sheet resistance versus relative humidity for a 12-mn plasma exposure