

# Contamination-free suspended graphene structures by a Ti-based transfer method

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Since its first discovery in 2004<sup>1</sup>, graphene has attracted great interest because of its exceptional physical and chemical properties<sup>2</sup>. Protocols for the production of high quality and large area of graphene foils have been developed using Chemical Vapour Deposition (CVD) on metal substrates<sup>3</sup>. In order to integrate graphene on functional devices, these layers should be detached from the growth substrate and transferred to the device surface, preserving mechanical and chemical properties and avoiding contaminations. From the technological point of view, the transfer from catalytic metal substrate to the final surface is still an open issue. The most diffused methods are based on the use of polymeric sacrificial layers whose complete removal is still an open issue<sup>4</sup>. We recently developed a new PMMA-free method of CVD-graphene transfer from copper to a different substrate, which can be used for the fabrication of both supported and suspended graphene layers. The approach involves the deposition via electron-beam evaporation of a 15 nm-thick titanium supporting layer on graphene which is removed in a hydrofluoric solution after the graphene transfer, resulting in ultraclean graphene structures, as verified by X-ray photoelectron spectroscopy (XPS). SEM images of suspended graphene obtained with both methods are shown in Figure 1.

This new approach opens up a new way to obtain high-quality transferred graphene for all fields of application where pure graphene surface is required. XPS is a surface sensitive technique usually applied in vacuum condition that recently found applications on liquid samples, thanks to the fabrication of liquid cells with graphene windows<sup>4</sup>. However, to maximize graphene transparency to electrons, the residual amounts should be minimized. We applied our method to encase a liquid solution into a liquid bubble, as shown in the AFM image in Figure 2, in order to investigate Fe<sup>3+</sup> reduction from a solution of FeCl<sub>3</sub> as a function of the temperature. In biology, cell often grow in adhesion of a substrate and their properties are determined by the mechanical and chemical properties of the latter. Therefore a precise control of substrate chemistry is important. We applied our method to produce patterned graphene substrates for neuronal growth. The pattern will be used to control the growth direction and neuronal alignment, while graphene conductivity will be exploited to form localized electrical contacts to the neuron network.

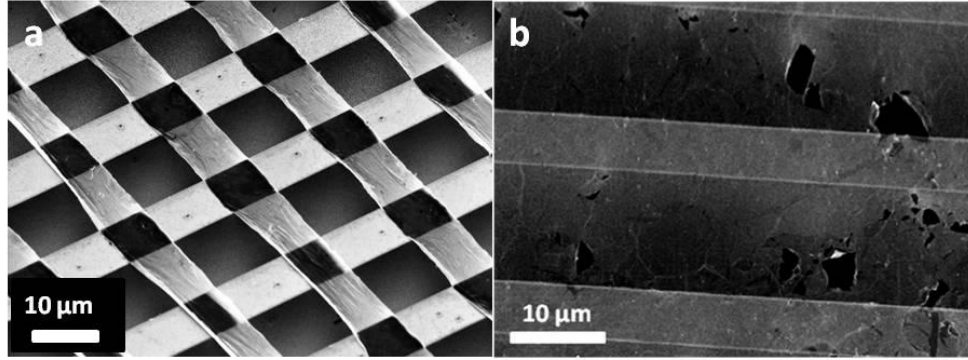
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<sup>1</sup> K. S. Novoselov *et al.*, Science. 306 , 666 (2004).

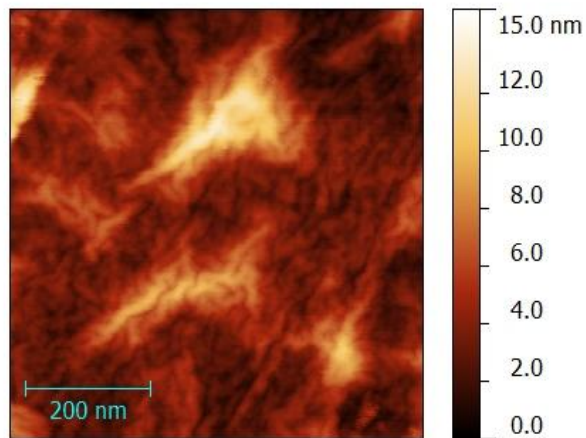
<sup>2</sup> M. J. Allen, V. C. Tung, and R. B. Kaner, Chem. Rev. 110, 132–145 (2010).

<sup>3</sup> Y. Zhang, L. Zhang, and C. Zhou, Acc. Chem. Res. Vol 46, No. 10, 2329-2339 (2013).

<sup>4</sup> A. Kolmakov, D.A. Dikin, L.J. Cote, J. Huang, M.K. Abyaneh, M. Amati, L. Gregoratti, S. Günther, and M. Kiskinova. Nat. Nanotechnol, 6 (10), pp. 651-657 (2011).



*Figure 1:* SEM images of suspended graphene obtained with: (a) PMMA method. Graphene is patterned in stripes 10 μm long with plasma oxygen; graphene stripes are not transparent and this suggests strong contamination due to acetone and polymer visible on the back surface of suspended part. (b) Titanium method using a layer of Ti then removed in HF: graphene resulting after the Ti removal is clean; visible defects are propagated at grain boundaries.



*Figure 2:* AFM image of liquid bubbles of  $\text{FeCl}_3$  solution trapped between a  $\text{TiO}_2$  substrate and graphene.