Micro- and Nanostructuring of Graphene on various Substrates using UV-NIL

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In this work we demonstrate the micro- and nanostructuring of graphene using UV-based Nanoimprint Lithography (NIL) on nickel, copper, or silica substrates. Graphene is a single graphite layer with carbon atoms arranged in a honeycomb crystal lattice with unique properties like a very high electron mobility of 18000 cm^2/Vs [1]. Exfoliated as well as chemical vapor deposited (CVD) graphene was used to demonstrate that our technique is suitable for large-area patterning (1 x 1 cm^2). Feature sizes down to 20 nm were achieved by a wafer-scale process which opens up new possibilities for low-cost and high-throughput manufacturing of graphene-based devices for high frequency applications [2], graphene optoelectronics [3], [4] photonics [5], plasmonics [6].

The most frequently reported method to structure graphene is e-beam lithography [7], despite of its low throughput. NIL allows fast nanopatterning of structures on large areas and is therefore a suitable technique for future mass production. In the last years few approaches have been started to achieve structured graphene using NIL. Liang et al. have reported a method using exfoliation of graphene layers with a patterned graphite stamp [8] and electrostatic assisted exfoliation [9]. Moreover, first steps were undertaken by the same group to achieve nanopatterned graphene by thermal NIL on top of electrostatically exfoliated graphene flakes and subsequent oxygen-assisted etching [10]. One drawback of all these methods is the dependency on random graphene flakes which furthermore were subject to a varying number of layers. Our work represents the first comprehensive investigation of a potentially low-cost, direct imprint process capable of achieving large areas of micro- and nanostructured graphene showing a UV-based NIL process (Figure 1) on exfoliated graphene (Figure 2), on CVD graphene on nickel and copper substrates over 1 x 1 cm^2 [11], [12] (Figure 3) and patterning of CVD graphene transferred from copper onto silica (Figure 4). For the results shown here a two layer resist system (LOR1A and mr-UVCur06) was spin coated on a graphene substrate (Figure 1(a)). The mr-UVCur06 is structured using UV-based NIL on 2.5 x 2.5 cm^2 and the pattern is transferred to the substrate by reactive ion etching using oxygen (Figure 1(b)). Afterwards the LOR1A is dissolved in a developer such that the structured graphene layers remain (Figure 1(c)). The processed graphene films show electron mobilities of up to 4.6 10^3 cm^2/Vs, which confirms them to exhibit state-of-the-art electronic quality.

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References

[1] K.S. Novoselov et al., *Science* **2004**, *306*, 666.
[2] Y.M. Lin et al., *Science* **2010**, *327*, 662.
[3] T. Mueller et al., *Nature Photon*. **2010**, *4*, 297.
[4] M. Liu et al., *Nature* **2011**, *474*, 64.
[5] A. Vakil and N. Engheta, *Science* **2011**, *332*, 1291.
[6] F. Koppens et al., *Nano Lett*. **2011**, *11*, 3370.
[7] A.K. Geim et al., *Nature Mater*. **2007**, *6*, 183.
[8] X. Liang et al., *Nano Lett*, **2007**, *7*, 3840.
[9] X. Liang et al., *Nano Lett*, **2009**. *9*, 467.
[10] X. Liang et al., *Nano Lett*. **2010**, *10*, 2454.
[11] M. Losurdo et al., *J. Phys. Chem. C* **2011**, *115*, 21804.
[12] M. Losurdo et al., *Phys. Chem. Chem. Phys*. **2011**, *13*, 20836.

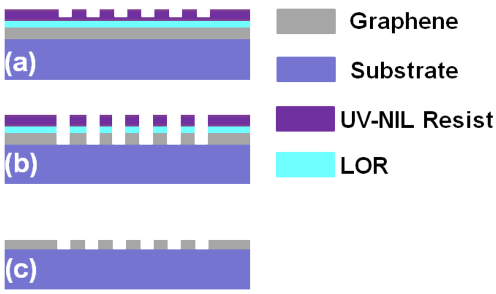

Figure 1: Schematic drawing of UV-based NIL structuring process of graphene using (a) spin coating of resists, (b) Imprinting and etching, (c) lift-off of resists and remaining patterened graphene.

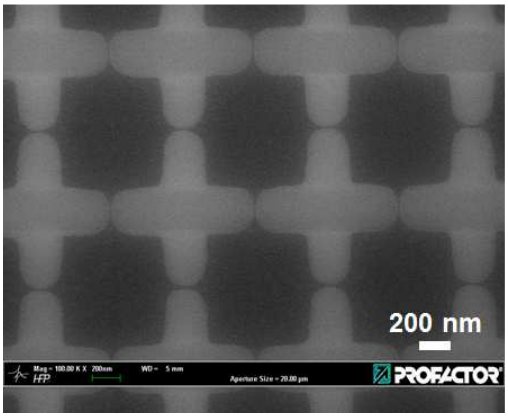

Figure 2: Structured graphene with feature sizes down to 20 nm (dark area) and a period of 600 nm in either lateral direction.

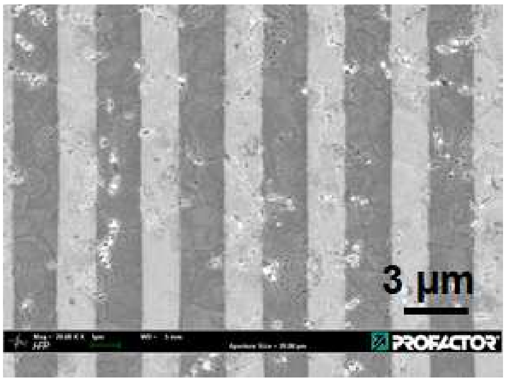

Figure 3: Microstructured graphene on copper substrate with a patterned area of 1 x 1 cm².

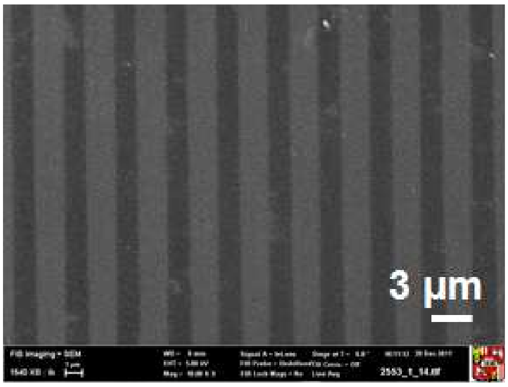

Figure 4: CVD graphene transferred on silica and microstructured by UV-based NIL.