Novel mechanical properties of graphene using atomic force microscopy

Mick Phillips[1] and Roger Proksch[2]

Asylum Research, an Oxford Instruments Company, Bicester, UK,
Asylum Research, an Oxford Instruments Company, Santa Barbara, CA USA
mick@AsylumResearch.co.uk

Graphene was first synthesized[1], [2] in 2004 and since then, research into graphene and related materials has grown extremely rapidly, notably earning a Nobel prize in 2010. The juxtaposition of impressive mechanical, electrical and thermal properties makes these materials likely candidates for disruptive technological breakthroughs, in fields spanning high performance and quantum computing, energy collection and storage, and novel sensors and detectors. They have specific applications in spintronics, as single-molecule sensors and terahertz oscillators, in nanoelectromechanical systems (NEMS), and as transparent electrodes for use in touch-screen displays and photovoltaics. They also offer potential successors to silicon that may take us beyond Moore's law.

Atomic Force Microscopy (AFM) is uniquely positioned to provide structural, mechanical, optical and electrical characterization of graphene and related two-dimensional materials, allowing us to probe their structure, properties and function. Here, we will discuss recent results from selected AFM techniques applied to graphene: amplitude-modulation frequency-modulation (AMFM), loss-tangent mapping and friction force microscopy (FFM).

AM-FM and loss tangent imaging[3] can be used together to give complementary information about local stiffness and energy dissipation. Briefly, the cantilever is driven at first two flexural resonances. Recently, a number of multifrequency AFM schemes have been proposed to improve high resolution imaging, contrast, and quantitative mapping of material properties.[4], [5] [6], [7] Bimodal imaging using more than one resonant vibrational mode of the cantilever simultaneously. The resonant modes can be treated as independent “channels” with each having separate observables. The two examples shown here illustrate nanomechanical contrast. The somewhat surprising results will be interpreted in terms of long range conservative interactions and short range dissipative interactions.

FFM allows clear and easy discrimination between graphene and an underlying substrate. We will present data to demonstrate this, and how high resolution FFM can be used to reveal the relative orientation of graphene flakes, providing insight into graphene growth processes.[8]

References

---

[1] K. S. Novoselov, A. K. Geim, S. V. Morozov, D. Jiang, Y. Zhang, S. V. Dubonos, I. V. Grigorieva, and A. A. Firsov, *Electric field effect in atomically thin carbon films*, Science, 306(5696):666–669 (2004).

[2] K. S. Novoselov, A. K. Geim, S. V. Morozov, D. Jiang, M. I. Katsnelson, I. V. Grigorieva, S. V. Dubonos, and A. A. Firsov, Nature, 438(7065):197–200 (2005).

[3] R. Proksch, and D. Yablon, Appl. Phys. Lett. 100(7), 073106 (2012).

[4] M. Stark, R. W. Stark, W. M. Heckl and R. Guckenberger, Proc. Natl. Acad. Sci 99, 8473 (2002).

[5]T. R. Rodriguez and R. Garcia, Appl. Phys. Lett. 84, 449 (2004).

[6] R. Proksch, Appl. Phys. Lett. 89, 113 121 (2006).

[7] N. F. Martinez, S. Patil, J. R. Lozano, and R. Garcia, Appl. Phys. Lett. 89, 153 115 (2006).

[8] A. J. Marsden, M. A. Phillips and N. R. Wilson, *Friction force microscopy: a simple technique for identifying graphene on rough substrates and mapping the orientation of graphene grains on copper*, http://arxiv.org/abs/1302.0177, (2013).

Figures

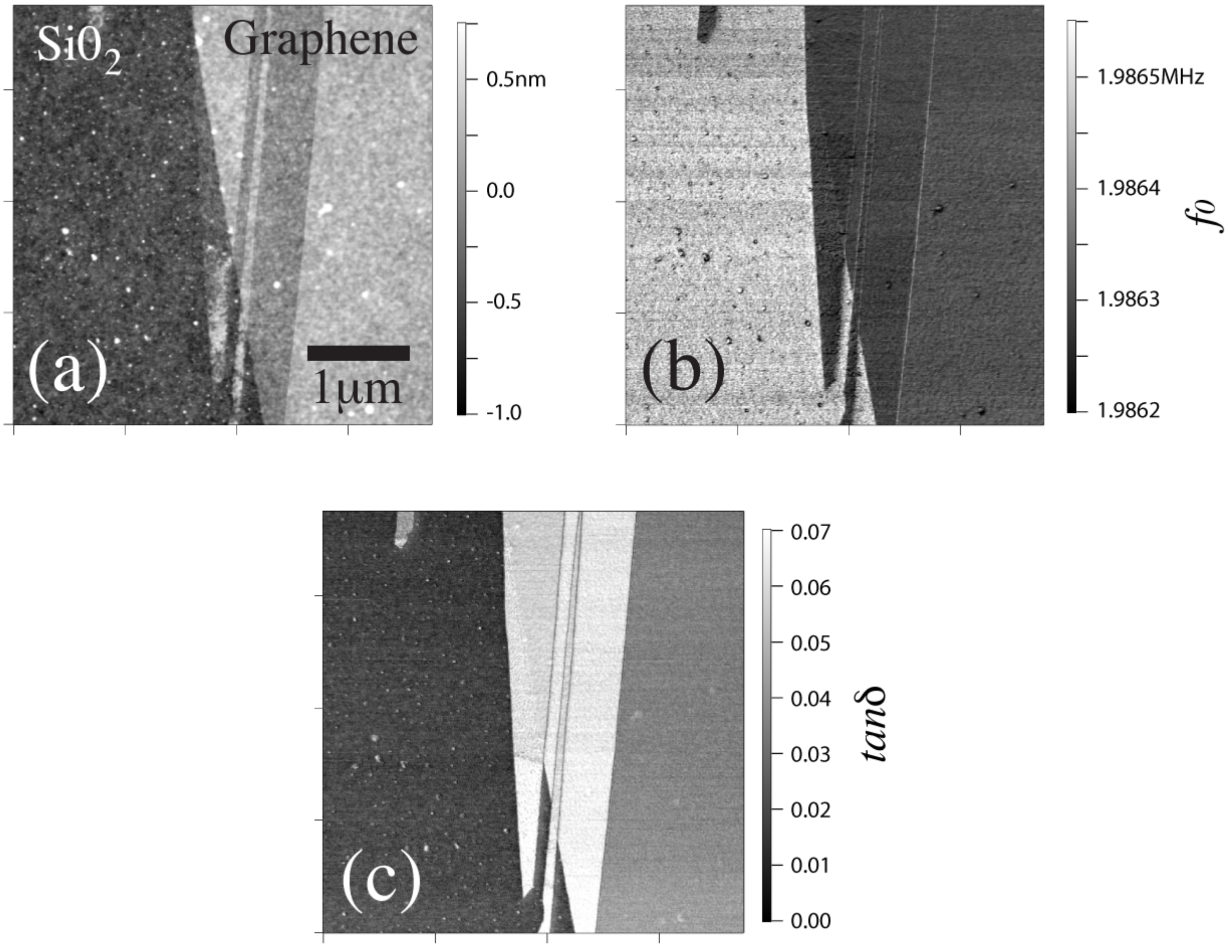

Figure 1: Graphene on SiO$_2$. (a) topography, (b) AM-FM and (c) loss tangent images of a graphene on SiO$_2$. Note that the graphene appears less stiff than the substrate. The edge layers exhibit a larger loss tangent, indicative perhaps of water trapped between the graphene and SiO$_2$.

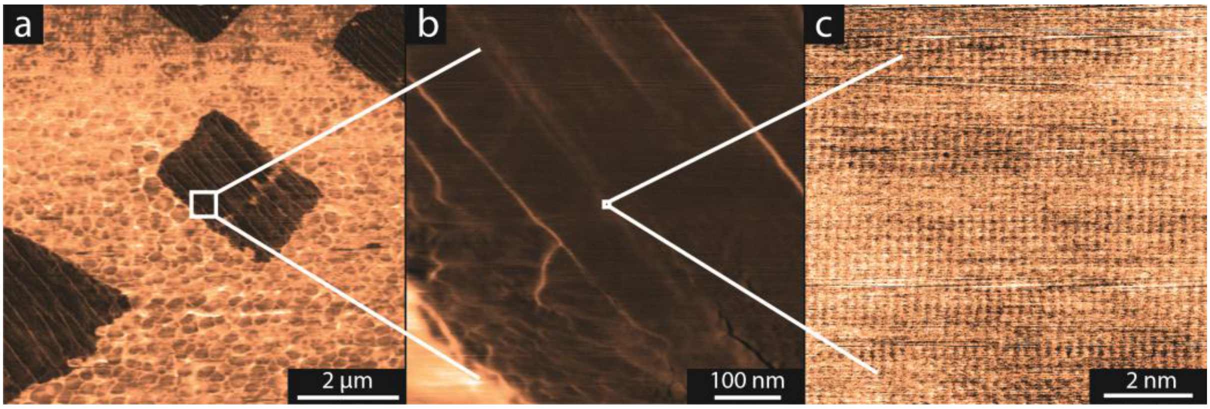

Figure 2: Friction force images of graphene grown on copper by chemical vapour deposition. The graphene flakes can be readily distinguished from the copper by their low friction. At smaller scan sizes, the graphene lattice can be resolved clearly.