Macroscopic self-reorientation of interacting two-dimensional crystals

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Microelectromechanical systems, which can be moved or rotated with nanometre precision, already find applications in such fields like RF electronics[1], micro-attenuators[2], sensors[3] and many others[4-7]. Especially interesting are those which allow fine control over the motion on atomic scale due to self-alignment mechanisms and forces acting on the atomic level[8]. Such machines can produce well-controlled movements as a reaction to small changes of the external parameters. Here we demonstrate that, for the system of graphene on hexagonal boron nitride (hBN), the interplay between the van der Waals and elastic energies results in graphene mechanically self-aligning along the hBN crystallographic directions. Such rotation is macroscopic (for graphene flakes of tens of micrometres the tangential movement can be on hundreds of nanometres) and can be used for reproducible manufacturing of aligned van der Waals heterostructures[9-11].

References

1 Yao, J. J. RF MEMS from a device perspective. *Journal of Micromechanics and Microengineering* **10**, R9-R38, doi:10.1088/0960-1317/10/4/201 (2000).

2 Suzuki, K. Micro electro mechanical systems (MEMS) micro-switches for use in DC, RF, and optical applications. *Japanese Journal of Applied Physics Part 1-Regular Papers Short Notes & Review Papers* **41**, 4335-4339, doi:10.1143/jjap.41.4335 (2002).

3 Cumings, J. & Zettl, A. Low-friction nanoscale linear bearing realized from multiwall carbon nanotubes. *Science* **289**, 602-604, doi:10.1126/science.289.5479.602 (2000).

4 Kim, S. H., Asay, D. B. & Dugger, M. T. Nanotribology and MEMS. *Nano Today* **2**, 22-29, doi:10.1016/s1748-0132(07)70140-8 (2007).

5 Hsu, S. M. Nano-lubrication: concept and design. *Tribology International* **37**, 537-545, doi:10.1016/j.triboint.2003.12.002 (2004).

6 Hedgeland, H. *et al.* Measurement of single-molecule frictional dissipation in a prototypical nanoscale system. *Nature Physics* **5**, 561-564, doi:10.1038/nphys1335 (2009).

7 Guerra, R., Tartaglino, U., Vanossi, A. & Tosatti, E. Ballistic nanofriction. *Nature Materials* **9**, 634-637, doi:10.1038/nmat2798 (2010).

8 Delrio, F. W. *et al.* The role of van der Waals forces in adhesion of micromachined surfaces. *Nature Materials* **4**, 629-634, doi:10.1038/nmat1431 (2005).

9 Geim, A. K. & Grigorieva, I. V. Van der Waals heterostructures. *Nature* **499**, 419-425, doi:10.1038/nature12385 (2013).

10 Novoselov, K. S. & Neto, A. H. C. Two-dimensional crystals-based heterostructures: materials with tailored properties. *Physica Scripta* **T146**, 014006, doi:10.1088/0031-8949/2012/t146/014006 (2012).

11 Novoselov, K. S. Nobel Lecture: Graphene: Materials in the Flatland. *Reviews of Modern Physics* **83**, 837-849, doi:10.1103/RevModPhys.83.837 (2011).

Figures

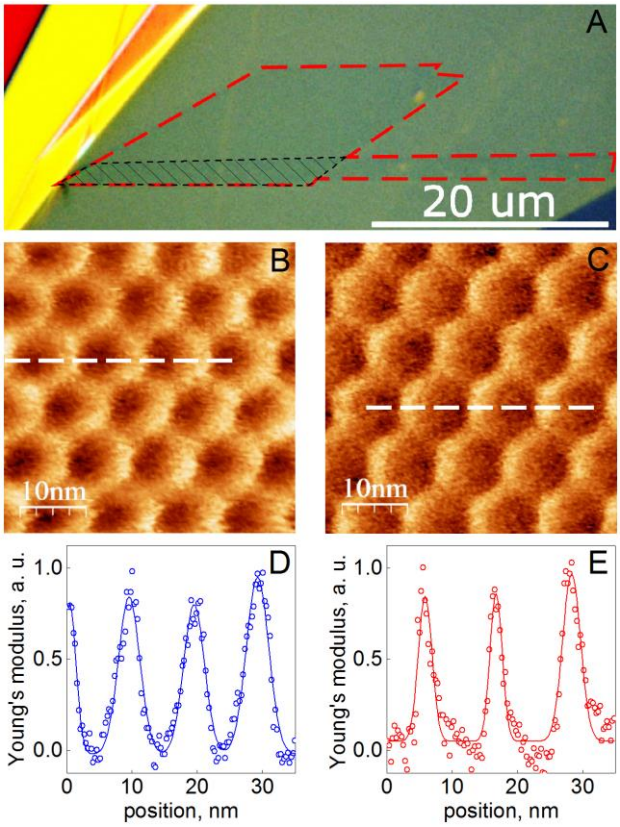

Figure 1: *(A) Optical microscopy image of the flake, demonstrating a very clean interface (bubble free) between graphene and hBN. Different colours correspond to different thicknesses of hBN. Graphene is practically invisible and is marked by red dashed line. The hatched area is bilayer graphen.e. (B) and (C) Young modulus distributions obtained in PeakForce Tapping mode of the moiré superlattice before (B) and after (C) self-alignment. (D) and (E) line profiles across the respected Young modulus distribution images, which indicates the smaller width of the Young's modulus peaks in the annealed (self-rotated) sample. Symbols – experimental data, solid curves – fitted peaks.*

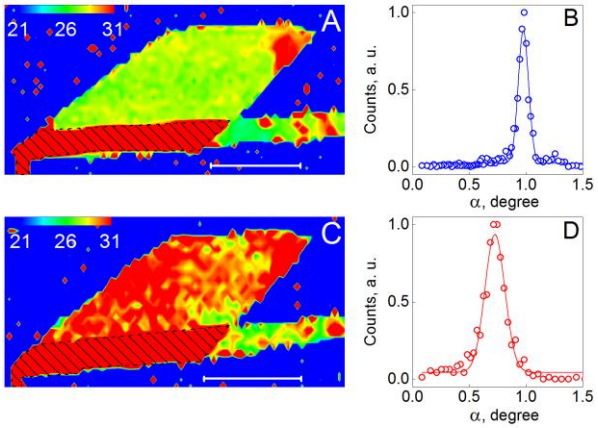

Figure 2: *(A) and (C) Maps of the FWHM of Raman 2D peak before and after annealing respectively. (B) and (D) histograms alignment angles, as recalculated from (A) and (C) respectively.*