Controlled formation of nanobubbles in graphene

Renan Villarreal[1]
Pin-Cheng Lin[1], Harsh Bana[1], Ken Verguts[2,3], Steven Brems[3], Stefan de Gendt[2,3], Manuel Auge[4], Felix Junge[4], Hans Hofsäss[4], E. Harriet Åhlgren[5], Hossein Ghorbanfekr[6], Morteza Fallah[6], François Peeters[6], Mehdi Neek-Amal[6], Chris Van Haesendonck[1], Lino M. C. Pereira[1]
[1]*Quantum Solid-State Physics, KU Leuven, 3001 Leuven, Belgium,*
[2]*Departement Chemie, KU Leuven, 3001 Leuven, Belgium,*
[3]*Interuniversitair Micro-electronica Centrum (imec), vzw, 3001 Leuven, Belgium,*
[4]*II. Institute of Physics, University of Göttingen, Göttingen 37077, Germany,*
[5]*Faculty of Physics, University of Vienna, 1090 Vienna, Austria,*
[6]*Department of Physics, University of Antwerp, 2020 Antwerp, Belgium*
Renan.Villarreal@kuleuven.be

Strained nanobubbles can be used to engineer the electronic structure of graphene through the creation of pseudomagnetic fields. While various approaches have been explored so far (e.g. via strain imposed by a selected substrate or mechanical actuators), they provide limited controllability, especially on a large-wafer scale. Here we report on the controlled formation of noble gas (He, Ne, Ar) nanobubbles in graphene (on various substrates) using ultra-low energy (ULE) ion implantation. ULE ion implantation allows us to precisely tune the number of implanted ions and their kinetic energy, which in turn controls the bubble formation efficiency and bubble density. Our experimental approach is based on a wide range of characterization techniques (structural and electronic), including scanning tunneling microscopy and spectroscopy (STM/STS), synchrotron-based X-ray photoelectron spectroscopy (XPS), Raman spectroscopy, among others. These experimental studies are complemented by density functional theory (DFT) and molecular dynamics (MD) calculations [1], which give insight into the bubble formation and stability mechanisms, and how they depend on gas species (e.g. He, Ne, Ar) and substrate (e.g. Cu and Pt). The new insights provided by our work establish a framework for the controlled formation of graphene nanobubbles, on a large-wafer scale. Building on these findings, we propose strategies for formation of periodic pseudomagnetic fields for flat-band engineering in graphene [2].

References

[1] H. Ghorbanfekr-Kalashami *et al.*, *Nat. Commun*. **8**, 15844 (2017).
[2] Y. Jiang et al., arXiv:1904.10147 (2019); S. P. Milovanović et al., arXiv:1910.11752 (2019).

Figures

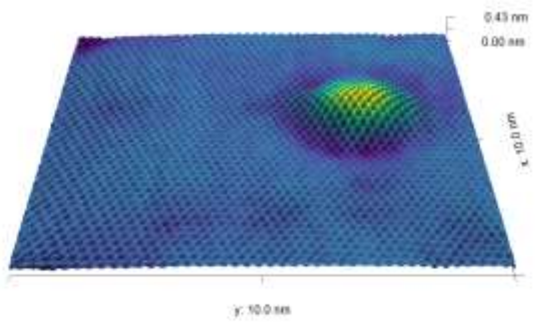

Figure 1: Helium nanobubble (radius ~ 2 nm) in graphene/Cu(111).