

Processing and Aberration-Corrected Imaging of Novel Low-Dimensional Nanostructures

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Low-dimensional nanostructured materials such as organic and inorganic nanotubes [1], nanowires [2] and platelets [3] are potentially useful in a number of areas of nanoscience and nanotechnology due to their remarkable mechanical, electrical and thermal properties [4]. However difficulties associated with their lack of processability have seriously hampered both. In the last few years dispersion and exfoliation methods have been developed and demonstrated to apply universally to 1D and 2D nanostructures of very diverse nature [3,5], offering a practical means of processing the nanostructures for a wide range of innovative technologies. To make real applications truly feasible, however, it is crucial to fully characterize the nanostructures on the atomic scale and correlate this information with their physical and chemical properties. Advances in aberration-corrected optics in electron microscopy have revolutionised the way to characterise nano-materials, opening new frontiers for materials science. With the recent advances in nanostructure processability, electron microscopes are now revealing the structure of the individual components of nanomaterials, atom by atom. Here we will present an overview of very different low-dimensional materials issues, showing what aberration-corrected electron microscopy can do for materials scientists.

Among the first materials to have benefitted most from these advances are the inorganic nanowires made up from molybdenum, sulfur and iodine (MoSI nanowires). Purification and dispersion in liquid phase media and exfoliation of the as-synthesized ropes down to single, sub-nanometer wide wires or very thin nano-sized bundles has allowed us to study their previously unknown atomic structure [6-7]. Innovative nanowire functionalisation routes are also studied. Leading edge sub-angstrom resolution electron microscopy techniques, combining aberration corrected High Resolution Transmission Electron Microscopy (HRTEM) and Scanning Transmission Electron Microscopy (STEM) are here applied to obtain crucial structure-properties correlations.

Other nanomaterials which have been at the centre of the most advanced nanotechnology research and that have most benefitted from a liquid phase dispersion method are graphene and graphene-like mono-atomic crystals. Until a few years ago the standard procedure used to make graphene was micromechanical cleavage [8], which is a very low yield production method. In order to fully exploit graphene's outstanding properties, a mass production method was necessary and the development of a method to exfoliate cheap, commercial graphite in organic solvents down to large area single graphene flakes with high yield was one major achievement [3]. Before applying this method for real high-tech purposes it is imperative to see whether the graphene structure endures the exfoliation procedure. In order to do so, flakes were characterized by aberration-corrected HRTEM, revealing

extremely high quality graphene structures. New advances in aberration-corrected annular dark field STEM allowed us to identify low-atomic number individual adatoms, vacancies and molecular-scale adsorbates in single-layer atomic crystals in which the nearest neighbors are 1.45 Å apart [9].

References

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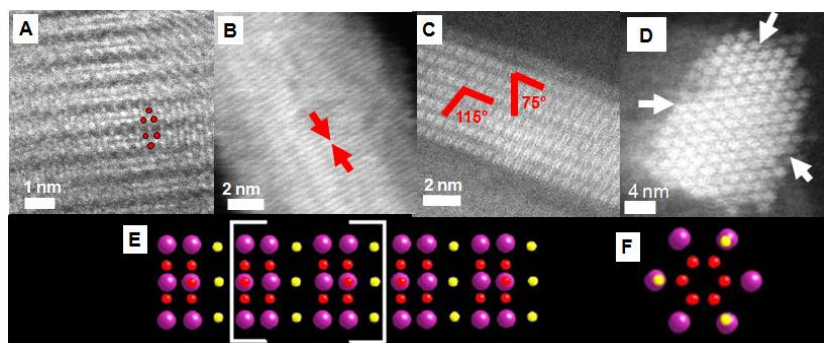


FIG. 1. a-b-c) Experimental HAADF STEM images of nanowire bundles viewed along the three high-symmetry directions; d) HAADF STEM image of a nanowire bundle cross section; e) The structure of a Mo₆S₃I₆ nanowire as determined by HAADF STEM; e) schematic view along the long axis of the wire; f) schematic cross section view.

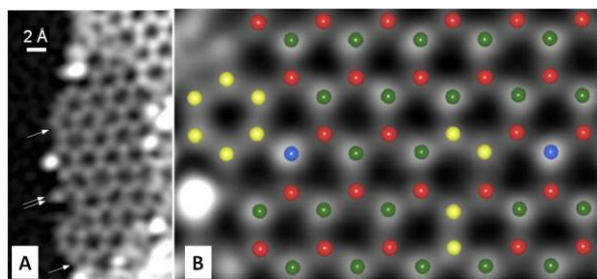


FIG. 2. a) A typical aberration-corrected MAADF image of the edge of a liquid phase exfoliated graphene; the arrows point at defects and dangling bonds. b) DFT simulation of a single boron nitride layer containing the experimentally observed substitutional impurities overlaid on the corresponding part of the experimental aberration corrected ADF STEM image, reproduced from [9]. C = yellow, B = red, N = green, O = blue.