ACCOUNTS
of chemical research

Editorial

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The Rise of Two-Dimensional Materials

This special issue of *Accounts of Chemical Research* reports many remarkable examples of the influence that both size and dimensionality have on materials properties. Structures with nanometric dimensions shaped into zero-, one- or two-dimensional materials have different electronic, chemical, optical, and magnetic properties. Fullerenes and quantum dots were among the first examples of 0D nanostructures. Their electronic properties are characterized by quantum confinement in three directions. Quantum wells or ultrathin semiconductor layers with confinement in one direction were the first examples of 2D structures. One-dimensional structures with a confinement in two directions came a bit later to complete the whole family. Just over 10 years ago, the isolation of graphene, the first example of 2D carbon, was reported by Novoselov and Geim.[1] The unique electronic properties of graphene triggered a great deal of attention toward 2D structures, thus boosting research on the synthesis and the characterization of other non-carbon-based 2D structures. Among the new systems, researchers have worked with hexagonal boron nitride (hBN), different transition metal chacolgenides (TMCs), and other elemental 2D systems such as germanane, silicene, and phosphorene (see Goldberger et al., DOI: 10.1021/ar500296e) or oxides (see Sasaki and Ma, DOI: 10.1021/ar500311w). Some materials classes have emerged from the physics community, for example, 2D topological insulators (see Cui et al., DOI: 10.1021/ar5003297), or have been discovered and then elevated quite recently like the MXenes and MAX phases (see Gogotsi et al., DOI: 10.1021/ar500346b). In the community of colloidal nanoparticles, nanoplatelets appear as the colloidal equivalent of epitaxial quantum wells and have been used as building blocks to realize novel optoelectronic devices.

Just like in graphene, the physicochemical properties of ultrathin sheets with 1D confinement are different compared with their bulk counterparts. This special issue includes excellent experimental and theoretical contributions regarding these fascinating 2D materials. From the synthetic standpoint, these layers can be produced via top down and bottom up approaches. For example, Lou and co-workers (DOI: 10.1021/ar500291j) summarize chemical vapor deposition routes toward monolayers of semiconducting TMCs such as MoS_2. Other authors review chemical top-down routes that enable the intercalation and exfoliation of layered systems so as to isolate monolayers (see Terrones et al., DOI: 10.1021/ar5002846). Furthermore, wet chemical approaches can be used to synthesize monocrystals and possibly monolayers of TMCs and other layered materials. Other synthetic approaches can lead to 2D colloidal semiconductor nanoplatelets and their heterostructures, and these are summarized by the teams of Buhro (DOI: 10.1021/ar500286j) and Dubertret (DOI: 10.1021/ar500326c).

Because the properties of these monolayers are very different from their bulk phases, researchers have designed ways to characterize and identify different types of monolayers. In this context, Pimenta et al. (DOI: 10.1021/ar500280m) and Kalbac et al. (DOI: 10.1021/ar500384p) demonstrate that Raman spectroscopy and resonant Raman spectroscopy allow one to distinguish and identify the material and the number of layers. Dong et al. (DOI: 10.1021/ar500306w) show that water is reorganized at the interface of 2D systems, and Xie et al. (DOI: 10.1021/ar500164g) develop solid state nanochemistry on 2D materials and the importance of defects when tailoring their properties. Much of this research is still in its infancy, but this and other techniques will be developed and improved in the near future.

Among the most promising applications of 2D materials are uses as flexible and nanoscale electronics and optoelectronics. Excellent contributions regarding the great opportunities to create electronic or optoelectronic devices with high performance and stability are covered by the groups of Kis et al. (DOI: 10.1021/ar500274g) and Dubertret et al. (DOI: 10.1021/ar500326c) In addition, the intrinsic electronic properties from the viewpoint of devices are reviewed (see Joswig et al., DOI: 10.1021/ar500318p), and possible applications in the fields of spin- and strain-tronics are explored by Heine (DOI: 10.1021/ar500277z), while Yakobson et al. (DOI: 10.1021/ar500302g) show how to make a virtue out of the necessity to deal with particular defect types that have a strong impact on the electronic properties of 2D materials.

The optical properties of nanostructures vary according to their dimensionality, and Eda et al. (DOI: 10.1021/ar500303m) nicely summarize the importance of optical characterization of mono- and few-layer TMCs. The nonlinear response of monolayers and the fact that optical properties change dramatically if an even or odd number of layers are stacked is fascinating. In Lhuillier et al. (DOI: 10.1021/ar500326c), it is demonstrated that 1D confinement can lead to a fluorescent emission line width close to kT at room temperature, a performance that has only been achieved for structures whose thickness is controlled with atomic precision. Giant oscillator transition strength and efficient lasing is also reported for colloidal 2D structures.

It is also possible to go from two dimensions to a third dimension, and researchers have now demonstrated that novel van der Waals solids can be produced by stacking layers of different materials (Terrones et al., DOI: 10.1021/ar5002846). This leads to heterostructures similar to the ones obtained with quantum wells. It is thus possible to use direct growth, but each individual layer can be transferred chemically. These systems are novel, and their properties are now being investigated.

This special issue represents only the tip of the iceberg, since many possibilities of van der Waals solids and other hybrid 2D systems can be constructed. Many materials are still waiting to be synthesized in two dimensions. This field is just emerging, and unprecedented properties of hybrid 2D materials will be unveiled within a short time. We hope that this special issue

Special Issue: 2D Nanomaterials beyond Graphene

Received: December 8, 2014
Published: January 20, 2015

ACS Publications

brings alive the recent results and current challenges concerning 2D materials.

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DOI: 10.1021/ar5004434
Acc. Chem. Res. 2015, 48, 1–2