EDITORIAL

The World Is Flat?

The World Is Flat: A Brief History of the Twenty-First Century is an international bestselling book by Thomas Friedman that analyzes globalization in the early 21st century.[1] The title, perhaps modified to *The World is 2D*, is also appropriate for science in the 21st century, as exemplified by the recent interest in graphene and other two-dimensional (2D) materials.[2] The isolation of graphene, by University of Manchester Nobel Laureates Profs. Andre Geim and Kostya Novoselov in 2004, has led to the discovery of an entirely new family of one-atom-thick 2D materials with novel properties.[3]

On 28 January 2013, the European Commission announced a project to study graphene led by frequent *ACS Nano* author Prof. Andrea Ferrari in its *Future and Emerging Technology* flagship initiative (another aims to model the human brain).[4−9] The flagship initiative funds large-scale, visionary projects involving many research institutions across Europe, and each initiative will be funded with up to 1 billion over 10 years. Before this announcement, the United Kingdom had already announced investment of up to £60 M in graphene-related technologies in 2011.[10] South Korea announced in 2012 that it will spend US $200 M on graphene commercialization activities over 6 years.[11]

Although widely touted as a superlative material, pristine graphene does not have a band gap, a property that is essential for many electronics and optoelectronics applications, including transistors. Engineering a graphene band gap increases fabrication complexity and either reduces mobilities to the level of strained silicon films or requires high voltages for operation. Recently, semiconducting 2D materials, including several transition metal dichalcogenides (*e.g.*, MoS_2, $MoSe_2$, WS_2, WSe_2, TiS_2, *etc.*), have attracted much interest due to their extraordinary properties in terms of both fundamental science and applications. Semiconducting 2D materials do not suffer from the zero-band-gap disadvantage of graphene. The sufficiently large band gaps of 2D semiconductors (*e.g.*, 1.8 eV for a MoS_2 monolayer)[12] and enhanced carrier mobility when integrated with high-*k* dielectrics[13] make these materials attractive for future nanoelectronic devices. The progress, challenges, and opportunities in 2D materials are presented in a recent review by Butler *et al.*[14]

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Researchers recently demonstrated how building multilayered heterostructures in a three-dimensional stack can produce exciting physical phenomenon that can be harnessed in devices (Figure 1).[9,15] This advance promises a route to tailor materials properties by the appropriate selection of materials and stacking order.[9]

In this issue of *ACS Nano*, Eda and Maier write a forward-looking Perspective on the rapid progress in this field, particularly in the growth of 2D crystals that can be implemented into complex heterostructured devices with desired functionalities.[16] It is known that semiconducting 2D crystals such as MoS_2 and WSe_2 exhibit unusual optical properties that can be exploited in flexible photovoltaic cells, second-harmonic generation, and other novel optoelectronics devices. The next challenge is enhancing light−matter interactions in atomically thin 2D films to enhance the output performance of such devices, for example with the use of plasmonic nanostructures.

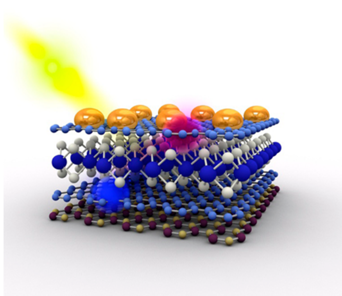

Figure 1. Interaction of light with multilayered two-dimensional heterostructures. Adapted with permission from ref 15; courtesy of Prof. Antonio Castro Neto, National University of Singapore.

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Around 330 BC, Aristotle proposed the spherical shape of the Earth based on empirical evidence, but it was not until Columbus' voyages around the world that the residual belief that the Earth is flat was refuted. But judging from the intense interest in this burgeoning new field, it appears that the 21st century may indeed become the era when the scientists and engineers again focus on the two-dimensional world!

Disclosure: Views expressed in this editorial are those of the author and not necessarily the views of the ACS.

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