One-dimensional van der Waals heterostructures

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1. Introduction

The demonstration of two-dimensional (2D) van der Waals (vdW) heterostructures—in which atomic layers are stacked on each other and different 2D crystals are combined beyond symmetry and lattice matching—represents a way of manipulating crystals to enable both the exploration of physics not observable in conventional materials and device applications. These 2D heterostructures have been fabricated by transferring preprepared layers (transfer approach) or by synthesizing layers onto a base layer (synthesis approach). Whether such artificial materials and interfaces can be fabricated in other dimensions remains an open question.

2. Results and discussion

Here we present the experimental synthesis of one-dimensional (1D) vdW heterostructures, a class of materials where different atomic layers are coaxially stacked. We demonstrate the growth of single-crystal layers of hexagonal boron nitride (BN) and molybdenum disulfide (MoS_2) crystals on single-walled carbon nanotubes (SWCNTs). For the latter, larger-diameter nanotubes that overcome strain effect were more readily synthesized. We also report a 5-nanometer–diameter heterostructure consisting of an inner SWCNT, a middle three-layer BN nanotube, and an outer MoS_2 nanotube (Figure 1). Electron diffraction verifies that all shells in the heterostructures are single crystals. [1]

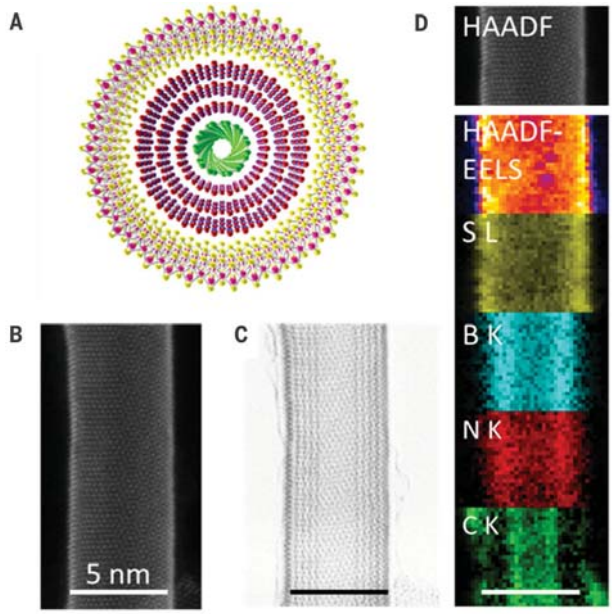

Figure 1. Atomic model (A), HAADF-STEM image (B), annular bright field (ABF)–STEM image (C),and EELS mapping (D) of a 5-nm–diameter ternary 1D vdW heterostructure, consisting of one layer of carbon, three layers of BN, and one layer of MoS_2. Scale bars, 5 nm.

We will also present our current understandings on the optical characterizations on 1D vdW heterostructures. In the case of SWCNT-BNNT heteronanotube, shifts in Raman and PL spectroscopy for inner SWCNT are routinely observed. We attribute these shifts to the effect of BN outer shells on the structure and the surface condition of the inner SWCNT. Furthermore, inner SWCNTs can be removed by burning SWCNT-BNNT nanotubes in an oxygen atmosphere, which allowed us to obtain BNNT-MoS_2 heterostructure. In this structure, the strong electron coupling between SWCNT and MoS_2 nanotube is eliminated, resulting in a strong PL emission from the outer direct band gap single-walled MoS_2 nanotubes. The ultrafast optoelectronic processes of our 1D vdW heterostructure were also investigated. [2]

3. Conclusions

This work suggests that all of the materials in the current 2D library could be rolled into their 1D counterparts and a plethora of function-designable 1D heterostructures could be realized.

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