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Topical Review

Atomically thin semiconducting layers and nanomembranes: a review

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Abstract

This article reviews the main physical properties of atomically thin semiconductors and the electronic devices based on them. We start with graphene, describing its physical properties and growth methods, followed by a discussion of its electronic device applications. Then, transition metal dichalcogenides (TMDs) are analyzed as a prototype of atomically thin semiconductors, their physical properties, growth methods, and electronic devices are discussed in detail. Finally, non-layered semiconducting membranes with thicknesses ranging from a few nanometers to about 50 nm, and considered as counterparts of atomically thin semiconductors, are analyzed, and their applications presented.

Keywords: 2D semiconductors, semiconductor membranes, heterostructures

(Some figures may appear in colour only in the online journal)

1. Graphene - the incentive of 2D materials

Atomically thin materials, also called two-dimensional (2D) materials, comprise materials with an extremely small thickness, of one or few atoms. A one-atom-thick material is referred to as monolayer, a two-atom-thick material as bilayer, and so on. More than 140 2D materials are presently known, many of them being semiconductors [1]. Atomically thin semiconductors generally originate from their bulk counterparts, termed as van der Waals materials, which are layered materials that consist of billions of monolayers held together by weak van der Waals forces. The simplest way to obtain a monolayer is to use scotch tape and mechanically exfoliate some layers from the bulk material (see figure 1). Then, the monolayers, bilayers, trilayers, or multilayers can be identified due to their different colors on a suitable chosen substrate, such as doped Si with a 300 nm thick SiO_2 layer on top of it, when illuminated by visible light. Finally, metallic contacts are deposited via e-beam lithography and e-beam deposition. In this way, the first atomically thin material, i.e. the graphene monolayer, was isolated from highly ordered pyrolytic graphite [2].

Although the scotch method is a primitive one, it is still the most used method to study 2D materials because the quality of exfoliated flakes is very high, and are in fact higher than that obtained from more sophisticated growth methods. Many 2D materials were obtained and studied in this way.

In particular, the electrical properties of 2D materials are studied in the widespread backgate field-effect transistor (FET) configuration illustrated in figure 2, in which 2D materials such as graphene or TMDs transferred on a doped Si/SiO_2 substrate form the channel. The doped Si acts as the backgate (G), and SiO_2 is the dielectric gate isolation layer.

