Two-Dimensional Materials: From Theoretical Predictions to Experimental Realizations and Technological Applications

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Two-dimensional (2D) materials have captivated the scientific community with their remarkable properties and potential applications. These materials are characterized by their atomic-scale thickness, typically consisting of a single layer of atoms arranged in a two-dimensional lattice. In 2D systems, the in-plane confinement limits the available phase space and reduces the screening, leading to enhanced correlations and quantum effects. As a result, these crystals exhibit outstanding optical, electronic, and magnetic properties, not achievable in their bulk counterparts.

The existence of truly two-dimensional materials was initially debated: according to the Mermin-Wagner theorem, fluctuations in two-dimensional systems would cause them to melt or crumble. These predictions suggested that 2D materials could not exist in a free-standing form without disintegrating or bonding to three-dimensional substrates.

The discovery of graphene in 2004 by Andre Geim and Konstantin Novoselov shattered these theoretical constraints. By exfoliating a single layer of graphite using adhesive tape, they isolated graphene, a one-atom-thick layer of carbon atoms arranged in a hexagonal lattice. This paved the way for the exploration of a variety of other 2D materials, each with its own set of extraordinary properties and potential applications, such as Transition Metal Dichalcogenides (TMDs) and hexagonal boron nitride (hBN).

In this talk, we will delve into the most relevant characteristics of 2D materials, from their crystal lattice to their electronic band structure. We will explore the fundamental role played by the inter-layer interaction and sample-substrate interaction in determining the crystal behavior. Different strategies aimed at tuning the response of 2D materials will be examined, including strain, pressure, alloying, and defect intercalation. Finally, we will discuss how the quasi-all-surface nature of 2D materials opens the way to the production of low-dimensional heterostructures, made up by stacking thin crystals of different species, to achieve brand new systems with tailor-made characteristics for material engineering.