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Layer-by-Layer Thinning of 2D Materials

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Two-dimensional (2D) structured materials are receiving huge interests since the discovery of graphene material first by the mechanical exfoliation method using scotch tape from the graphite in 2004 (1). Among them, graphene [1-15], molybdenum disulfide (MoS2) [10,16], black phosphorous [17], hexagonal-boron nitride (h-BN) [18-20], hafnium dioxide (HfO2) [21], molybdenum diselenide (MoSe2) [22], and 2D carbide nanosheets (MXene) [23] are emerging as many promising potential materials with novel properties in electronics and optoelectronics.

Unlike conductive graphene with gapless characteristics, other materials above present different energy band-gap. The controlled tuning of band-gap of 2D materials by layer-by-layer thinning using various strategies related to chemistry, physic, nanotechnology, and engineering in order to obtain the ultra-thinner material layer and resulting in improvement their electrical characteristics is highly desiring with targeting toward practical applications in the industry to serve human society(**Figure 1**).

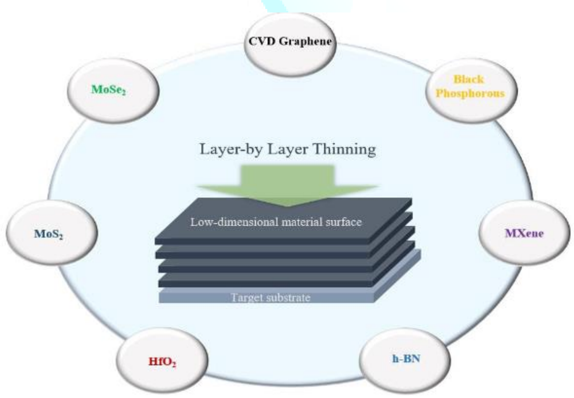

Figure 1: Schematic of strategies for layer-by-layer thinning on various low-dimensional material surfaces by chemistry, physic, nanotechnologyand engineering for tuning their electronics and optoelectronics.

The increasing the controlled band-gap of 2D materials would be raising up the current on-off ratio, photoluminescence, and other unexploited and unexplored exotic properties. The electronic properties of 2D layered materials are strongly dependent on their thicknesses. For instance, the thickness modulating of MoS2 layers will activate the optical energy gap which makes it promising for application in optoelectronic devices, such as photodetectors, photovoltaics, light emitters, phototransistors.Very recently, the progress in layer-by-layer thinning techniques on 2D materials has significant achieved [15-17,19-23]. By adjusting the etching rates (chemical and physical plasma engineering) [15-17,19-22] or gas molecular ratios and temperatures (chemical vapor deposition system) [23], we can achieve complete removal the layer-by-layer precisely and controllability [15-17,19-23]. Especially, the layer-by-layer etching by plasma (inductively coupled plasma, ion beam) without inducing the physical and chemical damage has successfully demonstrated in recent reports [15,17]. Consequently, it could unlock and take a leap forward on developing plasma-based thinning methods for other TMDs and low-dimensional materials in various advanced devices and applications.

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