Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 2, No. 1, 36-37
2018
DOI: 10.33805/2576.8484.111

Layer-by-Layer Thinning of 2D Materials

Viet Phuong Pham
SKKU Advanced Institute of Nano Technology (SAINT), Sungkyunkwan University (SKKU), Suwon, Republic of Korea; pvphuong85@ibs.re.kr (V.P.P.).

1. Introduction

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).

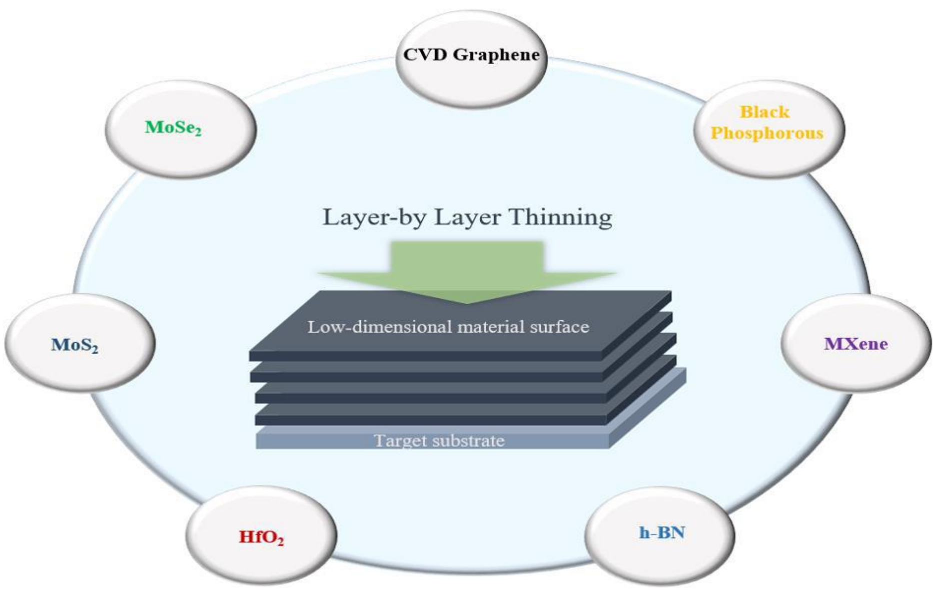

Figure 1.
Schematic of strategies for layer-by-layer thinning on various low-dimensional material surfaces by chemistry, physic, nanotechnology and engineering for tuning their electronics and optoelectronics.

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

History: Received: 13 January 2018; Accepted: 15 January 2018; Published: 19 January 2018

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.

References

[1] K. S. Novoselov *et al.*, "Electric field effect in atomically thin carbon films," *Science*, vol. 306, no. 5696, pp. 666-669, 2004. https://doi.org/10.1126/science.1102896

[2] V. P. Pham, H.-S. Jang, D. Whang, and J.-Y. Choi, "Direct growth of graphene on rigid and flexible substrates: Progress, applications, and challenges," *Chemical Society Reviews*, vol. 46, no. 20, pp. 6276-6300, 2017. https://doi.org/10.1039/c7cs00224f

[3] V. P. Pham *et al.*, "Chlorine-trapped CVD bilayer graphene for resistive pressure sensor with high detection limit and high sensitivity," *2D Materials*, vol. 4, no. 2, p. 025049, 2017. https://doi.org/10.1088/2053-1583/aa6390

[4] V. P. Pham, K. N. Kim, M. H. Jeon, K. S. Kim, and G. Y. Yeom, "Cyclic chlorine trap-doping for transparent, conductive, thermally stable and damage-free graphene," *Nanoscale*, vol. 6, no. 24, pp. 15301-15308, 2014. https://doi.org/10.1039/c4nr04387a

[5] V. P. Pham, K. H. Kim, M. H. Jeon, S. H. Lee, K. N. Kim, and G. Y. Yeom, "Low damage pre-doping on CVD graphene/Cu using a chlorine inductively coupled plasma," *Carbon*, vol. 95, pp. 664-671, 2015. https://doi.org/10.1016/j.carbon.2015.08.070

[6] V. P. Pham, A. Mishra, and G. Y. Yeom, "The enhancement of hall mobility and conductivity of CVD graphene through radical doping and vacuum annealing," *RSC Advances*, vol. 7, no. 26, pp. 16104-16108, 2017. https://doi.org/10.1039/c7ra01330b

[7] V. P. Pham *et al.*, "Low energy BCl3 plasma doping of few-layer graphene," *Science of Advanced Materials*, vol. 8, no. 4, pp. 884-890, 2016.

[8] V. Pham, "Chemical vapor deposited graphene synthesis with same-oriented hexagonal domains," *Eng Press*, vol. 1, pp. 39-42, 2018.

[9] K. N. Kim, V. P. Pham, and G. Y. Yeom, "Chlorine radical doping of a few layer graphene with low damage," *ECS Journal of Solid State Science and Technology*, vol. 4, no. 6, pp. N5095-N5097, 2015. https://doi.org/10.1149/2.0141506jss

[10] V. P. Pham and G. Y. Yeom, "Recent advances in doping of molybdenum disulfide: Industrial applications and future prospects," *Advanced Materials*, vol. 28, no. 41, pp. 9024-9059, 2016. https://doi.org/10.1002/chin.201651225

[11] A. Ferrari, F. Bonaccorso, and V. Fal'ko, "Science and technology roadmap for graphene, related two-dimensional crystals, and hybrid systems," *Nanoscale*, vol. 7, pp. 4587-5062, 2015.

[12] S. Z. Butler *et al.*, "Progress, challenges, and opportunities in two-dimensional materials beyond graphene," *ACS Nano*, vol. 7, no. 4, pp. 2898-2926, 2013.

[13] A. K. Geim and K. S. Novoselov, "The rise of graphene," *Nature Materials*, vol. 6, no. 3, pp. 183-191, 2007.

[14] W. J. Parak, A. E. Nel, and P. S. Weiss, "Grand challenges for nanoscience and nanotechnology," vol. 9, ed: ACS Publications, 2015, pp. 6637-6640.

[15] K. Kim *et al.*, "Atomic layer etching of graphene through controlled ion beam for graphene-based electronics," *Scientific Reports*, vol. 7, no. 1, pp. 2462-2462, 2017. https://doi.org/10.1038/s41598-017-02430-8

[16] Y. Liu *et al.*, "Layer-by-layer thinning of MoS2 by plasma," *ACS Nano*, vol. 7, no. 5, pp. 4202-4209, 2013.

[17] J. Park, S. Jang, D. Kang, D. Kim, and M. Jeon, "Layer-controlled thinning of black phosphorous by an ar ion beam," *Journal Mater Chem*, vol. 5, pp. 10888-10893, 2017. https://doi.org/10.1039/c7tc03101g

[18] C. R. Dean *et al.*, "Boron nitride substrates for high-quality graphene electronics," *Nature Nanotechnology*, vol. 5, no. 10, pp. 722-726, 2010.

[19] C. Elbadawi *et al.*, "Electron beam directed etching of hexagonal boron nitride," *Nanoscale*, vol. 8, no. 36, pp. 16182-16186, 2016. https://doi.org/10.1039/c6nr04959a

[20] Y. Liao *et al.*, "Oxidative etching of hexagonal boron nitride toward nanosheets with defined edges and holes," *Scientific Reports*, vol. 5, no. 1, p. 14510, 2015. https://doi.org/10.1038/srep14510

[21] J. Chen, W. J. Yoo, Z. Y. Tan, Y. Wang, and D. S. Chan, "Investigation of etching properties of HfO based high-K dielectrics using inductively coupled plasma," *Journal of Vacuum Science & Technology A: Vacuum, Surfaces, and Films*, vol. 22, no. 4, pp. 1552-1558, 2004. https://doi.org/10.1116/1.1705590

[22] Y. Sha, S. Xiao, X. Zhang, F. Qin, and X. Gu, "Layer-by-layer thinning of MoSe2 by soft and reactive plasma etching," *Applied Surface Science*, vol. 411, pp. 182-188, 2017. https://doi.org/10.1016/j.apsusc.2017.03.159

[23] B. Ding *et al.*, "A two-step etching route to ultrathin carbon nanosheets for high performance electrical double layer capacitors," *Nanoscale*, vol. 8, no. 21, pp. 11136-11142, 2016. https://doi.org/10.1039/c6nr02155g