Two-dimensional oxides: New flatland beyond graphene?

Minoru Osada[1,2]

[1] Institute of Materials and Systems for Sustainability, Nagoya University, Nagoya, Japan
[2] WPI Center for Materials Nanoarchitectonics, National Institute for Materials Science, Tsukuba, Japan

Two-dimensional (2D) nanosheets, which possess atomic or molecular thickness, have been emerging as important new materials due to their unique properties. In particular, the development of graphene has opened the possibility of isolating and exploring the fascinating properties of 2D nanosheets of other layered materials, which upon reduction to single/few atomic layers will offer functional flexibility, new properties, and novel applications. In this talk, we review the progress made in the synthesis, assembly, and properties of 2D oxide nanosheets, highlighting emerging functionalities in electronic/energy applications [1].

A variety of 2D oxide nanosheets (such as $Ti_{1-d}O2$, $Ti_{1-x}Co_xO_2$, MnO_2, and perovskites) were synthesized by delaminating appropriate layered precursors into their molecular single sheets via soft-chemical process. These oxide nanosheets have distinct differences and advantages compared with graphene because of their potential to be used as insulators, semiconductors, and even conductors, depending on their composition and structures. Another attractive aspect is that 2D oxide nanosheets can be organized into various nanoarchitectures by applying solution-based layer-by-layer assembly [2]. We utilized oxide nanosheets as building blocks in the LEGO-like assembly, and successfully developed various functional nanodevices such as all nanosheet FETs [3], high-density capacitors [4], artificial ferroelectrics/multiferroics [5], spinelectronic devices [6], Li-ion batteries/solar cells [7], actuator crystals [8], etc. Our work is a proof-of-concept, showing that new hybrid materials/devices can be made from 2D nanosheet architectonics.

[1] M. Osada, T. Sasaki, *Adv. Mater.* **24**, 209 (2012); *Dalton Trans.* **47**, 2841 (2018); *APL Mater.* **7**, 120902 (2019).
[2] K. Matsuba *et al.*, *Sci. Adv.* **3**, e1700414 (2017); Y. Shi *et al.*, *ACS Nano* **14**, 15216 (2020); L. Nurdiwijayanto *et al.*, *Nano Lett.* **21**, 7044-7049 (2021).
[3] S. Li *et al.*, *Nat. Mater.* **13**, 023113 (2018); T. Taniguchi *et al.*, *ACS Nano* **13**, 11214 (2019); T. Taniguchi *et al.*, *ACS Nano* **14**, 6663 (2020).
[4] B-W. Li *et al.*, *ACS Nano* **8**, 2658 (2014); C. Wang *et al.*, *ACS Nano* **8**, 5449 (2014); B-W. Li et al., *J. Am. Chem. Soc.* **139**, 10868 (2017); M-S. Khan *et al.*, *Small* **16**, 2003485 (2020).
[5] B-W. Li *et al.*, *ACS Nano* **4**, 6673 (2010); B-W. Li et al., *J. Am. Chem. Soc.* **13**8, 7621 (2016).
[6] M. Osada *et al.*, *ACS Nano* **5**, 6871 (2011); M. Osada *et al.*, *Nanoscale* **6**, 14227 (2014).
[7] X. Xu *et al.*, *Energy Environ. Sci.* 4, 3509 (2011); T-P. Chen *et al.*, *Adv. Energy Mater.* 8, 1701722 (2018)
[8] Y-S. Kim *et al.*, *Nat. Mater.* **14**, 1002 (2015); K. Sano *et al.*, *Angew Chem. Int. Ed.* **57**, 12508 (2018).