Thin Solid Films 616 (2016) 482–501

Contents lists available at ScienceDirect

Thin Solid Films

journal homepage: www.elsevier.com/locate/tsf

Critical review

Atomically-thin layered films for device applications based upon 2D TMDC materials

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ARTICLE INFO

Available online 31 August 2016

Keywords:
Transition metal dichalcogenides
2D materials
MoS_2
TMDC

ABSTRACT

This review seeks to cover recent developments in research on 2D layered materials, specifically transition-metal dichalcogenides (TMDCs), from a thin film perspective. Based upon materials which have a long and fruitful history, these TMDCs may provide significant opportunities for device applications in their atomically thin form.

Contents

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http://dx.doi.org/10.1016/j.tsf.2016.08.068
0040-6090/

1. Introduction

A rejuvenation of interest in layered van der Waals "2D" materials, particularly for electronic and optoelectronic applications, has blossomed since their recent isolation as atomically-thin layers by exfoliation [1,2]. Among the most famous 2D materials is perhaps graphene, the semimetal single-layer carbon thin film, which has been extensively reviewed over the past decade and is not in the scope of this review [See, for example: [3–7]].

Among 2D materials beyond graphene [8–10], some exhibit semiconductor behavior, such as transition-metal dichalcogenides (TMDCs), and present useful bandgap properties for applications even at the single atomic layer level. Examples include "MX_2", where M = Mo, W, Sn, Hf, Zr and X = S, Se and Te [11]. Research on TMDC materials has an extensive and rich bibliography dating back 50 years or more. Reviews of the earlier work have been published by Yoffe and coworkers [12] and was the subject of a conference book series that extend well beyond TMDCs and continued through the 1990s (see Table 1).

Perhaps the most studied TMDC is MoS_2, which is relatively abundant as a mineral [13,14] and well known for tribological [15], petroleum desulfurization [16], and catalytic applications [17]. More recently, MoS_2 and other TMDCs have been under exploration for nanoelectronics [18,19]. The interest in such TMDCs comes from the prospect of exploiting the physics and electronic structure in monolayer and few-layer TMDC thin films in devices and device components, including *d*-orbital electron effects, improved electrostatic control for field-effects a dearth of surface dangling bonds (in principle), and the relative ease in producing atomically-thin layers "simply" by exfoliation [20].

Table 1
Layered materials conference series titles with book chapters covering layered materials research from 1976–2000.

Physics and chemistry of materials with low-dimension structures
(Previously published under the series title: physics and chemistry of materials with layered structures)

1. R.M.A. Lieth (Ed.): *Preparation and Crystal Growth of Materials with Layered Structures*. 1977
ISBN 90-277-0638-7
2. F. Levy (Ed.): *Crystallography and Crystal Chemistry of Materials with Layered Structures* 1976
ISBN 90-277-0586-0
3. TJ. Wieting and M. Schluter (eds.): *Electrons and Phonons in Layered Crystal Structures.*1979
ISBN 90-277-0897-5
4. P.A. Lee (Ed.): *Optical and Electrical Properties*. 1976
ISBN 90-277-0676-X
5. F. Hulliger: *Structural Chemistry of Layer-Type Phases*. Ed. by F. Levy. 1976
ISBN 90-277-0714-6
6. F. Levy (Ed.): *Intercalated Layered Materials*. 1979
ISBN 90-277-0967-X

Physics and chemistry of materials with low-dimensional structures series a: layered structures
7. V. Grasso (Ed.): *Electronic Structure and Electronic Transitions in Layered Materials*. 1986
ISBN 90-277-2102-5
8. K. Motizuki (ed.): *Structural Phase Transitions in Layered Transition Metal Compounds*. 1986
ISBN 90-277-2171-8
9. L.J. de Jongh (ed.): *Magnetic Properties of Layered Transition Metal Compounds*. 1990
ISBN 0-7923-0238-9
10. E. Doni, R. Girlanda, G. Pastori Parravicini and A. Quattropani (eds.): *Progress* in *Electron Properties of Solids.* Festschrift in Honour of Franco Bassani. 1989
ISBN 0-7923-0337-7
11. C. Schlenker (Ed.): *Low-Dimensional Electronic Properties of Molybdenum Bronzes and Oxides.* 1989 ISBN 0-7923-0085-8
12. Not published.
13. H. Aoki, M. Tsukada, M. Schluter and F. Levy (eds.): *New Horizons in Low-Dimensional Electron Systems.* A Festschrift in Honour of Professor H. Kamimura. 1992
ISBN 0-7923-1302-X
14. A. Aruchamy (Ed.): *Photoelectrochemistry and Photovoltaics of Layered Semiconductors.* 1992 ISBN 0-7923-1556-1
15. T. Butz (Ed.): *Nuclear Spectroscopy on Charge Density Wave Systems.* 1992
ISBN 0-7923-1779-3
16. G. Benedek (Ed.): *Surface Properties of Layered Structures.* 1992
ISBN 0-7923-1961-3
17. W. Muller-Warmuth and R. Schollhom (eds.): *Progress in Intercalation Research.* 1994
ISBN 0-7923-2357-2
18. L.J. de Jongh (Ed.): *Physics and Chemistry of Metal Cluster Compounds. Model Systems for Small Metal Particles*. I994
ISBN 0-7923-2715-2
19. E.Y. Andrei (Ed.): *Two-Dimensional Electron Systems. On Helium and other Cryogenic Substrates*. 1997 ISBN 0-7923-4738-2
20. A. Furrer: *Neutron Scattering in Layered Copper-Oxide Superconductors.* 1998
ISBN 0-7923-5226-2
21. R.B. Heimann, S.E. Evsyukov and L. Kavan (eds.): *Carbyne and Carbynoid Structures.* 1999
ISBN 0-7923-5323-4
22. F.W. Boswell and J.C. Bennett (eds.): *Advances in the Crystallographic and Microstructural Analysis of Charge Density Wave Modulated Crystals.* 1999
ISBN 0-7923-5604-7
23. W. Andreoni (Ed.): *The Physics of Fullerene-Based and Fullerene-Related Materials.* 2000
ISBN 0-7923-6234-9
24. H.P. Hughes and H.I. Stamberg (eds.): *Electron Spectroscopies Applied to Low-Dimensional Structures.* 2000
ISBN 0-7923-6526-7