



ISSN 2321-743X

International Journal of Research in
Engineering and Bioscience

Volume 7 Issue 1 (Pages 14- 22)

IJREB

Journal home page: www.ijreb.org

**A REVIEW ON THE APPLICATIONS OF TWO-DIMENSIONAL
NANOMATERIALS IN ENERGY STORAGE**

Aiswarya M¹, Dr B Bindhu ^{1*}

Noorul Islam Center for Higher Education, Kumaracoil, Thuckalay, Tamil Nadu, India

*Corresponding Author

Email address of Author(s): aishuvijayan7@gmail.com, bindhu.krishna80@gmail.com

ABSTRACT

This review upholds the identification of different 2D materials that are widely used nowadays. Their properties are discussed. The broad synthesis strategies to produce 2D materials are briefly introduced in this overview. The multiple synthesis methodologies are then thoroughly explained, being classified into two groups: bottom-up approaches and top-down procedures, and various characterization techniques are covered. The potential uses of 2D metal nanomaterials in catalysis, and electrochemical energy storage devices like lithium-ion batteries, sulphur-ion batteries, and supercapacitors are covered.

Keywords: - *nanomaterials, synthesis, characterization techniques, supercapacitors.*

INTRODUCTION

Nanotechnology refers to the building and engineering of a functional system at a very microscale or in atomic level as well as the study of manipulating matter on an atomic scale. Nanotechnology, a relatively recent field of study, has the potential to replace conventional micron technologies and produce valuable materials with size-dependent properties. Nanomaterials are products of nanotechnology that contain particles or compounds with dimensions close to the nanometer.

Nanomaterials are made up of single particles with a diameter of 1 to 100 nm, known as nanoparticles. Nanoparticles have frequently been used to create materials with distinctive features. [Tawfik A. Saleh, 2022]

Nanomaterials

Nanomaterials are substances created via nanotechnology that contain particles or compounds semiconductors, composite materials, and more. They can also include crystalline and quasi-crystalline elements. Nanomaterials can be produced purposefully, unintentionally, or naturally.

Classification of Nanomaterials

Substances smaller than 100 nm are referred to as nanomaterials. With no discernible difference between the longest and shortest axes, nanoparticles are nanomaterials with all three dimensions at the nanoscale.

Nanomaterials are arranged as: Zero-Dimensional Nanomaterials, One-Dimensional Nanomaterials, Two-Dimensional Nanomaterials, Three - Dimensional Nanomaterials.

Approaches for Making 2D Nanomaterials

Because of their stark differences between physical, chemical, electrical, and magnetic properties from larger dimensions and vary on their form and size, nanostructure materials have garnered a lot of attention. To create nanostructured materials with controlled shape, size, dimensionality, and structure, numerous approaches have been designed. Materials' qualities determine that how they perform. Chemical vapour deposition, mechanical exfoliation, and liquid exfoliation, and intercalation are the techniques that are used the most. [Vidushi Sharma,2020].

The synthesis of nanomaterials can be done in one of two ways, Top- down approach and Bottom–up approach.

a) Top -down approach

The mass substance is broken into nanostructured materials or fragments using a top-down approach.

b) Bottom-up approach

The methods used to create micro-sized particles have been extended to create top-down synthesis. Top-down strategies are easier to implement and concentrate on either the division or removal of bulk material or the minimization of bulk

production techniques to create the desired structure with the right characteristics. [Paul Chinonso Uzoma, 2019].

From the ground up, atom by atom, molecule by molecule, or group by group, a substance is built. This approach is known as a bottom-up approach

CHARACTERISTIC TECHNIQUES AND SYNTHESIS ROUTES

The key component of nanoscience and nanotechnology is the synthesis of nanomaterials and nanostructures. Only when nanostructured materials are made available with appropriate size, shape, morphology, crystal structure, and chemical composition are new physical properties and uses of nanoparticles possible. The unique optical, magnetic, electrical, mechanical, and chemical properties of nanostructures relative to bulk materials have increased interest in their synthesis. To create nanoparticles, a variety of technological methods and methodologies have been investigated.

Top-down approach

In a top-down method, the bulk material is broken down into nanoscale structures or particles. Top-down synthesis methods are an extension of those that have been utilised to create particles with a diameter of less than a micron. Top-down strategies rely on either the removal or division of bulk material or the downsizing of bulk manufacturing methods to create the desired structure with the right attributes. They are

intrinsically simpler. [Paul C. Uzoma, Huan Hu, 2020].

Mechanical Exfoliation

Mechanical exfoliation, often referred to as micromechanical cleavage, was initially described in 2004 as a productive method of generating atomically thin graphene. Scotch tape was used in this method to successfully separate single-layer graphene from tiny crystals of highly orientated pyrolytic graphite (HOPG). The mechanics entail applying a standard force to a piece of scotch tape that has been placed on the HOPG surface. The graphitic layer eventually thins out until it transforms into single-layer graphene from its parent layered bulk crystals by repeatedly applying this normal force. Additionally, the synthesis of additional 2D materials like TMDCs, h-BN, and NbSe₂ has made extensive use of this technique.

The mechanically cleaved ultrathin 2D materials are highly sought-after candidates for fundamental research into the fundamental physical, optical, and electronic properties of these materials as well as for use in high-performance electronic and optoelectronic devices like transistors and phototransistors. Although this technology is straightforward and practical, its lack of scalability arises from its poor output yield and slow production rate. [Namra Abid, 2021].

Nanolithography

Lithography is a practical method for creating nanoarchitectures with a concentrated electron or light beam. A strong method for creating nanoscale patterns with precisely regulated shape, size, and

spacing is nanolithography. It can be used to build precise 2D metal arrays on surfaces through a number of steps. By shrinking a predeposited "parent" layer with a concentrated electron beam, electron beam lithography (EBL), a typical branch of nanolithography, has been widely employed to create metal nanostructures.

Bottom-up approach

The term "bottom-up approach" describes the process of creating a substance atom by atom, molecule by molecule, or cluster by cluster.

Chemical Vapor Deposition (CVD)

The technology of chemical vapor deposition (CVD), which can produce high-quality mono- or few-layer 2D materials on a massive scale, is seen to be the most promising. In the CVD technique for the synthesis of graphene, carbonaceous gaseous species react at high temperatures (900–1100 °C) in the presence of metal thin films or foils, leading to the disintegration of the carbon species and the production of the graphene lattice. Precursor, metal's carbon solubility limit, lattice characteristics, crystal structure, system pressure, and temperature are some of the variables that affect how much graphene grows on a metal catalyst. These parameters can be changed to provide controlled growth of graphene with tunable lateral dimension, crystallinity, and number of layers. [Ye Chen.2017].

Physical Vapor Deposition (PVD)

Ultra-thin films and surface coatings can be created using the physical vapour deposition (PVD) technology. It is utilised to create metal vapour that

can be used to apply alloy coatings and ultra-thin films on the conductive layer. To create thin films, the PVD technique uses sputtering and evaporation. Sputtering is a carryover process that occurs in the vapour phase under supersaturation as part of the PVD process. The metal vapours are allowed to condense in an inert atmosphere, and they are then heated to create nanocomposites. It is a common process for film growth, which can avoid the complex interaction in growth parameters involved in the CVD process. [Ye Chen.2017].

Characterization Techniques of Nanomaterials

The study of composition, structure, and additional attributes like physical, chemical, electrical, and magnetic properties is referred to as characterization. There are numerous methods for characterising nanomaterials, however each method has some level of uncertainty. X-ray diffraction (XRD), SEM, EDX, TEM, DC-conductivity, Particle Size Analyzer (PSA), UV-visible Spectroscopy, and Thermo Gravimetric Analysis/Differential Thermal Analyzer (TG/DTA) are the techniques used to study the nanoparticles. Combining several characterization techniques is extremely desirable to understand the many structural aspects and properties of as-synthesized 2D nanomaterials because each methodology has its own advantages and limits.

APPLICATION OF TWO-DIMENSIONAL MATERIALS

Numerous consumer products, including sporting goods, windows, cars, etc., use nanocoatings and

nanocomposites. Glass bottles are being coated with a nanocoating that absorbs UV rays to protect beverages from sun damage. Tennis balls that survive longer are made using nano-clay composites. In dental fillings, nanoscale silica is employed as a filler.

In order to create optical detectors, sensors, lasers, displays, and solar cells, nanomaterials' optical characteristics are exploited. Both photoelectrochemistry and biomedicine utilise this characteristic. The electrodes of microbial fuel cells are comprised of carbon nanotubes. The resolution of the pixels in High Definition TV sets and personal computers is increased by using nanocrystalline zinc selenide in the display displays.

In order to create junctionless transistors, nanowires are used. Additionally, in order to react with harmful gases like carbon monoxide and nitrogen oxide and stop them from polluting the environment, nanomaterials are utilised as catalysts in power generating systems and catalytic converters for automobiles. Nano-TiO₂ is used in sunscreen formulations to raise the sun protection factor (SPF). The sensors are given a highly active surface using tailored nanolayers.

To cure cancerous cells like melanoma, fullerenes are employed. As light-activated antibacterial agents, they have also been employed. Quantum dots, nanowires, and nanorods have become popular in optoelectronics due to their optical and electrical characteristics. For use in tissue

engineering, drug delivery, and biosensors, nanomaterials are now being investigated.

Applications in 2D nanomaterials

2D nanomaterials are regarded to be the thinnest nanomaterials due to their thickness and dimensions on the macro- and nanoscale. These nanomaterials are layered, with strong in-plane bonding and weak van der Waals (vdW) between layers. These nanosheets are commonly composed of several layers, despite the fact that a single layer is the ideal state (less than ten layers). 2D nanomaterials like graphene, hexagonal boron nitride (hBN), and metal dichalcogenides (MX₂) have drawn a lot of attention recently due to their favourable properties and diverse applications in the fields of electronics, optoelectronics, catalysts, energy storage facilities, sensors, solar cells, lithium batteries, composites, etc. [Jiangwei Ju,2018].

Application in Energy Storage

To meet the rising demand for energy, it is crucial to create new functional nanomaterials for energy storage. Portable electronic devices, computers, and electric cars can all be powered by lithium-ion batteries (LIBs), which are a promising electrochemical technology. Supercapacitors, on the other hand, are important energy storage technologies because of their better cycle life, high specific capacitance, high power density, rapid charging and discharging rate, and extremely low internal discharge. In order to create supercapacitors with improved electrochemical performance, 2D nanomaterials such as graphene,

graphene-like materials, such as MXenes, and transition-metal dichalcogenide (TMDs) have been explored. Electrochemical super capacitors based on graphene have demonstrated high energy, better powder densities, and greater Li-storage capacity. These results are due to the 'Li + ion intercalation technique' capacity to accommodate many Li + ions while enhancing electronic conductivity and increasing the specific surface area of ultrathin materials. Graphene sheets are highly sought-after for energy storage applications due to their exceptionally large theoretical surface area of 2630 m² g⁻¹. These unique characteristics of graphene serve as the core building blocks for excellent electrochemical energy storage and conversion devices.

Batteries

Because of their outstanding electrochemical properties and apparent high surface-to-volume ratio, layered materials are another exciting option for electrodes to be used in batteries. A notable improvement has been realised using GAs in lithium-ion batteries (LIBs), sodium-ion batteries (SIBs), lithium-sulphur batteries (Li-S), and other types of batteries. [Xiaoyan Zhang ,2016].

Catalysis

A pioneering use of nanoparticles is in catalysis. Numerous substances and components, including aluminium, iron, titanium dioxide, clays, and silica, have all been utilised as nanoscale catalysts for a long time. The high activity, selectivity, and productivity of nanocatalysis have made it a burgeoning scientific field in recent years. Small

metal nanoparticles with a size between 1 and 10 nm show exceptional catalytic activity, sometimes even exceeding the related metal complexes. Numerous significant features, such as the high surface-to-volume ratio, the surface geometric effect, the electronic impact, and the quantum size effect, are thought to be responsible for the high activity of nanocatalysts.

DISCUSSION

Andrew Mcnamara et al (2014), prepared exfoliated hexagonal boron nitride-based polymer nanocomposite that enhanced the thermal conductivity for electronic encapsulation. They exhibited the improved thermal conductivity of their epoxy composite and created h-BN nanosheets by liquid exfoliating bulk h-BN flakes. Additionally, they discover that even at low filler loadings, utilizing h-BN nanosheets significantly improves thermal conductivity.

JianxinGeng, Shang Chen and Xin Chen (2020), studied the development of Two dimensional nanomaterials in the application of energy storage. They viewed the opportunities for meeting the demand for clean and sustainable energy exist with the use of two-dimensional (2D) nanomaterials and their composites as electrode materials for modern energy storage systems like supercapacitors and rechargeable batteries.

Qingye Li et al (2020), studied on the mass production of high thermal conductivity of Boron nitride/ nanofibrillated cellulose composite membranes. The usage of boron nitride nanoplates is extremely advantageous for thermal

management applications (BNNPs). The mechanical and thermal properties as well as their microstructured membranes can be adjusted by adjusting the refining time and pan gaps. The resulting membranes showed amazing mechanical properties and hold a lot of promise for the future development of portable electronics, boasting a tensile strength of 74.6 MPa and the highest thermal conductivity of 20.64 W m⁻¹ K⁻¹.

Jie Bao et al (2016), studied the synthesis and application of two-dimensional hexagonal boron nitride in electronics manufacturing. Hexagonal Boron Nitride has a great chemical stability and it is electrically insulating. It is considered that h-BN has been a favourable material for the applications in gate dielectrics for graphene transistors and interconnects and in electronic packaging insulators. In specific, this review was focused on the applications of manufacturing electronic devices with electrically insulating and with thermal properties of hBN can be potentially utilized.

Wei Lui et al (2019), studied the fabrication of the two-dimensional nanomaterial based polymer composites and their applications in energy storage systems. It has been investigated to improve the electrical, thermal, corrosion-resistance, and wear-resistance properties of polymers by adding nanoparticles to polymer matrices. The performance of the electrochemical reaction on the supercapacitor is improved and driven by the conducting 2D-based polymer composites' large quantity of surface area and multiple active sites. The porous character of both 2D materials and

polymers makes them suitable for use as battery separators. This boosts the batteries' coulombic efficiency by preventing all ions other than Li⁺ from passing through the separator.

Beatriz Mendoza-Sanchez and Yury Gogotsi et al (2016), studied on the Synthesis of Two-Dimensional Materials for Capacitive Energy Storage. Two-dimensional (2D) nanomaterials are very desirable for energy storage applications due to their distinctive characteristics and wide variety. They found out the advancements made in the use of 2D nanomaterials for capacitive energy storage.

Mehdi Salehirad et al (2017), studied the synthesized and characterized exfoliated polystyrene grafted hexagonal boron nitride nanosheets and demonstrated their potential applications in heat transfer nanofluids. The exfoliation of the h-BN layered structure into a few layer sheets was encouraged by the functionalization, and the thickness of the sheets was influenced by the method of modification and the amount of polymer grafted onto nanosheets. Investigations were also conducted into the nanofluid's physical and electrical characteristics.

Jianxiao Nan, Xin Guo et al (2019), studied the Two dimensional MXene-Based materials for energy storage applications. The unusual physical/chemical characteristics of 2D MXene-based nanomaterials and their numerous applications in energy storage, catalysis, electronics, optoelectronics, and photonics. They examined the most recent findings and advancements in the field of 2D MXene-based

nanostructures and concentrated on their preparation techniques, characteristics, and potential uses in energy storage devices like lithium-ion batteries, sodium-ion batteries, lithium-sulfur batteries, and supercapacitors.

Fengmei Guo et al (2020), studied on high thermally conductive dielectric nanocomposites with synergistic alignments of graphene and boron nitride nanosheets. Electrically insulating polymer dielectrics having high energy densities and with great thermal conductivities showed great potential for dielectric energy storage. In polyimide (PI) composites, reduced graphene oxide (rGO) and boron nitride nanosheets (BNNS) were mechanically assembled into a well-aligned micro-sandwich structure. Moreover, the micro-sandwich nanocomposite came over the PI film with a tremendously high dielectric constant of ≈ 579 with high energy density and with a great thermal conductivity at a low hybrid filler having only 2.5vol%.

Jin chen et al (2018), fabricated and studied the highly thermally conductive still electrically insulating polymer/boron nitride nanosheets nanocomposites films for improved thermal management capability. Polymer composites' increased heat conductivity came at the expense of their lightweight, flexibility, and electrical insulation. The improved polymer nanocomposites in this study have aligned boron nitride nanosheets (BNNSs), which dramatically enhanced heat conductivity while also providing excellent electrical insulation and exceptional flexibility. These nanocomposites films can be created by

electrospinning nanofibers made of polymer and BNNSs, pressing them repeatedly, and folding them vertically.

SUMMARY AND CONCLUSION

This present study deals with the application of Two-dimensional nanomaterials in the field of energy storage. The 2D nanomaterials can be synthesized using both top-down approach including mechanical exfoliation and bottom-up approach including chemical vapor deposition method and physical vapor deposition method. Several characterization techniques is extremely desirable to understand the many structural aspects and properties of synthesized 2D nanomaterials because each methodology has its own advantages and limits. Two-dimensional nanomaterials can be used as electrode materials in energy storage devices such as supercapacitors and in rechargeable batteries for energy storage are described effectively.

REFERENCE

1. Tawfik A. Saleh, Elsevier BV "Properties of nanoadsorbents and adsorption mechanisms" 2022
2. M.A Shah and Tokeer Ahmed, "Principles of Nanosciences and Nanotechnology", Narosa Publishing House Pvt. Ltd. 2010.
3. Zahra Rafiei-Sarmazdeh, Seyed Morteza Zahedi-Dizaji and Aniseh Kafi Kang, "Two-Dimensional Nanomaterials", 2019.

4. Kavintheran Thambiratnam, Harith Ahmad, "Application of two-dimensional materials in fiber laser systems in Nano-Optics", 2020
5. Alagarasi, Introduction to nanomaterials, (2011), 424-428
6. Vidushi Sharma, Dibakar Datta, "Synthesis, Modeling, and Characterization of 2D Materials, and Their Heterostructures", 2020.
7. Liu, Bo , Zhou, Kun , "Recent progress on graphene-analogous 2D nanomaterials: Properties, modeling and applications.", Journal, Progress in Materials Science 2019 / 02 Vol. 100
8. Paul C. Uzoma, Huan Hu, Mahdi Khadem and Oleksiy V. Penkov, " Tribiology of 2D materials , A Review" 2020 , 10(9), 897.
9. Sen, Mousumi, "Nanocomposite Materials", Journal, Nanotechnology and the Environment. (2020) 10.5772/intechopen. 87903.
10. Ye Chen, Zhanxi Fan, Zhicheng Zhang, Wenxin Niu, Cuiling Li, Nailiang Yang, Bo Chen, and Hua Zhang " Two-Dimensional Metal Nanomaterials: Synthesis, Properties, and Applications" , 2D Materials Chemistry, ACS Publications, 2017
11. Namra Abid, Aqib Muhammad Khan, Sara Shujait, Kainat Chaudhary et al. "Synthesis of nanomaterials using various top-down and bottom-up approaches, influencing factors, advantages, and disadvantages: A review", Advances in Colloid and Interface Science, 2021
12. Chaoliang Tan, Xiehong Cao, Xue-Jun Wu, Qiyuan He et al. "Recent Advances in Ultrathin Two-Dimensional Nanomaterials", Chemical Reviews, 2017