A Review on Advancements in Supercapacitor Technologies Materials, Methods, Applications and Future Perspectives

Chandramauli Sati[1], Paarth Benjwal[2], Ujjwal Ruhela[3]
[1]*Sixth Semester 22-PH-13, Doon University*
[2]*Sixth Semester 22-PH-11, Doon University*
[3]*Sixth Semester 22-PH-20, Doon University*

Abstract—**The constant observation of novel electrode materials, synthesis pathways, and structural advancements has fueled the quick development of supercapacitor technology. An overview of recent advancements in supercapacitor materials is given in this review, with particular attention paid to borophene, ZnO, TiO_2, lanthanum telluride (La_2Te_3), MoS_2-graphene composites, and transition metal dichalcogenides (TMDs). We investigate their synthesis techniques, electrochemical characteristics, and hybridization strategies to increase specific capacitance, energy density, and cycling stability. We also discuss novel trendsin supercapacitor engineering, such as aqueous hybrid electrochemical capacitors (ACPECs) with up to 1000 V operation voltage, activated carbon electrodes for electrochemical CO_2 capture, and structural fatigue evaluations of enclosures for high-vibration conditions in rail transportation. Additionally, this review emphasizes the increasing importance of micro supercapacitors (MSCs) for future miniaturized energy storage.**

Recent breakthroughs like ultrafast laser-based maskless fabrication, entropy-driven glass forming liquid electrolytes for high-temperature applications, and integration with anticoagulant functionality for bio applications are elaborated upon here. Phase engineering (1T vs. 2H), the incorporation of MoS_2 and WS_2 with conductive carbon scaffolds, and thin-film enhancements in La_2Te_3 underscore the evolving nature of supercapacitor research. This research identifies key obstacles and opportunities in the development of scalable, high- performance, and environmentally friendly supercapacitor technologies by integrating these diverse innovations.

Index Terms—**Borophene, ZnO, TiO_2 , La_2Te_3 , MoS_2 -graphene, TMDs**

I. INTRODUCTION

The increasing demand for energy storage systems has led to the exploration of new and advanced materials, including molybdenum disulfide (MoS_2). Besides graphene, MoS_2 is a highly intriguing two-dimensional material exhibiting remarkable electrochemical and thermal properties. Supercapacitors can benefit significantly in terms of conductivity and longevity when these materials are combined, as demonstrated by recent research. This review outlines recent advances and key findings in the development of material combinations such as MoS_2 with graphene, La_2Te_3, and new two-dimensional materials like borophene. Typically, supercapacitors utilize both batteries and standard capacitors in hybrid power storage systems.

They serve unique functions such as:

- Instant power delivery
- Fast charging
- Extended lifespan

However, supercapacitors also face limitations: lower energy retention compared to batteries and material degradation over time. MoS_2 and graphene-based modifications are crucial to address these challenges. Researchers are employing these materials as supercapacitor electrodes to enhance energy storage capacity and extend device lifespan.
In addition, La_2Te_3 has emerged as a promising

material to improve the efficiency and durability of supercapacitor devices. While batteries generally offer greater energy storage, they often suffer from slower charging speeds and reduced longevity. In contrast, supercapacitors are capable of rapid energy discharge, making them ideal for applications in electric vehicles, renewable energy systems, medical devices, and transportation.

Despite recent advancements, the need for improved electrical storage technologies that can rival or exceed battery performance remains. This article highlights significant progress made through the use of MoS_2-graphene hybrids, La_2Te_3, and other advanced electrodes. Borophene, known for its high conductivity, is another highly efficient material contributing to next-generation supercapacitor technologies.

II. NOTABLE ADVANCEMENTS

- High-efficiency aqueous hybrid electrochemical capacitors (ACPECs) capable of operating in high-temperature and high-humidity environments.
- Supercapacitors combining high energy density and superior filtering performance at low voltages.
- CO_2 Super capacitive Swing Adsorption (SSA) for carbon capture and energy saving, offering environmental benefits.
- Structural fatigue analysis of supercapacitor enclosures to ensure durability in harsh environments, such as railway systems.
- Miniaturization through the development of micro supercapacitors (MSCs) with
  - High energy delivery
  - Fast charge-discharge rates
  - Long operational lifetimes

III. EMERGING SOLUTIONS

- Ultrafast laser-based techniques for rapid supercapacitor structure fabrication.
- Entropy-stabilized liquid electrolytes capable of withstanding extreme heat conditions.
- Biomedical integration of supercapacitors with anticoagulant properties for safe and effective medical applications.

By drawing on insights from diverse research domains, this review provides a comprehensive overview of the chemical, environmental, and structural dimensions of supercapacitor technology. It identifies critical challenges and proposes future research directions to enhance manufacturing efficiency and promote sustainability in energy storage systems.

IV. ENERGY STORAGE MECHANISMS

Electrochemical Double Layer Capacitance (EDLC)
The charge in electrochemical double layer capacitors (EDLCs) is stored through an electrostatic bond at the interface between the electrode and the electrolyte. This process does not involve charge transfer across the interface and is primarily dependent on the surface area of the electrode material. Common materials used include high-surface-area substances such as graphene and activated carbon.

Pseudo capacitance
In pseudo capacitors, charge storage occurs through fast and reversible faradaic (redox) reactions. These reactions take place at or near the surface of the electrode materials.
Conducting polymers and transition metal oxides, such as manganese dioxide (MnO_2) and molybdenum disulfide (MoS_2), are typical materials that exhibit pseudocapacitive behavior.

Hybrid Capacitance
Hybrid supercapacitors combine the mechanisms of both EDLCs and pseudo capacitors, incorporating electrostatic charge storage with faradaic redox reactions. This hybrid approach allows for improved energy and power density performance compared to systems that rely solely on either EDLC or pseudo capacitance mechanisms. Hybrid capacitors often utilize a combination of carbon-based materials and metal oxides to achieve these properties.

V. SUPERCAPACITOR TECHNOLOGIES MATERIALS AND SYNTHESIS

As consumers shift their focus to affordable and dependable energy sources, supercapacitors have emerged as a promising solution. They are characterized by long operational lifespans, high power density, and rapid charge-discharge cycles. To enhance their efficiency and overall performance, researchers are actively experimenting with a variety of electrode materials, including molybdenum disulfide (MoS_2), lanthanum telluride (La_2Te_3), borophene, and different metal oxides. These materials, with their unique electrochemical properties, significantly improve the performance characteristics of supercapacitors.

VI. TYPES OF SUPERCAPACITORS

Supercapacitors are a class of energy storage devices known for their fast-charging capabilities and high-power density.

They are generally classified into three main categories:

- Electric Double Layer Capacitors (EDLCs): These utilize carbon-based electrodes to store energy through electrostatic charge accumulation at the electrode electrolyte interface, without involving faradaic reactions.

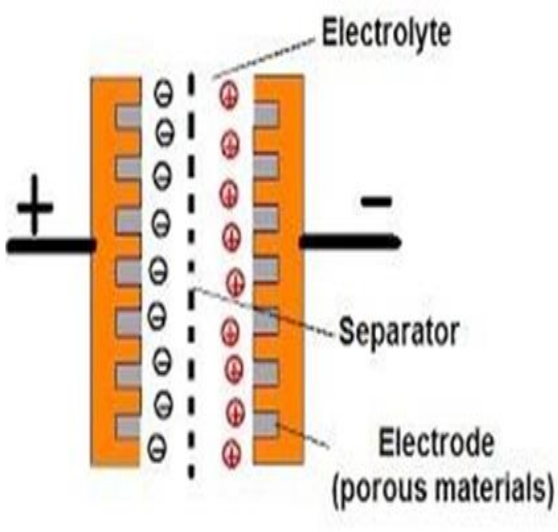

Fig1: Electric Double Layer Capacitor

- Pseudo capacitors: These supercapacitors store charge through fast and reversible faradaic (redox) reactions, typically using conducting polymers and transition metal oxides, such as MnO_2 and MoS_2.

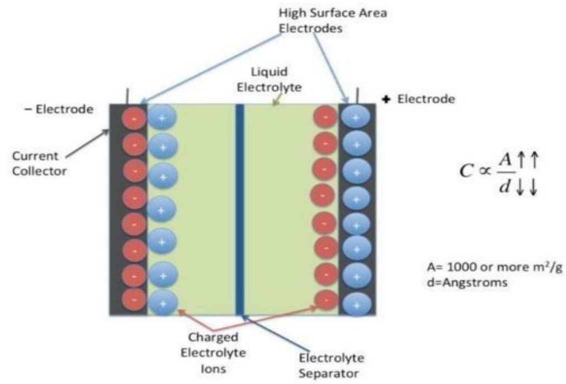

Fig2: Pseudo capacitor

- Hybrid Supercapacitors: These combine the features of EDLCs and pseudo capacitors, integrating both electrostatic and faradaic mechanisms. The hybrid approach results in improved energy and power density compared to either system alone.

.

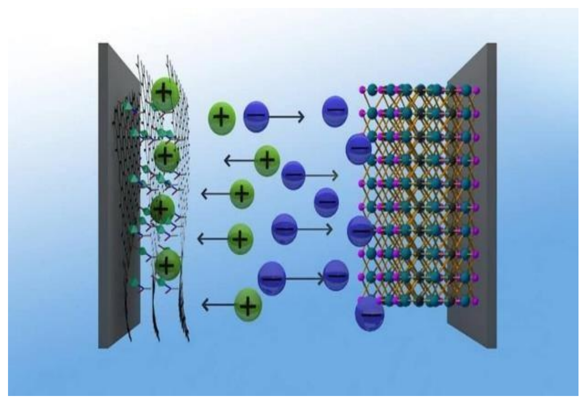

Fig3: Hybrid Supercapacitor Prominently used electrode materials in supercapacitors

Graphene

Graphene can be identified as a monolayer of carbon atoms arranged in a honeycomb lattice. It is often fabricated on substrates such as silicon dioxide (SiO_2), though the compound itself does not inherently contain alternating SiO_2 bonds.

For supercapacitor applications, graphene offers several advantageous properties:

- Relatively low electrical conductivity (approximately 106 S/m)
- Superior mechanical strength
- Substantial electrochemical stability
- Large specific surface area

These characteristics make graphene an ideal electrode material. At the interface between the electrode and the electrolyte, these properties facilitate rapid electron transport and enable significant charge accumulation, enhancing the performance of supercapacitor devices.

MoS_2-Graphene Composites

MoS_2 particles or nanosheets can be intercalated between graphene layers or attached to the graphene surface to form a hybrid composite. Various synthesis methods have been developed
to create this combination, including:

- Chemical Vapor Deposition (CVD)
- Solvothermal processes
- Liquid phase exfoliation and assembly
- Hydrothermal techniques.

Key Functional Attributes

- Electrical Conductivity: Graphene compensates for the poor conductivity of MoS_2 by facilitating rapid electron transport, thereby improving the overall efficiency of supercapacitors and batteries.
- Mechanical Strength: The incorporation of graphene enhances both flexibility and mechanical strength, making the composite suitable for flexible electronic devices.
- Electrochemical Performance: MoS_2 provides active electrochemical sites and a high specific surface area, while graphene helps retain structural integrity and conductivity during cyclic operations in energy storage systems.
- Synergistic Effects: The heterostructure formed between MoS_2 and graphene creates advantageous charge-transfer interfaces. These synergistic effects improve the performance of lithium and sodium-ion batteries, and contribute to applications in:
  - Supercapacitors
  - Hydrogen Evolution Reaction (HER) catalysis
  - Photodetectors
  - Transistors.

La_2Te_3

Crystal Structure

- Crystal System: Orthorhombic or cubic, depending on synthesis conditions and stoichiometry.
- Common Structure Type: Rare-earth sesquichalcogenides such as La_2Te_3 often crystallize in a defect NaCl-type structure.
- Space Group: Often I4/mmm (tetragonal) or C2/m (monoclinic), based on the degree of ordering and synthesis temperature.
- Layered Structure: Features alternating layers of La and Te atoms. The Te sublattice exhibits partial vacancies, leading to a defect rock-salt-type arrangement.

Electronic Properties

- Semi metallic or Narrow Bandgap Semiconductor: The electronic band structure is highly sensitive to stoichiometric variations and intrinsic defects.
- Fermi Level Tuning: Can be modulated via doping strategies or intrinsic defect engineering.
- Carrier Type: Typically, p-type due to Te vacancies, but can be engineered toward ntype with appropriate doping.

Thermoelectric Properties

- High-Temperature Performance: La_2Te_3 has been extensively studied for thermoelectric applications at elevated temperatures.
- Seebeck Coefficient: High values are observed, aided by defect-induced phonon scattering.
- Thermal Conductivity: Low, due to intrinsic lattice disorder and Te vacancies.
- Power Factor: Moderate, but significantly enhanced with doping (e.g., Ce, Yb, Sb).
- Figure of Merit (ZT): Ranges between 0.5 and 1.2 depending on doping level and operating temperature (600–1000 K).

Mechanical and Thermal Properties

- Thermal Conductivity: Low, approximately 1–2 W/m K, due to the presence of lattice imperfections.
- Melting Point: Moderate, ranging from 1300 to 1500 K.

- Thermal Stability: Stable in inert or reducing atmospheres; susceptible to oxidation when exposed to air at elevated temperatures.

WS_2-Graphene

The unique characteristics of both materials. The atom-thick layer of sp^2 hybridized carbon atoms known as graphene is well known for its high carrier mobility, mechanical strength, and exceptional electrical conductivity. WS_2 is a transition metal dichalcogenide (TMD) that is

valuable for optoelectronic and spintronic devices because of its strong spin–orbit coupling and direct band gap in its monolayer structure. When graphene and WS_2 are combined, synergistic effects improve charge transfer, structural stability, and optical characteristics, enhancing the van der Waals heterostructure of the resultant material. Important elements that affect the hybrid material's performance and electronic band structure are stacking order, interlayer coupling, and interface quality.

Structural Features:

- Lattice Structure: Graphene has a hexagonal lattice with a lattice parameter of

2.46 Å, whereas WS2 possesses an analogous hexagonal lattice with a lattice parameter of 3.15 Å. The mismatch will impact the creation of moiré's patterns and strain effects within the interface.

- Interlayer spacing: The standard spacing between layers of graphene and WS_2 within a heterostructure is typically in the range of 3.3–3.6 Å, ruled by weak van der Waals forces.
- Stacking orientation: Various twist angles between the layers can adjust electronic features like band alignment and excitonic behavior.

Quantum Properties:

- Electronic structure: WS_2–graphene heterostructures tend to show type-I or type-II band alignment, allowing for effective charge separation, particularly in photoactive devices.
- Optical properties: The Photoluminescence (PL) of WS_2 is suppressed upon contact with graphene as a result of charge transfer, which could be utilized in photodetectors or sensors.
- Mechanical stability: The heterostructure inherits high mechanical strength and increased flexibility, making it appropriate for flexible electronics.
- Thermal and electrical conductivity: Graphene increases the total electrical and thermal conductivity of the heterostructure, useful for energy storage and thermal dissipation.

TiO_2 Nanotubes

Usually created by anodic oxidizing titanium metal in electrolytes containing fluoride, titanium dioxide (TiO_2) nanotubes are one-dimensional nanostructures distinguished by their high aspect ratio. They are made up of vertically aligned, self-organizing tubes that have the following structural characteristics

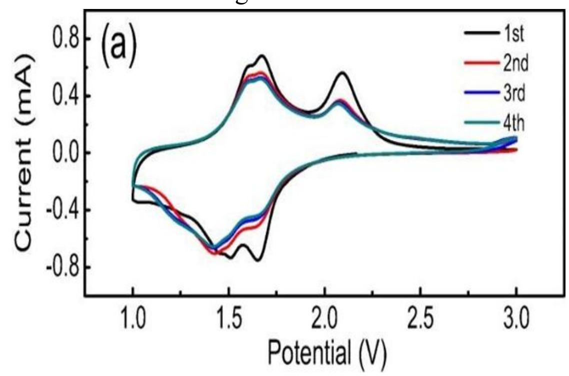

Fig4: C v/s V Curve of TiO_2

- Morphology: Hollow cylindrical tubes that can be several micrometers long and have diameters between 10 and 200 nm.
- Wall thickness: Depending on the synthesis settings, it is usually between 10 and 30 nm. Crystal phases: Nanotubes that have been anodized are amorphous. Depending on the temperature, they can anneal into rutile, anatase, or a combination of the two (rutile usually forms above 600 C, whereas anatase usually develops below 500 C).
- Layered architecture: Multiwalled or double-layered tube structures are produced under specific synthesis conditions.

Properties

TiO_2 nanotubes have several special chemicals, physical, and electrochemical characteristics. Large surface area: Perfect for energy storage, sensing, and catalytic applications.

- Behavior of semiconductors: They have band gaps of about 3.2 eV and 3.0 eV, respectively, which are appropriate for absorbing UV radiation. High photocatalytic efficiency, particularly during the anatase phase, characterizes photocatalytic activity.
- Biocompatibility: Fit for biomedical uses such as implants or medication delivery.
- Properties of electrochemistry: Outstanding ion movement and rapid charge/discharge rates. utilized as supercapacitor and battery electrode materials. Good substrate adherence and structural integrity under stress are examples of mechanical stability.

Borophene

Borophene, a two-dimensional (2D) allotrope of boron, has been widely researched due to its unique geometrical configurations and extraordinary physical properties. Recent studies focus on its synthesis, structural variations, and potential applications in fields like energy storage, electronics, and sensing technologies.

Structural Properties of Borophene

Unlike the hexagonal lattice structure of graphene, borophene exhibits polymorphic structures such as β_{12}, χ_3, and δ_6 phases. These unique configurations arise due to the electron deficiency in boron atoms, which allows a variety of bonding types. Borophene lattices have been successfully stabilized on several metal substrates, including Ag (110), Ag (100), Au (111), Ir(111), Al (111), and Cu (111), where these structures are commonly synthesized.

Mechanical Properties

Borophene is known for its excellent tensile flexibility and mechanical anisotropy. Although its inplane elasticity is comparable to graphene, it exhibits direction-dependent mechanical behavior. Upon hydrogenation, borophene transforms into borophane, which features structural buckling. This leads to remarkable mechanical characteristics, such as a nearly zero Poisson's ratio and extremely low bending stiffness, making it a highly flexible material.

Electronic Properties

In its pristine form, borophene acts as a metallic conductor. However, appropriate chemical modifications can significantly alter its electronic structure. For instance, hydrogenation of δ6-borophene results in a transition from metallic to a Dirac-like band structure. Additionally, some borophane polymorphs exhibit semi metallic behavior with Dirac nodal lines, making them suitable candidates for future topological electronic applications.

Optical and Thermal Properties

Borophene has strong optical anisotropy in the regions of visible and near-infrared light, which makes it a good choice for optoelectronic applications. Moreover, its thermal conductivity is exceptional and can be a good specifier for thermal management, generally in nanoelectronics. It is a definite expected hot topic in the field of future electronics, specifically, nanoelectronics, which will get smaller and smaller.

Material	Capacitance (F/g)	Energy Density (Wh/g)	Cycle Stability (%)
Graphene	150-300	10-15	95 (5000 cycles)
MoS_2-Graphene	600	35-40	90 (5000 cycles)
La_2Te_3	194	60	82 (1000 cycles)
WS_2-Graphene	383.6	30-50	100 (long cycle)
TiO_2	900	-	High mechanical stability

Table 1: Electrochemical performance of key electrode materials

Borophene as Novel Electrode

Borophene is a 2D version of boron and has remarkably come to the fore as an electrode material for energy storage applications owing to its outstanding electrical conductivity, high surface area, and mechanical robustness. Thus, it is particularly well-suited as anode material for lithium-ion (Li-ion) and sodium ion (Na-ion) batteries. First-principles calculations have revealed that borophene has impressive theoretical capacities, which can reach up to 1984 mAh/g for Li-ion batteries and 1240 mAh/g for Na-ion batteries, making the battery performance way better than the case of conventional graphite anodes (372 mAh/g). It is also a matter of fact that the material exhibits extremely fast ion diffusion capacities with energy barriers as low as 2.6 meV for lithium ions and 30 meV for sodium ions, thus enabling quick charge/discharge cycles.

Besides battery applications, it was revealed that borophene has potential in electrocatalysis. For example, it was disclosed that palladium-decorated borophene displays enhanced electrocatalytic activity in direct methanol fuel cells and leads to electric currents up to four times higher than those offered by palladium nanoparticles alone. Furthermore, borophene- based composites have found a use in biosensors, such as nickel phthalocyanine–borophene nanomaterials, which have been proven to have much higher performance in terms of electrical conductivity and analytical sensitivity for glucose detection.

VII. SYNTHESIS TECHNIQUES

Graphene

A wide range of methods have been developed for manufacturing graphene that is appropriate for use in supercapacitors:

- CVD, or chemical vapor deposition: On metal substrates, CVD yields high- quality, few-layer graphene. It is not appropriate for large-scale production, though, and it is costly.
- Graphene Oxide Reduction (rGO): The Hummer's method is capable of synthesizing graphene oxide (GO), which can then be reduced chemically, thermally, or electrochemically to yield rGO. Although this process is scalable, it frequently produces graphene that is flawed and has reduced conductivity.
- Techniques for Exfoliation: Although yield and quality may differ, producing graphene flakes from graphite through mechanical or liquid-phase exfoliation is a reasonably easy process.

MoS_2-Graphene

The combination of MoS_2-graphene composites has resulted in major attention due to their resultant synergistic properties, which are so useful in energy storage, catalysis, and sensing fields. A very interesting procedure includes the hydrothermal method in which ammonium molybdate tetrahydrate, graphene oxide (GO), and thioacetamide are used as precursors. This approach results in the petallike MoS_2 nanostructures with ultrathin layers (around 1-10 layers)

being present on the graphene surface. The process is a way to successfully produce both 1T and 2H phases of MoS_2 material, which are well-known for the improvement of electrical conductivity and catalytic activity. One more process that is easy to employ is the liquid-phase shear exfoliation, the principle of which is based on the combination of high-shear mixing and ultrasonication in deionized water without 14 additives. This method allows the exfoliation of large MoS_2 and graphite to nanosheets, giving the coexistence of MoS_2 and graphene in the heterostructure. The change of such parameters as shearing speed, time, and the MoS_2-to-graphite ratio directly affects the newly formed products and is essential in creating first-grade composites.

The materials, which thus obtained, possess higher electrochemical properties that are in line with sensor applications. All these ways used for the synthesis demonstrate that MoS_2– graphene composites are greatly flexible and promising in various technological applications.

La_2Te_3

Lanthanum telluride (La_2Te_3) thin films were fabricated via the process of successive ionic layer adsorption and reaction (SILAR). The method includes the dipping of a substrate in La^{3+} and Te^{2-} ions solutions, which are alternatively used to initiate the layer-by-layer deposition. As a result, La_2Te_3 thin films are formed, which exhibit plenty of hydrophilic features and are formed by the leaf-like flaky arrays that are connected. The structural and morphological features of the films were confirmed using analytical methods such as X-ray diffraction (XRD), Fourier-transform infrared spectroscopy

(FTIR), and field emission scanning electron microscopy (FE-SEM).

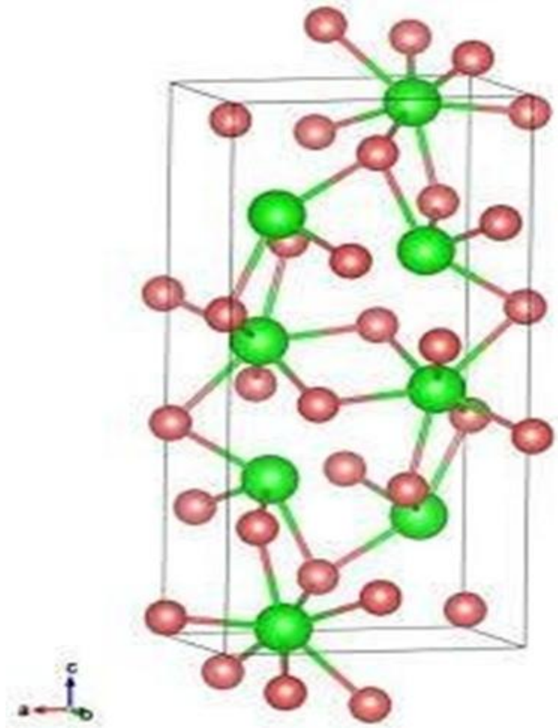

Fig5: La_2Te_3

It was found that the specific surface area of the synthesized La_2Te_3 from the Brunauer– Emmett–Teller (BET) method is 51 m2 /g. Based on the results of electrochemical tests, it is quite clear that the films produced have the characteristics of a supercapacitor, the energy storage applications of which are highly promising.

WS_2-Graphene Heterostructures:

Heterostructures WS_2-graphene are made with different techniques, each of them with special benefits. One of them is the sulfurization of WO_{3-x} thin films that are deposited on epitaxial graphene on a SiC substrate. A temperature as low as 700 C enables the growth of WS_2; that is 2 times lower than that of the conventional CVD process. To be specific, CVD can be an aid
to produce monolayer WS2 directly on the CVD graphene layer that is then transferred to SiO2/Si substrates. Here, the precursors are WO_3 and sulfur powders, and they are used for the growth reaction at about 900 C with suitable controls.

Hydrothermal synthesis is the third way in which WS_2 nanoparticles grow interlinked with graphene sheets and form heterojunctions, which will be very suitable for dye-sensitized solar cells. All these methods represent different ways to the preparation of WS_2–graphene structures that are modified to meet the required properties for different technological applications.

TiO_2 Nanotubes:

Titanium dioxide (TiO_2) nanotube materials are usually prepared with and electrochemical anodization method, where the oxidation of the titanium foil is immersed in an electrolyte solution containing fluoride ions such as ethylene glycol mixed with NH_4F and water. A voltage that usually ranges from 10–60 V is supplied, and this results in self-organized nanotubular structures because of the fieldassisted oxidation and subsequent chemical dissolution of the oxide layer.

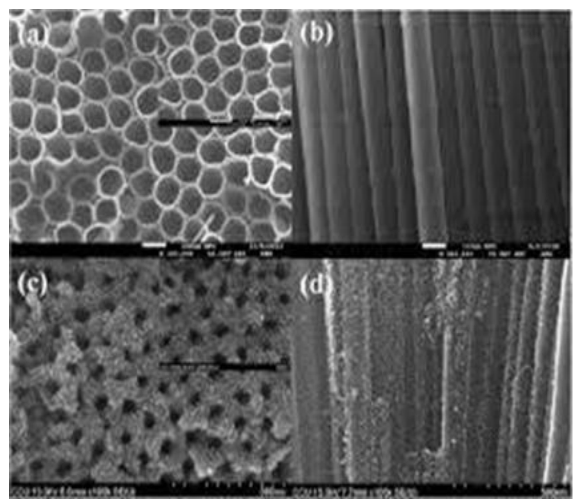

Fig6: TiO_2 Nanotubes

After the anodization process, the amorphous TiO2 nanotubes are heated at 450–500 C to become crystalline anatase or rutile phases and, in this way, their photocatalytic and electrochemical properties are enhanced. This easy and low-cost approach gives you TiO2 nanotube arrays that are very organized and have dimensions that can be changed based on the anodization parameters used.

VIII. COMPARISON OF SYNTHESIS METHODS FOR SUPERCAPACITOR MATERIALS

Method	Materials	Key Features	Advantages	Limitations
Hydrothermal	MoS_2, MnO_2	Controlled morphology, cost-effective	ıple process, scalable, ironmentally friendly	Requires precise temperature control, long processing time
Successive Ionic Layer Absorption and Reaction (SILAR)	La_2Te_3	Thin film deposition, good surface area	Uniform film formation, low- cost method	Requires multiple deposition cycles for uniformity
Anodization	TiO_2	Produces nanotubes, high surface area	Excellent porosity control, enhances capacitance	Requires specific electrolytes, can be time-consuming
Molecular Beam Epitaxy (MBE)	Borophene	High-quality films, complex fabrication	Atomically precise control, excellent crystallinity	Expensive, requires ultra-high vacuum conditions

Table 2: Different Synthesis Methods for Supercapacitor Materials

IX. ELECTROCHEMICAL ANALYSIS

Graphene

The electric double-layer capacitance (EDLC) mechanisms the main way that graphene electrodes retain charge. Pore structure and accessibility are two examples of the characteristics that affect the electrochemical performance.

- Defect density and conductivity
- Surface functional groups

In aqueous electrolytes, typical specific capacitance values fall between 100 and 300 F/g. Performance can be further improved via doping techniques and composite materials.

Composites Based on Graphene

Graphene-based composites have been created by researchers to get over restrictions like restacking and limited pseudo capacitance:

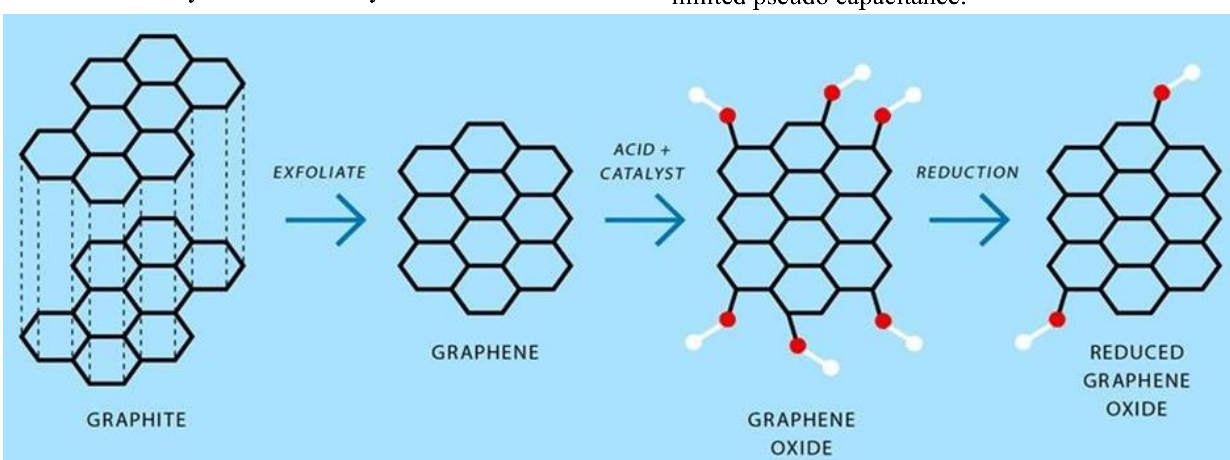

Fig7: Graphene Composited

- Metal oxide/graphene composites, such as MnO_2, RuO_2, and Fe_2O_3.
- Graphene/Conducting Polymer Composites, such as polypyrrole (PPy) and polyaniline (PANI) 3D
- Graphene Structures: hydrogels, foams, and aerogels that enhance electrolyte access and inhibit restacking

MoS_2-Graphene

Molybdenum disulfide (MoS_2)-graphene composites have attracted a lot of attention as electrode materials mostly for the reason of their synergistic electrochemical performance. MoS_2, a transition metal dichalcogenide made up of layers, has a high theoretical capacity and it can act as a pseudocapacitive material, while graphene brings good electrical conductivity and is structurally stable. In combination, graphene actually, through the suppression of MoS_2 nanosheets' restacking, provides a lot more active sites and promotes ion transport that proceeds faster.

Electrochemical characterizations show that MoS_2-graphene composites own not only a larger specific capacitance, better rate capacity, and cycling stability than pure MoS_2 or graphene but also are of remarkably improved performance. The conductive graphene matrix acts as a direct channel to promote rapid mobility of charge carriers, while MoS_2 becomes a source of charge storage. For instance, an electrode with a MoS_2/graphene composite can realize a specific capacitance of over 500 F/g at 1 A/g rate and retain a capacity of more than 90% after 1000 cycles.

The performance of these hybrids was greatly affected by synthesis approaches, which included hydrothermal growth, in-situ reduction, and ultrasonication- assisted exfoliation. The most important factor of the composites' electrochemical behavior was the even distribution of MoS_2 on graphene and the intimate contact of the two are the keys. These combinations are very likely to be the best options for high-performance supercapacitor materials and lithium-ion batteries.

La_2Te_3

Myriad of were reports about the magnificent electrochemical features of Lanthanum telluride (La_2Te_3), which have been exploited especially in energy storage and conversion. Being a representative of rare-earth chalcogenides, La_2Te_3 has a layered crystalline structure with highly pronounced electronic conductivity derived from Te-Te bonds and La's electron- donating character. Down to the present, numerous investigations have been carried out to demonstrate that La_2Te_3 could evidence its unmatched efficiency, especially in lithium-ion batteries (LIBs) and thermoelectric applications. The fact that it is redox-active means that Li^+ insertion is reversible and there is a high-capacity retention with low polarization.

To test the performance of La_2Te_3 at different rates, cyclic voltammetry (CV) and galvanostatic charge-discharge (GCD) experiments are carried out, and the results are in favor of La_2Te_3 since it looks like, it has no rate problem at all and the circle is stable. The high electrical conductivity of the material is a determining factor in the low internal resistance, which in turn leads to fast charge transport kinetics. Furthermore, the layered structure of the material, which accommodates the ionic transport, is also a good thing as it is reflected in the enhanced electrochemical performance of the material. The present paper discusses the difficulties still faced by the issue of volume expansion and the very low cycling stability that still exists. The authors make a suggestion to use La_2Te_3-based carbon or polymer matrix composites as more advanced materials to assure them of the ability to cope with mechanical stress and to become more durable. La_2Te_3 was suggested as an electrode material where the electronic structure was one of the most optimal and the ion transport characteristics were also among the most promising, yet still a little bit of work was needed to get to materials that could be used in practice.

WS_2-Graphene

Heterostructures formed from WS_2 and graphene give the materials better electrochemical properties through the combined action of the layered transition metal dichalcogenide (TMD) and the carbon network. WS_2 have high theoretical capacity and structure in which ion intercalation is easy to achieve, while graphene provides excellent electronic conductivity, mechanical strength, and a large surface area. When combined, the graphene sheets act as electron highways, thereby speeding up the process of charge transport and suppressing the overall resistance of the composite. The heterostructure also has the effect of preventing WS_2 nanosheet restacking and at the same time providing a mechanism for the phase transition volume leading to higher cycling stability.

Experiments such as cyclic voltammetry and galvanostatic charge–discharge tests show that the WS_2– graphene heterostructures have brought about an increase in both specific capacitance and rate capability. The pseudocapacitive behavior of WS_2 along with the electric double-layer capacitance of graphene results in a combination capable of fast ion adsorption/desorption and redox activity. The studies report specific capacitance values exceeding 500 F/g, which is an excellent case in point for the outstanding capacity retention that occurs over thousands of cycles.

The structure of this composite is set to be very helpful in solving the problems of gathering energy from solar cells, fuel cells, and so on, together with the charging and discharging capabilities of lithium/sodium ion cells. The implementation of techniques for both controlled synthesis and the adjustment of WS_2–graphene interface is crucial to the achievement of the best electrochemical performance.

TiO_2 Nanotubes

One-dimensional TiO_2 nanotubes have been widely recognized as a unique form for electrochemical applications that need to be high in the specific area of the surface and in the chemical stability. They are arranged in parallel and united vertically, which explains why they are good for the processing of charge and ion in electrical devices as well as in photoelectrochemical cells. Semiconducting TiO_2, particularly in the form of anatase, is an inherent material that makes it dielectric and can take part in the electron transfer. However, the very low electrical conductivity of semiconducting TiO_2 is an obstacle to the further utilization of these devices.

To improve the electrochemical behavior, the most common method is the modification of TiO_2 nanotubes, which can be done by the application of non-metallic elements such as Nb, N, or C, or by polymerization with conductive fibers like graphene or transition metal oxides.

These tactics can boost the conductivity, the ability of the charge to flow, and the number of cycles. In the context of the input voltage (CV) and electrochemical impedance spectroscopy (EIS), study the varied TiO_2 nanotubes utilizing the improved capacitive behavior and the reduced charge transfer resistance. In addition, their mechanical robustness allows them to work for extended periods of time without any structural degradation taking place.

On the whole, TiO_2 nanotubes can provide a suitable groundwork for more advanced energy storage solutions. By engineering the structure and modifying the surface, we can easily control the electrochemical nature of TiO_2 nanotubes and consequently pave the way for the production of high-performance electrode materials.

Borophene

Borophene, a 2D allotrope of boron, with its exceptional electrochemical properties has become a vital subject for researchers. The atomic structure of borophene, especially its puckered surface and the different boron bonding configurations, result in superior electronic and chemical properties. Based on recent investigations, borophene recorded a high density of states near the Fermi level, thus promoting easier electron transport during electrochemical reactions, a property that can lead to its use in high-performance batteries, supercapacitors, andcatalysts.

The utilization of borophene in lithium-ion and sodium-ion batteries is beneficial for both types of batteries, as borophene material contributed very good charge/discharge cycling stability and high specific capacities compared to traditional anode materials. Furthermore, its high conductivity and large surface area make borophene a perfect material for supercapacitors, where both rapid charge/discharge cycles and high energy density are required.

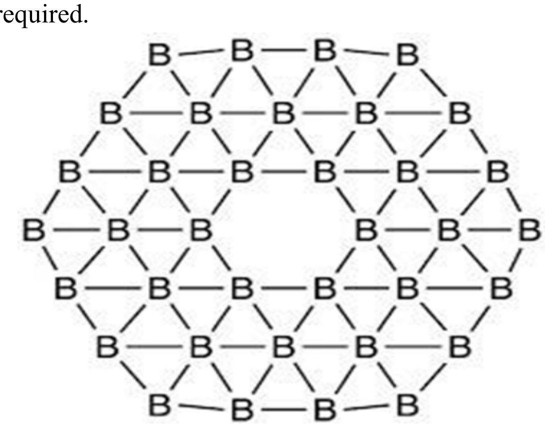

Fig8: Borophene structure

Moreover, the electrocatalysis potential of borophene especially for hydrogen evolution and oxygen reduction reactions is very high due to its high catalytic activity and electronic properties being tunable. The structural tunability of borophene that is achieved through various synthesis methods like chemical vapor deposition or mechanical exfoliation opens more avenues to enhance the material's electrochemical performance.

X. FUTURE DIRECTIONS AND APPLICATIONS

Graphene

Graphene may be regarded as a type of material which is actually a single layer of carbon atoms assembled in a hexagonal honeycomb pattern and which displays some brilliant electronic, mechanical, and thermal properties. The sp^2 hybridization of the carbon atoms gives it a planar structure and the resultant σ bonds are very strong, while the electrical conductivity of the graphene (which is very good) is due to the π bonds formed above and below the plane. The symmetrical lattice and the high carrier potency of the material are perfect attributes for the given task, and the material ends up being highly suitable for flexible electronics, sensors, and energy storage devices.

MoS_2-Graphene

MoS_2, a material that can be pictured as a transition metal dichalcogenide (TMD), has a 2D structure with semiconducting properties due to the way the sulfur atoms sandwich the Mo atoms, and form a layered structure. The coexistence of MoS_2 in composites with graphene leads to charge transfer and mechanical strength being significantly improved while the electrochemical performance is also enhanced. The interatomic spacing between MoS_2 and graphene is such that it forms the unique electronic properties required in batteries, supercapacitors, and catalysis applications.

The large area between MoS_2 layers is one of the reasons; it allows for high surface density of the ions drawn and this can not only increase the energy density of the device but also the conversion effects and therefore performance will be significantly improved.

La_2Te_3

La_2Te_3, an example of a lanthanide-based compound, is described as having a hexagonal layered crystal structure ($P6_3/m$ space group) and displaying thus a number of semiconducting and thermoelectric properties. La atoms first form a honeycomb-like structure by interacting with Te atoms, and the interlayer force is so weak that it can thus be employed for low- dimensional diode and thermoelectricity. The highly anisotropic character of the lattice structure can cause the thermoelectric performance of the material to be greatly improved, and the material—the La_2Te_3—significant thus the latter can be used to extract energy from renewable sources through the Seebeck effect and then convert the energy into usable power (termed energy-harvesting applications).

WS_2-Graphene Heterostructures

Like its precursor, MoS_2, WS_2 is another TMD with a hexagonal lattice. This structure is the result of the sulfur (S) atoms which are layered over the tungsten (W) atoms. The WS_2- graphene heterostructures serve as a basis for better performance of optoelectronics, energy storage, and catalysis by taking advantage of both semiconducting and conductive materials. The electron mobility is improved and the contact resistance between WS_2 and other materials is decreased due to the presence of the graphene layer. The strong coupling effect occurring at the interface allowed the electronic and optoelectronic properties to be regulated, thus it is possible to fabricate devices such as photodetectors and solar cells.

TiO_2 Nanotubes

One of the distinguishing features of titanium dioxide (TiO_2) nanotubes is their lattice structure in which titanium atoms are arranged tetragonally with oxygen atoms bonding with titanium in the corners of the lattice. A competent method to prepare nanotubes goes through the synthesis of them that are anodized in a fluoride-containing electrolyte with the use of titanium, thus creating a highly ordered array of TiO_2 nanotubes. The anatase phase, which is the tetragonal structure of TiO_2 that is distorted, enables the truth about the high photocatalytic property. One of the benefits of such a structure is that it provides a larger interface area and facilitates the direct transportation of electrons, that's why TiO_2 nanotubes can be used in applications like photocatalysis, sensors, and supercapacitors.

Borophene

A 2D allotrope of boron called borophene has a peculiar, puckered lattice structure, that is quite different from graphene. The lattice of borophene is featured with unique bonding arrangements like the presence of five-membered and six-membered boron rings, which, in turn, suggests the possible existence of different structures, e.g., honeycomb and quasi-honeycomb patterns. The latter structures are very important for energy storage, catalysis, and electronics applications since they have a larger surface area as well as electronic properties such as the availability of numerous states near the Fermi level. The possibilities are further expanded by the fact that their structural features and properties may be adjusted during the synthesis process.

XI. FUTURE DIRECTIONS AND APPLICATIONS

MoS_2-Graphene

MoS_2-Graphene composites have shown encouraging features for applications in energy storage, catalysis, and electronics. The future direction of research could be the utilization of MoS_2-Graphene composites utilizing incorporating the MoS_2 material with graphene to deal with the adverse effects of poor cycling stability and low MoS_2 electrode conductivity.

One feasible way is to achieve the required functionality of MoS_2 layers through the simultaneous hybridization of other 2D materials and thereby improving the properties of the composite through charge transmission and charge storage. MoS_2-Graphene composites could be the breakthrough in the battery, supercapacitor, and electrocatalytic applications, especially the lithium/sodium-ion batteries and electrocatalytic hydrogen production reactions (HER).

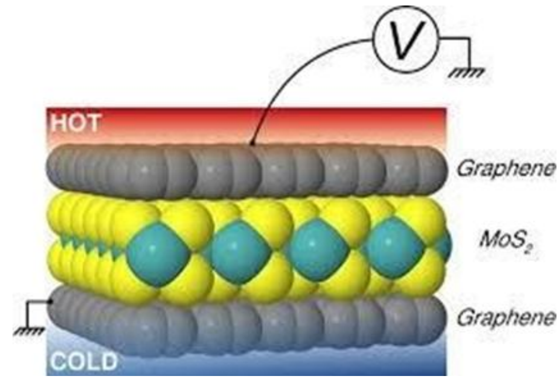

Fig9: MoS_2-Graphene

Furthermore, these materials could come up with a new application for flexible and wearable electronic devices, which would also take advantage of graphene's flexibility and the semiconducting properties of MoS_2.

La_2Te_3

La_2Te_3 is a high-temperature thermoelectric material with the potential for waste heat recovery, energy harvesting and power generation at low temperatures. To start with, the future research should be about optimizing the electrical and thermal conductivity of La_2Te_3 through doping the material.

For example, nano structuring, when using nanowires, nanoparticles, or thin films, is one of the feasible methods to enhance the power factor and figure of merit of La_2Te_3-based thermoelectric devices.

This material can replace the current technology of waste heat recovery units, converting– through the Seabeck effect– the heat dissipated during industrial processes into electrical energy thereby enabling energy to become more sustainable.

WS_2-Graphene

The marriage of WS_2 with graphene in heterostructures has resulted in some quite promising examples in terms of optoelectronic, energy storage, and catalysis applications. In the days to come, investigations should concentrate on adjusting the WS_2 and graphene interface to facilitate charge transfer and develop even better devices.

This involves finding out the ways to order the stacking and coupling between the layers of the materials, which can be the stimuli for the change in the electronic properties, and this is specific to some new applications. Another point to mention is that WS_2-Graphene heterostructures might just be the play key role in forthcoming electronic devices such as photodetectors, field-effect transistors, and solar cells.

The flexibility and the transparency that these materials possess make them the perfect choice for the development, and the use, of the new-generation devices, like flexible and transparent electronics

TiO_2 Nanotubes

TiO_2 nanotubes have been a subject of extensive research for various applications such as photocatalysis, energy storage, and sensors. The new directions for the development of TiO_2 nanotubes are aimed at improving the photocatalytic efficiency.

This goal can be achieved by doping with metals/non-metals and adjustment of the size and shape for selected applications. Moreover, blending TiO_2 nanotubes with other materials, such as graphene or carbon nanotubes could additionally enhance their electrical conductivity and photocatalytic performance enabling them for efficient energy storage devices and clean-up operations in the environmental. The potential of TiO_2 nanotubes in hydrogen production from water splitting and in the environmental technologies for the removal of organic contaminants is vast.

Borophene

With borophene's one-of-a-kind lattice structure and electronic potentials in mind, it is undoubtedly a groundbreaking material with uncountable applications. The upward mobility of the research application of borophene will be directed towards the performance of the synthesis process and subsequent improvement of its stability.

The next steps in the fabrication and functionalization processes will solve the problem of the commercial release of the material for the electronics of the future, and it can be used in energy storage and catalysis. The high potential of both the surface area and electronic properties of borophene may result in its being used as the material for batteries, supercapacitors, and a catalyst for hydrogen evolution reaction and oxygen reduction reactions.

Besides, designing and developing a borophene-based transparent and flexible electronic technology and integrating it with 2D materials can be a crucial step forward in the field of device miniaturization and performance.

XII. SUMMARY

Following is the discussion on the latest developments in supercapacitor technologies through material innovations, synthesis techniques, and structure design towards enhanced energy density, charge/discharge capabilities, and life. The article is critical in explaining significant electrode materials such as borophene, graphene, MoS_2-graphene composites, La_2Te_3, WS_2- graphene heterostructures, and TiO_2 nanotubes that display high surface area, electrical conductivity, electrochemical stability, and compatibility as ideal candidates in future energy storage devices.

Particular emphasis is placed on MoS_2 and graphene hybrids owing to their enhanced cycle life and conductivity, whereas La_2Te_3 has high thermoelectric properties and the potential for long-term stability. Borophene is also emphasized, owing to its high theoretical capacity, rapid ion diffusion, and electrocatalytic capability. The review also evaluates various synthesis techniques, such as hydrothermal treatment, anodization, and chemical vapor deposition, with particular emphasis on their impact on material performance. A few of the recent technological trendsin the field of supercapacitor engineering are Aqueous Hybrid Electrochemical Capacitors (ACPECs) of up to 1000 V, super capacitive swing adsorption (SSA) for capture of CO_2, and fatigue analysis of structural elements for tough environments such as railway systems.

Micro supercapacitors (MSCs) for downsized applications and integration of supercapacitors into biomedical systems are also the focus of research. The article concludes by taking into account major directions of future research, including the hybridization of MoS_2 with other 2D materials, La_2Te_3 doping optimization for better thermoelectric properties, and optimization of borophene synthesis and stability. These developments will make it possible to create scalable, high-performance, and environmentally benign supercapacitors for a wide range of applications, from flexible electronics to energy harvesting and catalysis.

XIII. CONCLUSION

With an emphasis on materials science, fabrication techniques, electrochemical performance, and lattice structure analysis, this review painstakingly compiles the most recent developments in supercapacitor research. It emphasizes how important nanostructured materials are for improving capacitance, cycle life, and energy density. Examples of these materials are borophene, La_2Te_3, MoS_2, and their hybrids. A potential roadmap for next-generation energy storage is demonstrated by the combination of structural advances (such as thin-film and heterostructures) and developing manufacturing technologies (such as ultrafast lasers, SILAR, and anodization). A move toward multipurpose and sustainable applications is indicated by the focus on high-voltage aqueous systems, CO_2-capturing supercapacitors, and miniature biomedical devices. Scaling these technologies, preserving long-term structural stability, and striking a balance between performance and environmental friendliness are still difficult tasks, though. To move supercapacitor technologies from experimental success to commercial significance, it will be essential to close these gaps using interdisciplinary techniques and more thorough lifecycle analysis.

REFERENCES

[1] Mannix, A. J., et al.” Borophene: Two-Dimensional Boron Monolayer: Synthesis, Properties, and Potential Applications.” *Chemical Reviews*, vol. 122, no. 1, 2022, pp. 1000– 1051.

[2] Yu, M., et al.” Structures, Mechanics, and Electronics of Borophanes.” *The Journal of Physical Chemistry C*, vol. 125, no. 41, 2021, pp. 22917–22928.

[3] Wang, K., et al.” Borophene: Synthesis, Chemistry, and Electronic Properties.” ChemPlusChem*, vol. 89, no. 10, 2024.

[4] Li, Q., et al.” Synthesis of Borophane Polymorphs through Hydrogenation of Borophene.” *Science*, vol. 371, no. 6534, 2021, pp. 1143–1148.

[5] Huang, X., Zeng, Z., and Zhang, H.” Metal Dichalcogenide Nanosheets: Preparation, Properties and Applications.” *Chemical Society Reviews*, vol. 42, no. 5, 2013, pp. 1934–1946. https://doi.org/10.1039/C2CS35387E.

[6] Chhowalla, M., et al.” The Chemistry of Two-Dimensional Layered Transition Metal Dichalcogenide Nanosheets.” *Nature Chemistry*, vol. 5, 2013, pp. 263–275. https://doi.org/10.1038/nc.

[7] Song, Y., Li, Y., Ye, D., et al.” Scalable Production of MoS2/Graphene Heterostructures by Liquid-Phase Shear Exfoliation for Ultrasensitive Dopamine Detection.” *ACS Applied Nano Materials*, vol. 4, no. 7, 2021, pp.6717–6727. https://doi.org/10.1021/acsanm.1c00622.

[8] Bhuse, V. M., and Darade, R. M.” Chemical Synthesis and Super capacitive Properties of Lanthanum Telluride (La2Te3) Thin Film.” *American Elements*, 2021. https://www.americanelements.com/chemical-synthesis-and-supercapacitive-properties-oflanthanum-telluride-thin-film

[9] Zhang, Z., Yang, Y., Gao, G., and Yakobson, B. I.” Two-Dimensional Boron Monolayers Mediated by Metal Substrates.” *Nanoscale*, vol. 8, no. 26, 2016, pp. 15340– 15347. https://pubs.rsc.org/en/content/articlelanding/2016/nr/c6nr04186h.

[10] Mortazavi, B., Dianat, A., Rabczuk, T., and Zhuang, X.” Borophene as an Anode Material for Ion Storage: A First-Principles Study.” *Nano Energy*, vol. 27, 2016, pp. 595– 602. https://www.sciencedirect.com/science/article/abs/pii/S2211285516300222.

[11] Li, W., and Wang, Y.” Borophene Is a Promising Anode Material for Sodium-Ion Batteries with High Capacity and High-Rate Capability.” *RSC

Advances*, vol. 8, no. 41, 2018, pp. 23175–23182.https://pubs.rsc.org/en/content/articlelanding/2018/ra/c8ra01942h.

[12] Bhardwaj, R., Sengar, P., and Aswal, D. K.” Ultrasonic Synthesis of Borophene as a 2D Electrode Material with High Electrocatalytic Activity for Use in Fuel Cell Applications.” *Borophene.com*, 2023.https://www.borophene.com/article/ultrasonic-synthesis-of-borophene-as-a-2d-electrode-materialwith-high-electrocatalytic-activity-for-use-in-fuel-cell-applications.

[13] Srivastava, S., et al.” Nickel Phthalocyanine–Borophene Nanocomposite-Based Electrochemical Biosensor for High-Performance Glucose Detection.” *Materials Advances*, vol. 5, 2024, pp. 1284–1292.https://pubs.rsc.org/en/content/articlehtml/2024/ma/d3ma00829k.

[14] Liu, et al. *ACS Applied Materials & Interfaces*, 2020. *PubMed*.

[15] Kumar, et al. *2D Materials*, 2019. *IOPscience*.

[16] Naskar, et al. *Journal of Cluster Science*, 2020. *Springer*.

[17] Wang, Y., et al.” MoS2–Graphene Hybrid Materials for Electrochemical Energy Storage.” *Energy & Environmental Science*, vol. 6, 2013, pp. 872–878. https://doi.org/10.1039/C3EE00064A.

[18] Guo, S., Liu, P., Liu, X., Wang, G., and Zhuang, Q.” La2Te3 as a Novel Anode Material for Lithium-Ion Batteries with High Capacity and Cycling Stability.” *Electrochimica Acta*, vol. 259, 2018, pp. 1109–1115. https://doi.org/10.1016/j.electacta.2017.11.168.

[19] Zhou, M., Zhang, Y., Zhang, L., and Zhao, Y.” Rare-Earth Tellurides as Potential Thermoelectric and Energy Storage Materials: A Review.” *Journal of Materials Chemistry A*, vol. 5, no. 25, 2017, pp. 12862–12879. https://doi.org/10.1039/C7TA02993A.

[20] Wang, Xiangya, et al.” An Anticoagulant Supercapacitor for Implantable Applications.” *NatureCommunications*https://doi.org/10.1038/s41467-024-54862-

[21] Qiu, Meijia, et al.” Tailoring Tetrahedral and Pair-Correlation Entropies of GlassForming Liquids for Energy Storage Applications at Ultralow Temperatures.”*Nature Communications*, 2024, https://doi.org/10.1038/s41467-024-54449-x.

[22] Yuan, Yongjiu, et al.”Laser Maskless Fast Patterning for Multitype Microsupercapacitors.” *Nature Communications*, 2023,https://doi.org/10.1038/s41467-023-39760-3.

[23] Wang, Y., et al.” Layered La2Te3-Based Composites for High-Performance Li-Ion Batteries.” *Journal of Power Sources*, vol. 455, 2020, 227984. https://doi.org/10.1016/j.jpowsour.2020.227984.

[24] Zhang, C., et al.” WS2–Graphene Nanocomposites for High-Performance Energy Storage Devices.” *Advanced Energy Materials*, vol. 6, no. 7, 2016, 1502217. https://doi.org/10.1002/aenm.201502217.

[25] Zhang, Y., et al.” Electrochemical Properties of Borophene for Energy Storage and Conversion.” *Nature Communications*, vol. 11, no. 1, 2020, pp. 1–8. https://doi.org/10.1038/s41467-020-18133-1.

[26] Novoselov, K. S., et al.” Electric Field Effect in Atomically Thin Carbon Films.” *Science*, vol.306, no.5696,2004, pp.666–669.https://doi.org/10.1126/science.1102896.

[27] Geim, A. K., and Grigorieva, I. V.” Van Der Waals Heterostructures.” *Nature*, vol. 499, 2013, pp. 419–425. https://doi.org/10.1038/nature12385.

[28] Hu, Xing, et al.” Fatigue Analysis of an Energy Storage Supercapacitor Box under Random Vibration Loading.” *Scientific Reports*, 2025,https://doi.org/10.1038/s41598-025-92116-3.

[29] Xu, Zhen, et al.” Enhancing Electrochemical Carbon Dioxide Capture with Supercapacitors.” *Nature Communications*, 2024,https://doi.org/10.1038/s41467-024-52219-3

[30] Lokhande, Vaibhav, et al.” Charge Storage in WO3 Polymorphs and Their Application as Supercapacitor Electrode Material.” *Results in Physics*, 2019.https://doi.org/10.1016/j.rinp.2019.02.012.

[31] Hareesh, K.” Recent Advances in Borophene Nanosheet for Supercapacitor Application: Mini

Review." *Journal of Energy Storage*, 2024. https://doi.org/10.1016/j.est.2024.110857.

[32] Chen, Wushuang, et al." Hierarchical Architecture of Coupling Graphene and 2D WS2 for High-Performance Supercapacitor." *Electrochimica Acta*, 2018.https://doi.org/10.1016/j.electacta.2018.12.096.

[33] Razaa, Waseem, et al." Recent Advancements in Supercapacitor Technology." *Nano Energy*, 2018. https://doi.org/10.1016/j.nanoen.2018.08.013.

[34] Joseph, Nikhitha, et al." Recent Advances in 2D-MoS2 and Its Composite Nanostructures for Supercapacitor Electrode Application." *ACS Energy & Fuels*, https://dx.doi.org/10.1021/acs.energyfuels.0c00430.

[35] Nagarajarao, S. H., et al." Recent Developments in Supercapacitor Electrodes: A Mini Review." *ChemEngineering*, vol. 6, 2022, p. 5.https://doi.org/10.3390/chemengineering6010005.

[36] Rajangam, K., et al." Synthesis and Characterisation of Ag Incorporated TiO2 Nanomaterials for Supercapacitor Applications." *Journal of Molecular Structure*, 2020. https://doi.org/10.1016/j.molstruc.2020.128661.

[37] Najib, Sumaiyah, and Emre Erdem. " Current Progress Achieved in Novel Materials for Supercapacitor Electrodes: Mini Review." *Nanoscale Advances*,https://doi.org/10.1039/c9na00345b.

[38] Zhou, Rui, et al." Hierarchical MoS2-Coated Three-Dimensional Graphene Network for Enhanced Supercapacitor Performances." *Journal of Power Sources*, 2017. https://doi.org/10.1016/j.jpowsour.2017.03.134.

[39] Pujari, R. B., et al." Chemically Deposited Nano Grain Composed MoS2 Thin Films for Supercapacitor Application." *Journal of Colloid and Interface Science*, 2016.https://doi.org/10.1016/j.jcis.2016.11.026.

[40] Sahin, M. E., et al." A Comprehensive Review on Supercapacitor Applications and Developments." *Energies*, vol. 15, 2022, p. 674.https://doi.org/10.3390/en15030674.

[41] Samy, O., et al." A Review on MoS2 Properties, Synthesis, Sensing Applications and Challenges." *Crystals*, vol. 11, 2021, p. 355. https://doi.org/10.3390/cryst11040355.

[42] Abdel Maksoud, M. I. A., et al." Advanced Materials and Technologies for Supercapacitors Used in Energy Conversion and Storage: A Review." *Environmental Chemistry Letters*, 2020. https://doi.org/10.1007/s10311-020-01075-w.

[43] Zhao, J., and A. Burke." Review on Supercapacitors: Technologies and Performance Evaluation." *Journal of Energy Chemistry*, 2020.https://doi.org/10.1016/j.jechem.2020.11.013.

[44] Gupta H.,et al."High-Performance Supercapacitor Based on 2D-MoS2 Nanostructures." *Materials Today: Proceedings*,https://doi.org/10.1016/j.matpr.2019.04.198.

[45] Patil, S. J., et al." Chemical Synthesis and Supercapacitive Properties of Lanthanum Telluride Thin Film." *Journal of Colloid and Interface Science*, 2016. https://doi.org/10.1016/j.jcis.2016.11.020.

[46] Rizzo, D. J., et al." Borophene: A New 2D Material for Energy Storage and Catalysis."Advanced Energy Materials*,vol. 10 no. 12,2020,2000090. https://doi.org/10.1002/aenm.202000090.

[47] Gong, C., et al." Borophene as a New 2D Material: From Structure to Properties." Nano Letters, vol.17, no.9,2017, pp.5733–5738. https://doi.org/10.1021/acs.nanolett.7b01761.

[48] Zhang, X., et al." TiO2 Nanotube-Based Composites for Photocatalysis and Energy Storage." *Materials Science and Engineering: B*, vol. 259, 2020, 114548. https://doi.org/10.1016/j.mseb.2020.114548.

[49] Choi, Y. J., et al." TiO2 Nanotube Arrays for Energy Storage and Environmental Applications." *Nature Materials*, vol. 16, 2017, pp. 314–321. https://doi.org/10.1038/nmat4879.

[50] Shi, Y., et al." Interfacing WS2 with Graphene for Electronic and Optoelectronic Applications." *Nature Materials*, vol. 16, 2017, pp. 815–823. https://doi.org/10.1038/nmat4921.

[51] Xu, M., et al." WS2/Graphene Heterostructures for Energy Storage and Photocatalysis." *Nature Communications*, vol. 5, 2014, p. 3434.

https://doi.org/10.1038/ncomms4434.
[52] Fu, C., et al." Enhanced Thermoelectric Properties of La2Te3 via Doping with RareEarth Elements." *Materials Research Express*, vol. 6, no. 11, 2019, 115042. https://doi.org/10.1088/2053-1591/ab4ea0.
[53] He, J., et al." Thermoelectric Properties of La2Te3: A First-Principles Study." *Journal of Materials Chemistry A*, vol. 5, 2017, pp. 4319–4325. https://doi.org/10.1039/c6ta08455a.
[54] Liu, Y., et al." M o S 2/Graphene Composite for Lithium-Ion Batteries: A Review." Journal of Energy Chemistry, vol. 28, no. 3, 2019, pp.420–433.
https://doi.org/10.1016/j.jechem.2018.10.010.
[55] Zeng, Z., et al." Graphene-like MoS2 Nanosheets for Fast Charge–Discharge Supercapacitors." *Nature Nanotechnology*, vol. 6, no. 5, 2011, pp. 277–281. https://doi.org/10.1038/nnano.2011.47.
[56] Gong, C., et al." Borophene as a new 2D material: From structure to properties." Nano Letters, vol. 17, no. 9, 2017, pp. 5733–5738.https://doi.org/10.1021/acs.nanolett.7b01761
[57] Choi, Y. J., et al." TiO2 nanotube arrays for energy storage and environmental applications." Nature Materials, vol. 16, 2017, pp. 314–321. https://doi.org/10.1038/nmat4879.
[58] Xu, M., et al." WS2/graphene heterostructures for energy storage and photocatalysis." Nature Communications, vol. 5, 2014, 3434. https://doi.org/10.1038/ncomms4434.
[59] He, J., et al." Thermoelectric properties of La2Te3: A first-principles study." Journal of Materials Chemistry A, vol. 5, 2017, pp. 4319–4325.https://doi.org/10.1039/c6ta08455a.
[60] Zeng, Z., et al." Graphene-like MoS2 nanosheets for fast charge–discharge supercapacitors." Nature Nanotechnology, vol. 6, no. 5, 2011, pp. 277–281. https://doi.org/10.1038/nnano.2011.47.