

# A brief review on graphene applications in rechargeable lithium ion battery electrode materials

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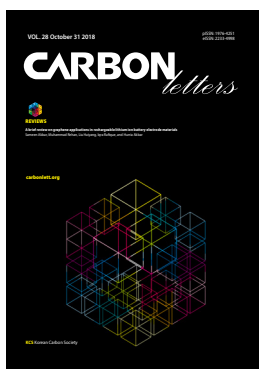
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## Abstract

Graphene is a single atomic layer of carbon atoms, and has exceptional electrical, mechanical, and optical characteristics. It has been broadly utilized in the fields of material science, physics, chemistry, device fabrication, information, and biology. In this review paper, we briefly investigate the ideas, structure, characteristics, and fabrication techniques for graphene applications in lithium ion batteries (LIBs). In LIBs, a constant three-dimensional (3D) conductive system can adequately enhance the transportation of electrons and ions of the electrode material. The use of 3D graphene and graphene-expansion electrode materials can significantly upgrade LIBs characteristics to give higher electric conductivity, greater capacity, and good stability. This review demonstrates several recent advances in graphene-containing LIB electrode materials, and addresses probable trends into the future.

**Key words:** graphene, electrode materials, electrochemical characterizations, lithium ion battery

## 1. Introduction

The constantly increasing need for energy has driven numerous researchers to devote intense effort to discovering new energy sources and developing new energy storage and transformation technologies. Many among these studies have revealed numerous extraordinary benefits of lithium ion batteries (LIBs) over traditional batteries, including high open circuit voltages, high energy densities, long lifetimes, and minimal contamination. These characteristics drove the rapid development of LIBs to provide the spectrum of batteries presently utilized in cell phones, laptop computer tablets, and other versatile electronic gadgets [1]. Inside LIBs, lithium ions move from the positive electrode (cathode) to the negative electrode (anode) during the charging process and then flow in the opposite direction during the discharging process. The regularly utilized LIB cathode materials are lithium transition metal oxides (such as  $\text{LiCoO}_2$ ,  $\text{LiMn}_2\text{O}_4$  and  $\text{LiFePO}_4$ ), while the usually utilized anode materials include graphite and metal oxides (including that of tin). At present, these anode materials present a few disadvantages that hinder their wider utilization. For instance, carbon materials offer great cycle stability, but small initial charging and discharging capacity. In contrast, the metal oxide anode materials have great theoretical capacity, but relatively low cycle stability [2]. Graphene is an extraordinary material with excellent electrical conductivity, large surface area, and extreme robustness. Research indicates it is a reasonable choice to solve the limitations of current anode materials [3]. For the anode materials, researchers have focused on certain alloys with useful metals and their respective oxides. Some major examples of such materials are Si,  $\text{Fe}_3\text{O}_4$ ,  $\text{Co}_3\text{O}_4$ , and  $\text{SnO}_2$ . These materials are considered better alternatives to graphite because of their greater specific capacities. However, these metals or mixes of metals with metal oxides have low cycle performance and exhibit structural degradation. The main reason for their slow cycling is the low conductivity of these materials [4]. One effective way to minimize these problems was to improve their conductivity. The synthesis of three-dimensional (3D) graphene anode composite materials increased conductance and

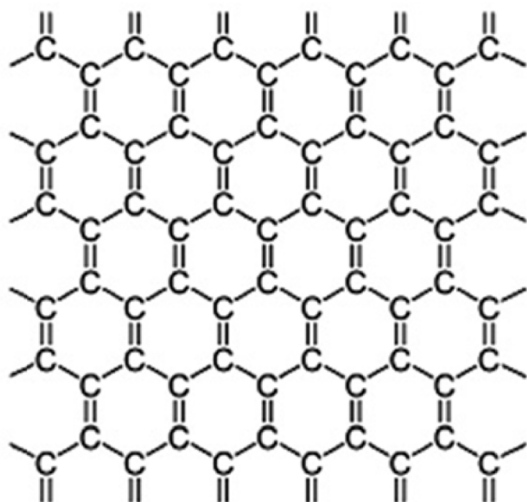


Fig. 1. Structural model of graphene.

minimized related issues [5].

Graphene, which is a single-atom layer of graphite, comprises carbon atoms ( $sp^2$  hybridized) in a honeycomb pattern, as shown in Fig. 1 [6]. Graphene is a 2D material, implying that each molecule is a surface particle. The essential configuration of graphene structure behaves in ways reminiscent of graphite with additional carbon atoms in the form of nanotubes. During 2004, Novoselov et al. [7] created graphene by means of a direct technique [8] after which it rapidly gained worldwide attention, attributable to its native organization and characteristics. For instance, these 2D arranged carbon atoms have a specific surface of  $2600 \text{ m}^2 \text{ g}^{-1}$  [7] from its honeycomb structure, conceivably bringing about higher lithium storage capacity. Moreover, it has increased electron flexibility ( $15,000 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ ), extraordinary thermal conductivity ( $3000 \text{ W mK}^{-1}$ ), great chemical dependability, and amazing mechanical characteristics that make it a perfect candidate for framing of composite materials utilized in the anode [9].

Enhanced electrodes add to the capacity for the flow of lithium ions and increase the battery function. Thus, the lives of batteries that include graphene can be longer than the lives of typical batteries [9]. In ordinary lithium batteries, lithium ions are inserted and then extracted, during the charge and discharge cycles, respectively. This induces repeated changes in the volume of the electrode materials, and results in their relatively rapid breakdown. Because such changes in volume also affect the battery containers, the use of graphene is preferred for its relatively high conductivity, which reduces the resistive heat that develops within the electrodes. This allows the batteries to work at lower temperatures, which enhances battery safety [3].

Graphene has numerous other properties, for example, the quantum Hall effect, bipolar field effect, high electron mobility, superconductivity, and ferromagnetism [10]. These characteristics make graphene suitable for exploitation in various fields. Moreover, logical future advances have already taken into consideration improvements that will reduce the effort and add basic techniques for preparing graphene. This is especially vital for its use at much larger scale and for wider purposes. Following is a review of the utilization of graphene and graphene support composites as electrodes in LIBs, as well as methods for future improvement.

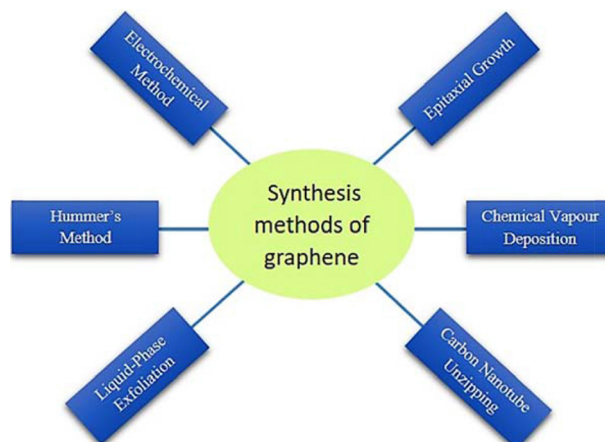


Fig. 2. Illustration of various methods of graphene preparation.

## 2. Techniques for preparation of graphene

Graphene is prepared using a number of unique strategies: micromechanical peeling of carefully arranged graphite [11-13], epitaxial development [3,14], chemical vapor deposition [15,16], and reduction of graphene oxide. The evidence from studies on graphene delivered by micromechanical cleavage and synthetic vapor indicates single layer morphology. On the other hand, these techniques are both unreliable and capable of creating only small quantities of graphene. Consequently, they are not appropriate for large-scale manufacturing of graphene. Chemical reduction of graphene oxide is presently the most practical technique for creating substantial amounts of graphene. Therefore, most of the graphene utilized in LIB electrode materials, is acquired by reducing graphene oxide.

Graphene oxides are created from normal graphite using the Hummers strategy [17,18], the Brodie technique [10], or the Staudenmaier strategy [19]. The Hummers technique is the one most often utilized. A long product lifetime is delivered by using  $\text{NaBH}_4$  (hydrazine hydrate) [20] and other reducing operators to create graphene. This method of preparation is basic and empowers large-scale manufacturing of graphene. The drawback of this strategy is that the oxygen released, influences the electrochemical characteristics of graphene in ways that bring about its disintegration. In spite of this disadvantage, chemical reduction of graphene oxide is still the essential technique utilized by specialists. This is attributable to its relative simplicity and modest requirement for equipment.

## 3. Utilization of graphene in cathode materials for LIBs

Polyanion compounds like  $\text{LiFePO}_4$ ,  $\text{LiCoO}_2$ ,  $\text{LiMn}_2\text{O}_4$ ,  $\text{Li}_3\text{V}_2(\text{PO}_4)_3$ , and  $\text{LiFeSO}_4\text{F}$ ; as well as transition metal oxide (TMO) compounds such as  $\text{LiCoO}_2$  (LCO),  $\text{LiNiO}_2$  (LNO), and  $\text{LiMnO}_2$  (LMO) are cathode materials widely utilized in LIBs [21]. These resources include electronic conductivities of  $10^{-6} \text{ S cm}^{-1}$ ,  $10^{-4} \text{ S cm}^{-1}$ ,  $2.4 \times 10^{-7} \text{ S cm}^{-1}$  and  $10^{-9} \text{ S cm}^{-1}$  [2,22]. The

**Table 1.** Cathode materials containing graphene for LIBs

Crystal structure	Composites	Graphene composite Specific capacity (mAh g <sup>-1</sup> )	Theoretic specific capacity of bare compound (mAh g <sup>-1</sup> )	Synthesis techniques	Author (year)
Olivine	LiFePO <sub>4</sub> /graphene	160	113	Coprecipitation	Ding et al. (2010) [24]
Tavorite	Li <sub>3</sub> V <sub>2</sub> (PO <sub>4</sub> ) <sub>3</sub> /graphene	191	167	Sol-gel	Tong and Fang (2017) [25]
Olivine	LiMnPO <sub>4</sub> /graphene	159	171	Solvothermal	Wang et al. (2014) [26]
Spinel	LiMn <sub>2</sub> O <sub>4</sub> / graphene	137	458	Microwave-assisted hydrothermal	Bak et al. (2011) [27]
Hexagonal layered structure	LiNi <sub>1/3</sub> Co <sub>1/3</sub> Mn <sub>1/3</sub> O <sub>2</sub> / Graphene	188	280	Microemulsion and ball milling	Venkateswara Rao et al. (2011) [28]

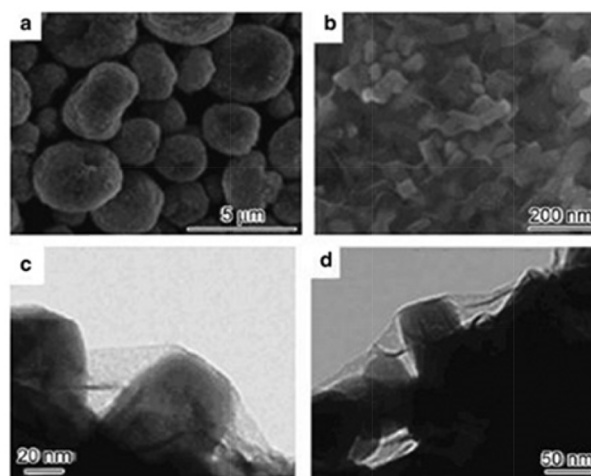
property of electronic conductivity should be high when higher battery performance is required; thus, complementary materials are often added to enhance the electrochemical characteristics of the cathode materials. Many reviews demonstrate that uncontaminated graphene is not a direct replacement for existing carbon-based commercial cathodes in LIBs because of its low columbic output, high charge/discharge rates, and poor cycle stability [3]. The utilization of graphene in composite cathode materials has assumed a critical role in the development of LIBs. Now, scientists have started to contemplate graphene

modification because a graphene-based cathode material can fundamentally enhance the electrochemical performance of an LIB [23]. Furthermore, the expansive 2D surface area and excellent electron exchange capacity of a graphene support successfully enhances and broadens the capacities of ion and electron mobility in cathodes. A number of different cathode materials that include graphene, along with their specific capacities and synthesis techniques, are presented in Table 1 [24-28].

### 3.1. Graphene-LiMPO<sub>4</sub> (M = Fe, V, Mn, Co) as cathode materials

#### 3.1.1. Graphene LiFePO<sub>4</sub> composites as cathode materials for LIBs

When LiFePO<sub>4</sub> (LFP) is used as electrode material it is possible to achieve far above the base specific capacity (170 mAh g<sup>-1</sup>) with easier and less effort [29]. Nevertheless, its low electrical conductivity (10<sup>-9</sup> S cm<sup>-2</sup>) and poor lithium ion diffusion (10<sup>14</sup> to 10<sup>16</sup> cm<sup>2</sup> S<sup>-1</sup>) rapid to capacities blur rapidly under increased rate of charging or discharging [9]. Using graphene to enhance the electrical characteristics of phosphate depends on the following characteristics. First, graphene increases the conductivity, which improves the conductance of the cathode. Moreover, the mechanical characteristics of the graphene maintain the micro-structure of the phosphate and enhance its cyclic reliability. In reality, for a graphene compound material, the flexible work configuration of the graphene enhances its electrical conductivity and performance rates. The graphene nanocomposites were synthesized using different combination techniques such as hydrothermal and solid-state methods [30]. Likewise, scientists also synthesized LiFePO<sub>4</sub> nanoparticles and blended them with graphite oxide. The mixture was then splash-dehydrated and sintered to get the graphene LiFePO<sub>4</sub> compound shown in Fig. 3. The results indicated that graphene covered the

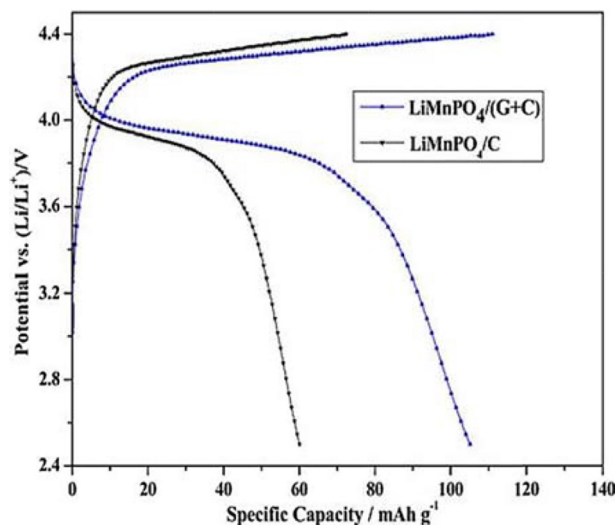


**Fig. 3.** SEM and TEM images of the LFP composite. Reprinted from Guan et al. *Trans Nonferrous Met Soc China*, **27**, 141 (2017), with permission of Elsevier [23].

surface of LiFePO<sub>4</sub> to a thickness of about 2 nm (roughly 3–5 layers of graphene) and created a constant composition. The LiFePO<sub>4</sub> nanoparticles had consistent size (2–5 nm). The substance thus acquired shows regular morphology and organization, which could be considered an expansive way to upgrade the conductivity. This substance can be covered with carbon support to get graphene-based LiFePO<sub>4</sub> with extraordinary lifetime and cycling potential.

#### 3.1.2. Graphene Li<sub>3</sub>V<sub>2</sub>(PO<sub>4</sub>)<sub>3</sub> (LVP) composites as LIB cathode materials

In contrast with LiFePO<sub>4</sub>, Li<sub>3</sub>V<sub>2</sub>(PO<sub>4</sub>)<sub>3</sub> is an appealing cathode material for LIBs, in light of the fact that its normal insertion voltage is around 4.0 V and its theoretical capacity is 197 mAh g<sup>-1</sup>. Li<sub>3</sub>V<sub>2</sub>(PO<sub>4</sub>)<sub>3</sub> has high working voltage and demonstrates decent execution at high discharge current. In any case, its naturally small electronic conductivity (240 ns cm<sup>-1</sup> at 25 C) limits its velocity; therefore, graphene is used to enhance its electrochemical performance. Graphene-based cathodes have been prepared using sol-gel strategies [31,32]. The material that was synthesized by the sol-gel technique demonstrates magnificent rate capacity and cycling strength [33].



**Fig. 4.** Charge-discharge curves of  $\text{LiMnPO}_4/\text{C}$  and  $\text{LiMnPO}_4/(\text{G}+\text{C})$  composites at 0.05 C. Reprinted from Jiang et al. *J Mater Res*, 28, 2584 (2013), with permission of Material Research Society [34].

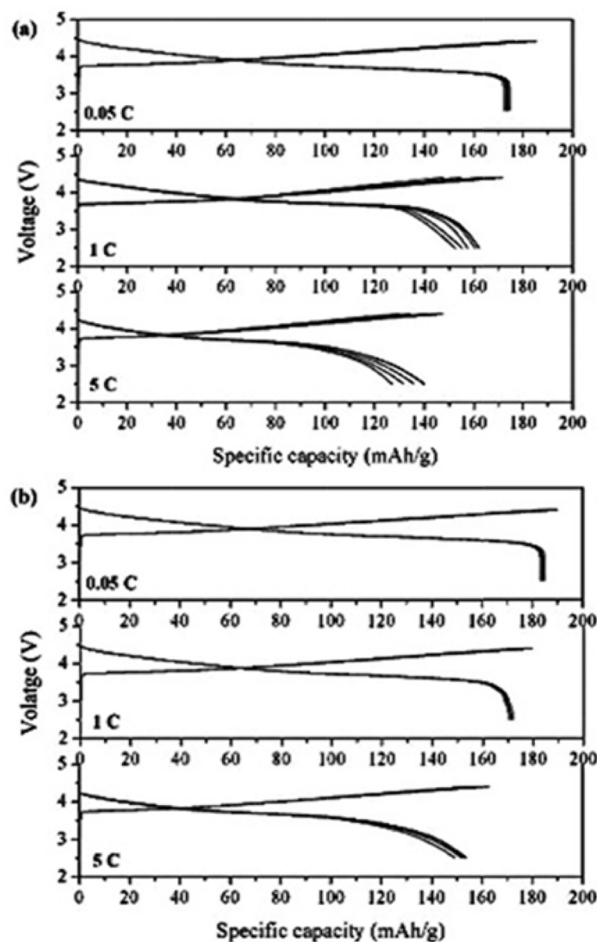
### 3.1.3. Graphene $\text{LiMnPO}_4$ (LMP) composites as cathode materials for LIBs

Another attractive candidate electrode material for LIBs is  $\text{LiMnPO}_4$  because of its high  $\text{Li}^+$  insertion potential (4.1 V). As a result, 21% more energy density could be achieved than with  $\text{LiFePO}_4$ . The property that hinders this material is its low electrical conductivity. To deal with this problem, graphene-modified  $\text{LiMnPO}_4$  was synthesized. The role of graphene was not only to serve as substrate but also to play a crucial role in enhancing the conductivity of the electrode material for LIBs [34]. It was reported that its electrochemical performance was much better than that of bare  $\text{LiMnPO}_4$  (for the new material:  $105.1 \text{ mAh g}^{-1}$  at 0.05 C). The specific capacity curves for the charge and discharge of the  $\text{LiMnPO}_4/\text{C}$  and  $\text{LiMnPO}_4/\text{G}+\text{C}$  compounds can be seen in Fig. 4.

In general, the main reason to use the graphene phosphate composite can be explained by its two major characteristics. First, graphene has the ability to maintain the phosphate nanostructure and improve the cycle stability. Second, the conductance of the cathode material with graphene is increased, compared to unmodified materials.

### 3.1.4. LIB composite cathode materials of graphene plus lithium with Mn, Ni, and Co metal oxides

$\text{LiMn}_2\text{O}_4$  is another cathode material, and it is more attractive because of its easy availability and abundance [35]. Its low electrical conductivity brings about a low rate capacity. It is reported in different manuscripts that graphene sheets are viable operators for enhancing the rate capacity and conductivity.  $\text{LiMn}_2\text{O}_4$  graphene composites with higher rate capacity were combined using a hydrothermal strategy [36]. The composites showed reversible capacities of 102 and  $118 \text{ mAh g}^{-1}$  at 50 and 100 C, respectively. In another study, a  $\text{LiMn}_2\text{O}_4$  graphene compound was integrated via self-assembly transfer using a combined strong lithiation strategy



**Fig. 5.** Charge-discharge curves of (a)  $\text{LiNi}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}\text{O}_2$  and (b)  $\text{LiNi}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}\text{O}_2$  graphene at different scan rates. Reprinted from Venkateswara et al. *ACS Appl Mater Interfaces*, 3, 2966 (2011), with permission of American Chemical Society [28].

[14]. The upgrading of the electrochemical characteristics was ascribed to unparalleled  $\text{Li}^+$  dispersion energy and enhanced stability in spite of the high voltage passing through the crystalline  $\text{LiMn}_2\text{O}_4$  graphene amalgamation. Moreover, their abilities moved toward the hypothetical maximum and the cycling strength was improved.  $\text{LiCoO}_2$  is another widely used cathode material, but there are some drawbacks due to which its utilization as an electrode is limited. These drawbacks include toxicity, low thermal stability, and low specific capacitance ( $130$  to  $140 \text{ mAh g}^{-1}$ ). To overcome these issues, it is necessary to synthesize a promising new material with excellent electrochemical properties.

$\text{LiNi}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3}\text{O}_2$  graphene composites were prepared to increase the electrochemical efficiency of LIBs. The reported specific capacity of graphene- $\text{LiNi}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3}\text{O}_2$  was  $196 \text{ mAh g}^{-1}$  at 0.2 C [37], which was much greater than that of the bare  $\text{LiNi}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3}\text{O}_2$ . Venkateswara et al. [28] synthesized graphene-based  $\text{LiNi}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3}\text{O}_2$  composites that showed good electrochemical performance. The composites exhibited high rate capability, long cycle performance, and specific capacity of

**Table 2.** LIB anode materials (non-carbon) containing graphene

Anode materials	Composition	Capacity for first cycle	Capacity retention after several cycles	Synthesis scheme	Author (year)
TiO <sub>2</sub> /graphene	Rutile type	First discharge capacity 499 mAh g <sup>-1</sup>	After the 10 cycles sustain 150 mAh g <sup>-1</sup>	Gas/liquid interface reaction	Tung et al. (2009) [12]
Fe <sub>3</sub> O <sub>4</sub> /graphene	Trans spinel	First discharge capacity 1426 mA hg <sup>-1</sup>	After 100 cycles sustain 580 mAh g <sup>-1</sup>	Reduction	Kim et al. (2016) [38]
CuO/graphene	Sphalerite	First discharge capacity 640 mAh g <sup>-1</sup>	After 50 cycles sustain 583.5 mAh g <sup>-1</sup>	N-methyl-2-p yrrolidone Solvent	Wu et al. (2010) [39]
Mn <sub>3</sub> O <sub>4</sub> /graphene	Spinel	First discharge capacity 900 mAh g <sup>-1</sup>	After 100 cycles sustain 390 mAh g <sup>-1</sup>	Hydrothermal	Wei et al. (2013) [40]
Co <sub>3</sub> O <sub>4</sub> /graphene	Spinel	First discharge capacity 1826 mAh g <sup>-1</sup>	After 40 cycles sustain 1310 mAh g <sup>-1</sup>	Solvothermal	Lian et al. (2010a)
SnO <sub>2</sub> /graphene	Orthorhombic	First discharge capacity 1588 mAh g <sup>-1</sup>	After 40 cycles keep 730 mAh g <sup>-1</sup>	Hydrothermal	Zhu et al. (2011)
Fe <sub>3</sub> O <sub>4</sub> -SnO <sub>2</sub> -graphene	-	First discharge capacity 1740 mAh g <sup>-1</sup>	After 115 cycles sustain 1198 mAh g <sup>-1</sup>	Gas/liquid interfacial Reaction	Lian et al. (2011) Choucairet
CeO <sub>2</sub> /graphene	Face-centered cubic	First discharge capacity 1469 mAh g <sup>-1</sup>	After 100 cycles sustain 605 mAh g <sup>-1</sup>	Hydrothermal	Wang et al. (2011) [41]
SnS <sub>2</sub> /graphene	Hexagonal crystal	First discharge capacity 1664 mAh g <sup>-1</sup>	After 500 cycles sustain 600 mAh g <sup>-1</sup>	Solution phase method	Lian et al. (2010) [42]

188 mAh g<sup>-1</sup>, which were better than for LiNi<sub>1/3</sub>Mn<sub>1/3</sub>Co<sub>1/3</sub>O<sub>2</sub>. The specific capacity at different discharge rates can be seen in Fig. 5.

This promising candidate (LiNi<sub>1/3</sub>Mn<sub>1/3</sub>Co<sub>1/3</sub>O<sub>2</sub>) for use in cathode materials has some other excellent characteristics. It has already been demonstrated to have higher energy capacity, good reliability, and improved safety [30].

#### 4. Anode materials with graphene in LIBs

Graphene has opened up new potential in the field of LIB materials because of its high electrical conductance, common mechanical flexibility, light weight, and material stability [11]. These properties become valuable when graphene is utilized in an anode material. The use of graphene in anode materials provides greater surface area, higher electric conductivity, high surface to volume ratio, structural adaptability for flexible electrodes, and dependable synthesis, which ensure its strength under harsh conditions.

Recently, anode materials for LIBs that do not depend on carbon have been predominantly tin based anode materials, as well as transition-metal based and silicon materials [38]. Despite the fact that the previously mentioned materials have high theoretical capacity, the downsides to their utilization as anode materials are volume changes during lithiation and delithiation, and extensive internal stresses. After constant charging and discharging, these materials tend to disintegrate, bringing about reduced cycling execution. To overcome these weaknesses, graphene is utilized. Table 2 [12,38-42] shows the different properties of LIB anode materials doped with graphene. Some of the more broadly and generally utilized materials are discussed in this paper.

#### 4.1. Graphene-silicon-based compound materials as anodes for LIBs

As an anode material, silicon (Si) and lithium (Li) particles have the structure Li<sub>4.4</sub>Si. The theoretical charge capacity of this substance is up to 4200 mAh g<sup>-1</sup> and it has a low discharge voltage. Nonetheless, a constraint to its utilization is its charge volume impact. During the discharging procedure, silicon and lithium take the form Li<sub>3.75</sub>Si. Subsequently, the silicon volume expands up to 2.7 times, which causes safety issues [13]. The expansion of Si nanomaterials and a carbon layer can support this volume extension to some degree. When graphene is added; it can accommodate the assembly of silicon nanoparticles and enhance the electron and lithium ion transport capacity. Yushin and his co-researchers utilized a vapor deposition strategy to prepare a consistent Si film on the surface of a graphene sheet. After that, high temperature coating with propylene permitted the Si surface to be covered with carbon.

#### 4.2. Graphene-transition metal-based composites as LIB anode materials

To achieve higher capacity in LIBs, TMO, which have high lithium storage capacity, were identified as a potential option for anode material. Graphene can similarly be utilized to enhance their electrical and chemical characteristics, due to the occurrence of the changes in volume during charging and discharging and to their low conductance.

The theoretical capacity of Co<sub>3</sub>O<sub>4</sub> is 890 mAh g<sup>-1</sup>. Nevertheless, huge changes in volume may occur during charge and discharge. The electrochemical characteristics of Co<sub>3</sub>O<sub>4</sub> can be adequately enhanced by the use of graphene in the anode material [40]. For instance, with CoOH<sub>2</sub>, in the first cycle the specific capacity of lithium was 200 mA g<sup>-1</sup> at a current density of 662

mAh g<sup>-1</sup>. The specific capacity was enhanced to 1120 mAh g<sup>-1</sup> during hydrothermal reduction synchronization with graphene. The reverse capacity after 30 cycles of the complex materials retained 83% of the initial capacity. The theoretical capacity of Mn<sub>3</sub>O<sub>4</sub> is 935 mAh g<sup>-1</sup>. Be that as it may, because of its reduced electrical conductivity (around 10<sup>-7</sup> to 10<sup>-8</sup> S cm<sup>-1</sup>); the highest real capacity when doped with cobalt reached only 400 mAh g<sup>-1</sup>. When the graphene composite was synthesized through a two-stage fluid technique, followed by a hydrothermal treatment, the delithiated proportion capacity of this composite material was around 900 mAh g<sup>-1</sup> at small current densities (40 mA g<sup>-1</sup>), near the maximum theoretical capacity. When the current density achieved was 1600 mA g<sup>-1</sup>; the capacity of this compound remained 380 mAh g<sup>-1</sup>.

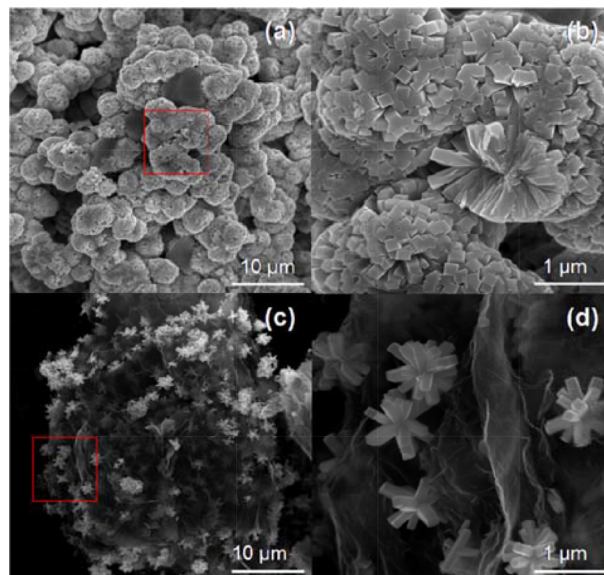
CuO has a small energy band gap and high reactant action. When it is utilized as an anode material, it has low conductance but large capacity extension properties. These deficiencies can be enhanced by combining copper oxide CuO with graphene [39]. To begin with, copper oxide CuO and graphite oxide are utilized to prepare a graphene compound by means of an aqueous solution, which is followed by a reducing procedure. After 50 cycles, the reverse capacity achieved for the compound material was 583 mAh g<sup>-1</sup> and its capacity retention was 77.5%.

Graphene compounds have excellent increase in their rate execution, with the exception of when they are arranged using a gas/liquid interface strategy. Another compound of Fe<sub>2</sub>O<sub>3</sub> and graphene was achieved via a hydrothermal technique. The growth of graphene retained Fe<sub>2</sub>O<sub>3</sub> within the assembly and furthermore, moderated the change in material volume. With 1170 mA g<sup>-1</sup> current density, the reversible capacity of the compound remained at 670 mAh g<sup>-1</sup> after 100 cycles. Graphene with TiO<sub>2</sub> is an additional nanocomposite that can be integrated via a simple gas and liquid line reaction. The benefit of this nanocomposite is that the oxygen clusters on the graphene sheets are diminished subsequent to the heat treatment and the remaining practical deposits, as well as the plane of the graphene sheets, can associate closely by way of the metal particles during the mixing procedure. The uniform hybridization of TiO<sub>2</sub> nanoparticles and ultrathin graphene sheets occurred with a 3D porous association of TiO<sub>2</sub> graphene nanocomposites. Nanoparticles have provided a method by which to favor the mobility of electron and lithium ions to drive lithium-ion adsorption and extraction with remarkable rate capacity.

### 4.3. Graphene-tin based oxide composites as LIB anode materials

Tin oxides have potential for use in the anode materials of LIBs. Nevertheless, there are flaws that limit their utilization. One is that an electronic barrier repulsive to Li<sup>+</sup> will frequently occur due to chemical reduction. Two reactions (lithiation and delithiation:  $\text{Sn} + 4.4\text{Li}^+ + 4.4\text{e}^- \leftrightarrow \text{Li}_{4.4}\text{Sn}$ ) may result in substantial volume change. The pummeling of the particles and electrical disconnect of the electrodes are the results of these reactions. Keeping in mind the final goal to bypass these obstacles,

innovative graphene-containing electrode materials have been presented in numerous previous reviews. For instance, when tin-particles with graphene were utilized, the function of the anode was enhanced [43]. The volume change, as well as the



**Fig. 6.** SEM illustration of flower-like graphene at different magnifications. Reprinted from Huang et al., with permission of Elsevier.

charge/discharge rates, was improved by the graphene matrix. In addition, as a result of the increased electronic conductivity, electron transport was also promoted. It is essential to utilize a hydrothermal method followed by annealing to synthesize this sort of anode for LIBs. For higher lithium storage capacity, graphene composites can be prepared using a basic hydrothermal technique. Tin oxide nanorods (800 nm) were the result of a preparation procedure with density of 50 mA g<sup>-1</sup>, as shown in Fig. 6. The product was used to demonstrate initial discharge and charge capacity of 1588 and 1240 mAh g<sup>-1</sup>, respectively [42].

## 5. Conclusions and Outlook

From comparison of common carbon-containing electrode materials, it is evident that graphene has low columbic effectiveness, higher charge time, and a number of other deficiencies. These make it impossible to replace conventional graphite in electrode materials. Graphene demonstrates excellent conductivity, good mechanical strength, outstanding flexibility, high specific surface area, and good chemical stability. It is particularly observable when chemically converted graphene offers a wider range of functional groups, that it has great potential as a suitable composite electrode material for LIB applications. When graphene is used as an electrode material, it can visibly shrink the area of the dynamic material before the nanoparticles are distributed, and induce higher transition rates of ions and electrons in ways that enhance the characteristics of the electrodes.

As a consequence, electrode materials prepared with graphene have great storage capacity and high rate-performance. Electrode materials with graphene such as Si-based compounds, tin-based composites, and LiMPO<sub>4</sub>-graphene have been broadly considered in this manuscript. The advantages of these composite

materials can be summarized as follows. First, the flexibility of graphene makes it perfect for supporting the metals used to extend the electrode capacity, with better rates of charging and discharging. This also increases the life cycle performance of the electrode material. The outstanding electrical characteristics of graphene can improve the conductivity of metal electrode materials. In addition, the synthesis of metal oxide particles can be managed utilizing graphene. Smaller particles decrease the separation and dispersion of the lithium ions and electrons, and this increases the efficiency of the material rates. Finally, the capacity of lithium storage with respect to compound materials of metal oxides with graphene has been significantly enhanced. For the preparation of graphene, different methodologies are available. These vary from fundamental methodologies to the in situ control of different reactions, as well as unnatural reactions that provide better graphene morphology and structures. The best approach to improving the potential use of graphene in LIB electrode materials would be to develop adequately replicable methods for creating graphene.

Although significant improvement has been achieved, studies in this field are still in their initial stages, and some significant challenges remain. For instance, the creation of graphene-based material with dependable physical characteristics still needs advancement. Moreover, the lithium storage capacity of graphene is still inadequate amid long cycling times, low volumetric energy density, and low tap density. Moreover, the systems of the graphene-based materials used in vital storage frameworks are not totally clear, and the understanding of lithium storage in different types of graphene is as yet confounding. However, graphene-based materials have been utilized to enhance the performance of LIBs. After completely investigating the capability of graphene through the multidisciplinary efforts of scientists, physicists, and materials researchers, we feel certain that numerous utilizations of these to form new materials will occur soon. In addition, to get better LIB performance, it is essential to investigate more clearly the interaction between graphene composites and their morphologies in the future.

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## Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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