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REVIEW

3D Flower-like Composites in Energy Storage and Photocatalytic Applications: A Review

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This extant review looks at the energy storage and photocatalytic degradation efficiency of various three-dimensional flower-like composites. Cobalt/nickel composites with porous structure and high surface area were efficient in energy storage applications. Graphene in 3D flower-like compounds with cobalt/nickel compounds improves the electrochemical performance. Photocatalytic degradation of bismuth compounds/silver compounds containing 3D flower-like composites was effective. 3D Flower-like graphene composites have excellent energy storage and photocatalytic properties. This review will generate interest among researchers to develop new 3D flower-like composites with unique properties in energy storage and photocatalysis. This study could lead to more innovative methods of creating novel 3D flower-like composites with high potential for future applications.

Keywords: 3D Flower-like composites, Energy storage, Photocatalytic degradation, Battery, Super capacitor.

INTRODUCTION

With the spiraling energy demand and due to the extinction of the fossil fuels in the upcoming generation there is the need of growth in the electrical storage device in the electric vehicles (EVs), portable devices and hybrid EVs, hence it becomes necessary for researches to think of the surrogates for the petro-based engines and is the most challenging task to enhance the electrochemical performance [1]. In this context, we have reviewed 3D flower like composites which has been employed for the electrical energy storage devices in the batteries such as lithium ion batteries and sodium ion batteries. On the contrary, burning of the fossil fuels causes the most serious issue of the global warming and the environmental pollution [2,3]. Moreover, this review also looks after the photocatalytic application of these composites. Due to the ability of three-dimensional (3D) flower-like composites to speed up the movement of ions and electrons through more electroactive sites in contact with the electrolyte, the 3D nanomaterials with flower-like structures and have large specific surfaces which has attracted increasing interest of the scientists [4-8]. According to Wang *et al.* [9] some 3D micro flower composites have structural advantages such as faster electron/ion transport and diffusion, large specific surface areas and sufficient electroactive sites that make them prime candidates for energy storage applications. Due to their extremely high-power density, quick charge/discharge nature, extended cycling life and advantageous safety, supercapacitors (SCs) are ideal energy storage devices and power sources for digital and other portable electronic devices [10,11]. Some of the integrated 3D flower nanocomposites such as a nanosheets of TiO_2 coated MoS_2 on carbon and reduced graphene oxides with 3D nanoflower of hierarchical Cu_2NiSnS_4 utilized as an advanced anode electrode in sodium ion batteries [12-16].

Hussain *et al.* [17] constructed the nanocomposite with the 3D flower like morphology based on the ZnO/NiO and was well scrutinized using SEM, TEM, XPS and XRD techniques and further electrochemical analysis was done using the cyclic voltammetry (CV), galvanostatic charge-discharge (GCD) and electrochemical impedance spectroscopy (EIS), which exhibits the specific capacitance of 350 C g^{-1} at current density of 2 A g^{-1} and shows 72.1% of the cyclic stability with 8000 cycles.

Because of their enhanced surface area, reduced ion and charge penetration routes and higher electrical conductivity, 3D structured mixed transition metal oxides have been widely used in super capacity applications [18]. Mixed transition metal oxides with 3D architecture have gained popularity in supercapacitor applications because they provide a synergistic effect of all the individual constituents with increased surface area, reduced ion and charge penetration paths and increased electrical conductivity. In last decade, $Ni(OH)_2$ has received a lot of interest as a pseudocapacitive transition metal oxide due to its low cost, eco-friendliness, high theoretical capacitance and good stability in alkaline electrolytes [19]. Due to its favourable capacitive characteristics and environmental compatibility, $Co(OH)_2$ is widely regarded as a promising electrode material for supercapacitors [20,21]. Researchers developed composites of $Co(OH)_2$ by combining it with conducting substrates such as carbon materials and Ni foam to produce composites with superior properties [22-24]. Cao *et al.* [25] also developed the electrochemical sensor for the perilous photographic emerging agents using the porous flower like nanoplates of carbon/graphene@Co_3O_4, which parades the excellent recital towards the metol, hydroquinone and catechol that frequently contaminates the environments and acts as a water pollutant.

Ni foam is frequently employed in energy storage because of its superior conductivity and 3D structure [26] that can be used as an electrode substrate. Jeong & Chae [27] explored the 3D flower like nanocomposite of tin monosulfide/carbon nanostructure for an anode in sodium ion batteries. Graphene, a fascinating carbon material, has a large surface area and unique features such as electrical conductivity, chemical stability and superior mechanical and thermal capabilities [28-30].

3D Flower-like composites including $Ni(OH)_2$ or $Co(OH)_2$ have gained attention in the development of nanoporous materials with increased surface area for LiBs and supercapacitors. The high surface area and nanoporous structure of 3D flower-like composites containing nickel, cobalt or graphene improves the energy storage capabilities. Incorporating $Ni(OH)_2$ into graphene or other carbon materials results in prospective products with good electrochemical performance from each component [31]. Metal oxides (or hydroxides) with reversible redox processes have higher specific capacitance and energy density than carbon materials [32-34].

Nickel hydroxide is particularly appealing because of its well-defined electrochemical redox activity, high specific capacitance and inexpensive cost [35]. Ternary transition metal oxides ($NiCo_2O_4$, $MnCo_2O_4$, $FeCo_2O_4$) have more active centers for improved electrochemical properties because they provide more redox reactions per active centre resulting from each component and their coupling effects [36]. The high electrochemical performance of 3D flower-like composite materials was achieved by creating specialized 3D architectures with large active centers and simple ion diffusion pathways [37-39]. Because of its enhanced surface area, which increases the number of redox reaction sites in the porous structure and results in excellent super capacitive performance, low cost $Ni(OH)_2$ has attracted more attention in the development of nanoporous 3D flower-like composites. Further, 3D flower like spinel oxide of $NiCo_2O_4$ consisting of 110.4 m^2 g^{-1} considered to a large surface area unveiling much higher methanol electro-oxidation current of 148 mA cm^{-2} at 0.6 V (*vs.* Hg/HgO) [40].

With the increasing industrialization and urbanization, the limitation of the fresh waterbodies and elevating water pollution can be the critical recognized issue. The 3D-flower like composites acts as a photocatalyst for photocatalytic degradation of the certain organic pollutant such as a pesticide, dyes, antibacterial material and drugs can be done using efficient visible light irradiation [41-49]. In photocatalytic applications of 3D flower-like composites, BiOCl-containing 3D composites were discovered to have enhanced visible light sensitivity because BiOCl had less activity in visible light. Because of its high activity and other unique qualities in the photodecomposition of organic pollutants in visible light, Ag_3PO_4 as a photocatalyst has gained attention [50-56]. Because of the increased separation rate of photogenerated electron hole pairs, Ag_3PO_4-containing 3D flower-like composites perform better photo catalytically [57]. AgX (X = Cl, Br, I) is a potential visible light photocatalyst in the degradation of contaminants. Composites produced by depositing AgX on a semiconductor with a staggered band exhibit excellent photocatalytic capabilities [58]. Nevertheless, some Fe based 3D flower like photocatalyst was also utilized for the organic chemical and dye degradation while also can degrade the drugs like ciprofloxacin [59-61]. Some metal oxides explored as photocatalysts were efficient in degradation of harmful organic substances and designing crystalline nanostructures, with controllable morphology using environmentally friendly protocols remains a vital challenge in nanoscale chemistry [62,63]. In the form of several BiOI-based composites, BiOX (X = Cl, Br, I) has emerged as an efficient photocatalyst with improved characteristics [64-76]. Bi_2WO_6 is a possible n-type semiconductor material with a narrow band gap (2.8 eV), high stability and efficient photodegradation under visible light [77]. Because of the SPR effect, photocatalysts containing Ag exhibit significant pollutant degradation. Furthermore, Ag nanoparticles absorb light at the specific wavelengths, accelerating catalytic performance [78,79]. Thus, 3D flower-like composites have attracted researchers as it is found to be efficient in photocatalytic and energy storage applications.

3D Flower-like composites in energy storage applications: Researchers have made a groundbreaking discovery regarding 3D flower-like composites that present a remarkable potential for various energy storage applications. This development opens up a wide array of possibilities and promises to revolutionize the way we store and utilize energy [80-82]. The unique structure of these composites provides exceptional properties, including increased surface area, enhanced conductivity and improved stability. These qualities make them ideal candidates for high-performance energy storage devices such as batteries and supercapacitors. With such promising findings, we can look forward to advancements that will help us to address the growing demand for efficient and sustainable energy storage methods [81,83-85].

3D Flower-like composite materials having cobalt compounds in battery applications: 3D Flower-like composites containing cobalt compounds were made and evaluated for electrochemical performance [86-90]. Some examples of 3D flower-like composites incorporating cobalt compounds include:

The 3D flower like structure of $CuCo_2O_4$ structure embedded on the nickel foam exhibiting the capacity of 1160 mAh g^{-1} later 200 cycles when employed as an anode for lithium anions batteries and specific capacitance of 1002 F g^{-1} subsequently 3000 cycles [86]. 3D Flower-like (Co(1-xs)/MoS_2), 3D flower-like $NiCo_2O_4$@MnO_2, 3D Co_3O_4/CNF and 3D flower like $NiCo_2O_4$-CN-180 composite having cobalt compounds were reported with good specific capacity. When used as an anode for LiBs, a 3D flower-like Co(1-xs)/MoS_2 composite [87], demonstrates a high discharge capacity of 1033 mAh g^{-1} after 100 cycles at 0.2 A g^{-1}. The huge surface area to grow MoS_2 in 3D flowers like Co(1-xs) results in superior electrochemical performance. The energy storage is better in the 3D flower like Co(1-xs)/MoS_2 composite because the MoS_2 nanosheets develop on the surface area of the 3D flower like Co(1-xs). Zhang *et al.* [88] also developed a one-of-a-kind 3D flower like $NiCo_2O_4$@MnO_2 nanocomposite with increased electrochemical properties.

The porous surface shape and enhanced specific surface area of 3D flower-like $NiCo_2O_4$@MnO_2 nanocomposite allow for more interaction with the electrolyte and electrode material, resulting in faster ion and electron transport [88,91,92]. After 100 cycles, the 3D flower-like $NiCo_2O_4$@MnO_2 was found to have a high specific capacity of 841.9 and 1000 mAh g^{-1}. The increased pore capacity in the 3D floral composite made the Li^+ insertion/extraction process more efficient. The anode material for a lithium-ion battery was a 3D Co_3O_4/CNF nanocomposite [93]. After 50 cycles, the hexagonal flower-like structure of 3D Co_3O_4/CNF has a large surface area and active sites, resulting in a high specific capacity of 911 mAh g^{-1} at a current density of 200 mAh g^{-1}.

Similarly, $NiCo_2O_4$-CN-180, a 3D flower-like $NiCo_2O_4$-CN nanocomposite [94] catalyst with N-doped carbon and linked $NiCo_2O_4$ nanosheets produced by hydrothermal reaction at 180 ºC, has high-capacity performance up to 738.7 mAh g^{-1}. The 3D Flower-like composites with large surface area, porous shape and more active sites boost the efficiency of the Li^+ ion insertion process, resulting in outstanding electrochemical performance.

3D Flower-like composites having nickel compounds in battery application: 3D Flower-like composites containing nickel compounds are also reported and its energy storage properties were also tested [95-99]. The 3D Flower like porous ZnO-NiO/graphene composite [95] was synthesized by introducing flexible graphene into the flower like porous ZnO-NiO. The 3D porous ZnO-NiO/graphene provided more storage space for lithium and shows high specific capacitance and excellent cycling stability. The porous morphology, high active surface area and the presence of graphene sheets in the 3D flower-like composite improve the electrochemical performance and cyclic stability. By introducing flexible graphene into the flower-like porous ZnO-NiO in the composite provides large enough inner space and high active surface area. The graphene sheets present in the 3D flower like ZnO-NiO composite helps to set up a 3D carbon conductive network that provides high electronic conductivity. The 3D flower-like ZnO-NiO/graphene composite exhibits the reversible capacity of 452.7 mAh g^{-1} after 50 cycles at a current density of 300 m A g^{-1}. 3D Flower-like NiS-Ni_3S_4/sterotaxically constructed graphene composite (NiS-Ni_3S_4/SCG) in which the SCG serves as an efficient 3D conductive network that results in reversible specific capacity of 322.9 mAh g^{-1} at a current density of 10 A g^{-1} after 2000 cycles [96]. The 3D flower-like composites containing nickel compound [95,96] possess high surface area with porous morphology that provided more storage space for lithium ions. The flower-like architecture in 3D flower like composites containing nickel compounds provides more contact area with the electrolytes resulting in high electrochemical performance. Table-1 presents the 3D flower-like composites with their specific capacity in battery applications.

TABLE-1
3D FLOWER-LIKE COMPOSITES IN BATTERY APPLICATION

3D Flower-like composite materials	Specific capacity	Current density	Ref.
Cobalt			
$CuCo_2O_4$/NF	1160 mAh g^{-1}	1 A g^{-1}	[86]
(Co(1-xs)/MoS_2)	1033 mAh g^{-1}	0.2 A g^{-1}	[87]
$NiCo_2O_4$@MnO_2	1000 mAh g^{-1}	500 mA g^{-1}	[88]
3D Co_3O_4/CNF	911 mAh g^{-1}	–	[93]
$NiCo_2O_4$-CN-180	738.7 mAh g^{-1}	–	[94]
Nickel			
ZnO-NiO/graphene	452.7 mAh g^{-1}	300 mA g^{-1}	[95]
NiS-Ni_3S_4/SCG	322.9 mAh g^{-1}	10 A g^{-1}	[96]

3D Flower-like composite materials containing cobalt/cobalt compounds: 3D Flower like composites having cobalt compounds [19,100-103] were prepared and tested for its electrochemical performance. 3D Flowery $Co(OH)_2$/N-doped graphene composite (NGE-$Co(OH)_2$) synthesized using sol gel process exhibit superior electrochemical properties [100]. The presence of doped N atoms in the skeleton of graphene and the formation of an electric tunnel between $Co(OH)_2$ and graphene resulted in high specific capacitance of 2276 F g^{-1} at 1 A g^{-1}. The NGE-$Co(OH)_2$ composite possess higher specific surface area (109.1 m^2/g) with Co atoms present on the surface of cobalt hydroxide. 3D Flower like RGO/Co_3O_4/$Ni(OH)_2$ composite film on nickel foam (RCNN) was synthesized using a modified active metal substrate route to employ them as super capacitor electrodes [19]. In nickel foam (NF), the formation of 3D flower like network structure is more advantageous compared to the planar network structure due to the increased surface area and effective ion transfer between RCNN and electrolytes, where RCNN shows improved specific capacitance of 2133.2 F g^{-1} at a current density of 2.3 A g^{-1} in 1 M KOH solution.

Han's group [101] developed the sponge type 3D flower like well-engineered heterogenous core shell composite of the $CuCo_2O_4$@$CuCo_2S_4$ which acts as advanced cathode electrode and activated carbon as an anode to give the progressed energy density and stability for the asymmetric supercapacitor. This core shell heterogenous composite acting as cathode electrode was depicting the flower like structure in the SEM and TEM images. The specific capacity of the sponge type 3D flower like well-engineered heterogenous core shell nanocomposite of $CuCo_2O_4$@$CuCo_2S_4$ an electrode material depicts up to 1459.15 C g^{-1} at 1 A g^{-1}. Further, the specific capacity remains 93.23% after 10000 cycles even at 10 A g^{-1} [101]. 3D Flower like MoS_2/$NiCo(OH)_2CO_3$ (MoS_2/NiCoHC) has large specific surface area and more active sites that provides high super capacitive performance with a specific capacity of 583 C g^{-1} (1296 F g^{-1}) at 1 A g^{-1} [104]. 3D Flower-like iron doped cobalt copper phosphide/phosphate composite (FeCoCuP) was used as an efficient electrode material with a specific capacity of 1290 C g^{-1} at 1.0 A g^{-1} current density. The 3D flower-like structure of FeCoCuP sample provides a large surface area (58.98 m^2/g) with more active sites, resulting in strong electrochemical activity. With its high surface area and electrical conductivity, the 3D flower-like FeCoCuP provides additional active sites that induce excellent superconductor performance [18].

The 3D flower-like structure of MoS_2/NiCoHC composite enhances the surface area and provides more active sites for good super capacitive performance, whereas 3D flower-like $Co(OH)_2$/Ni foam composite exhibit high specific capacitance (1350 F g^{-1} at 30 mA cm^{-2}) and excellent rate capability [105]. In 3D flower like $Co(OH)_2$/Ni foam composite the flower-like $Co(OH)_2$ micropheres were assembled on the 3D porous structured nickel foam for high performance supercapacitor applications. At a current density of 1 A g^{-1}, a 3D MnS/Co_9S_8(MCS) microflower composite with serrate edges on Ni foam [10] exhibits a high specific capacity of 1070 C g^{-1}. The increased surface area of the 3D microflower composite with serrate edges substantially boosted the electrochemical performance of the electrode material in producing energy storage devices. 3D Flower-like $Co_2(OH)_3Cl$-MnO_2 hybrid composite [106] were prepared using shell membrane aided synthesis method in which egg shells were used to provide a unique nucleation environment for the formation of nanostructured 3D flower like porous $Co_2(OH)_3Cl$-MnO_2 hybrid composite with high capacitance of 134.8 F g^{-1} at 0.2 A g^{-1}. In the 3D flower-like $CoNi_2S_4$ grown on graphene decorated nickel foam (3D flower-like CNS/GNF) the 3D flower-like CNS with strong skeleton and nickel foam provides good surface area to support the CNS micro flowers [107]. The graphene layers were introduced between the CNS and nickel foam enhances the electrochemical property of the 3D flower-like CNS/GNF composite with good specific capacitance of 6.58 F/cm^2 at a current density of 6 mA/cm^2.

In 3D flower-like composites containing cobalt compounds for supercapacitor applications the 3D flower-like structure is more advantageous as it provides more surface area that increases the storage space and effective ion transfer between the 3D flower-like composite and the electrolyte. Hence, 3D flower-like composites containing cobalt compounds have gained attention in super capacitors.

Nickel/nickel compound containing 3D flower-like composite materials in supercapacitor applications: The 3D flower-like composites containing nickel compounds were prepared by many workers [9,36,108-113] and its supercapacitor applications were also tested. The hierarchical dahlia flower-like $NiCo_2O_4$/$NiCoSe_2$ was synthesized and characterized, which reveals the formation of the 3D dahlia like flower structure and elemental composition and was employed for the high energy density supercapacitor in which it exhibits the specific capacitance of 2045.5 F g^{-1} at 1.8 A g^{-1} with durable cyclic stability of 82.5% after 10,000 charge-discharge cycles and was also utilized for electro-oxidation of methanol [108].

A novel 3D flower like Ni-V-Se composite (NiVSe/rGO/NF) possess large specific surface area and sufficient electroactive sites provided an exclusive nanostructure with a high specific capacity of 1197.6 C g^{-1} at 1 A g^{-1} [9]. The 3D flower-like NiVSe/rGO/NF composite has more electroactive sites due to the unique flower-like structure that ensures the efficient contact of the electrolyte/electrode. The high surface area and adequate electroactive sites in 3D flower-like NiVSe/rGO/NF composite provides efficient electrochemical energy storage performance. Another 3D flower-like NiMnLDH/rGO composite are also prepared with different loading of NiMnLDH on graphene nanosheets as reported by Huang *et al*. [109]. Similarly, 3D flower-like ultrathin layered double hydroxide of graphene@$NiCo_2S_4$@Ni-Mo exhibiting the elevated performance of electrochemical properties and depicting the specific capacitance of 1346 F g^{-1} at the current density of 1 A g^{-1} as reported by Cheng *et al*. [110].

The 3D flower-like NiMnLDH/rGO composite containing rGO 4.46 wt.% posess highest specific capacitance of 1500 F g^{-1} due to the large accessible specific surface area and porous structure. The NiMnLDH nanosheets were grown on graphene skeleton to facilitate electrolyte transport and obtain more electrochemical active sites. 3D Flower like $Ni_3V_2O_8$@CNT composite was synthesized with high electrical conductivity and charge transport by anchoring CNTs on $Ni_3V_2O_8$ [36]. The 3D flower-like $Ni_3V_2O_8$@CNT composite possess high specific capacitance (1054 F g^{-1} at 1 A g^{-1}) and excellent cycling stability. 3D flower-like $Ni_3V_2O_8$@CNT composite has a high specific surface area of 176 m^2/g with enhanced electrical conductivity. The presence of CNT in the 3D flower-like nanocomposite improves the electrical conductivity. The flower-like open architecture relieves the volume changes during the charge/discharge process and enhance the electrochemical performance of supercapacitor [111]. The XPS results revealed the successful composition of CNTs anchored on the 3D flower like $Ni_3V_2O_8$ with significant surface area and more ion diffusion channels. Similarly, another type of 3D hierarchical flower like $NiMoO_4$@Ni_3S_2 composite was studied by adding different amounts of ethylene glycol and the morphology change of Ni@$NiMoO_4$@Ni_3S_2 [114]. Alternatively, the 3D architecture nickel-cobalt manganese layered double hydroxide/reduced graphene oxide composite (NiCoMnLDH/rGO) with large surface area (103.6 m^2/g) and total pore volume (0.41 m^2/g) having large mesopores and macropores was explored as high performance electrode material for electrochemical capacitors. The NiCoMnLDH/rGO shows a specific capacitance of 912 F g^{-1} at a current density of 1 A g^{-1} [115].

The No-10/Ni_3S_2 composite, which is similar to $NiMoO_4$ @Ni_3S_2 type of 3D hierarchical flower, was synthesized with 10 mL of ethylene glycol. The nanosheets of Ni_3S_2 were dispersed on the No-10 matrix, yielding the flower-like structures, which exhibited a high specific capacity of 870 C g^{-1} at 0.6 A g^{-1}. In the 3D flower-like $NiMoO_4$@Ni_3S_2 composite, the presence of flower like Ni_3S_2 nanosheet provides more contact area with the electrolyte facilitate rapid redox reaction and safeguard the inner structure of $NiMoO_4$ that result in increased durability. The 3D $LaCO_3$-OH-$Ni(OH)_2$@RGO composite has high specific capacitance (572.47 F g^{-1}) due to the presence of $Ni(OH)_2$ and RGO as substrates, since $Ni(OH)_2$ possess high specific capacitance and RGO being highly conductive carbon substrate with excellent electrochemical activity [75]. The 3D flower-like composite was reported with high performance as photocatalyst and electrode material. 3D Flower like MnO_2/$Ni(OH)_2$/nickel foam composite (3D MnO_2/$Ni(OH)_2$/NF) was prepared by growing $Ni(OH)_2$ directly onto nickel foam (NF) and MnO_2 on $Ni(OH)_2$/NF [76]. The 3D flower-like microstructure with more micropores and large surface area in the 3D-flower like MnO_2/$Ni(OH)_2$/nickel foam composite provides more active sites for electrochemical reactions. The 3D flower like composite observed after the growth of MnO_2 on $Ni(OH)_2$/NF exhibits excellent supercapacitor performance with a specific capacitance of 506 F g^{-1} at 16.7 A g^{-1}. In N-doped reduced graphene oxide and $Ni(OH)_2$ (N-RGO & $Ni(OH)_2$), an improved electrochemical performance was ascribed to the covering of N-GO substrate by $Ni(OH)_2$ nanoplates that resulted in 3D flower composite with improved cycling stability [23]. The N-RGO and $Ni(OH)_2$ composite has high BET surface area of 166.99 m^2/g that influence the rapid charge/discharge process. The 3D flower-like architecture increases the effective contact area making N-RGO & $Ni(OH)_2$ a promising electrode material for supercapacitor.

Table-2 presents the 3D flower-like composites with varying specific capacity in supercapacitor applications. The high specific capacitance in 3D flower-like composites containing nickel compounds is due to the porous structure and large surface area. The presence of nickel foam provides more active sites. The 3D flower-like open architecture enhances the rapid charge/discharge process and provides good supercapacitor performance.

TABLE-2
3D FLOWER-LIKE COMPOSITE IN
SUPER CAPACITOR APPLICATIONS

3D Flower-like composite materials	Specific capacity	Current density	Ref.
	Cobalt		
MnS/Co_9S_8	1070 C/g	1 A g^{-1}	[10]
FeCoCuP	1290 C g^{-1}	1 A g^{-1}	[18]
RCNN	2133 F g^{-1}	2.3 A g^{-1}	[19]
NGE-$Co(OH)_2$	2276 F g^{-1}	A g^{-1}	[100]
$CuCoO_4$@$CuCo_2S_4$	1459.15 C g^{-1}	1 A g^{-1}	[101]
MoS_2/NiCoHC	583 C g^{-1} (1296 F g^{-1})	1 A g^{-1}	[104]
$Co(OH)_2$/Ni foam	1350 F g^{-1}	30 mA cm^{-2}	[105]
$Co_2(OH)_3Cl$-MnO_2	134.8 F g^{-1}	0.2 A g^{-1}	[106]
CNS/GNF	6.528 F cm^{-2}	6 mA cm^{-2}	[107]
$MnCo_2O_4$@NiO	1914 F g^{-1}	1 A g^{-1}	[116]
	Nickel		
NiVSe/rGO/NF	1197.6c/g	1 A g^{-1}	[9]
N-RGO&$Ni(OH)_2$	1382 F g^{-1}	6 A g^{-1}	[31]
$Ni_3V_2O_8$@CNT	1054 F g^{-1}	1 A g^{-1}	[36]
$NiCo_2O_4$/$NiCoSe_2$	2045.5 F g^{-1}	1.8 A g^{-1}	[108]
NiMnLDH/rGO	1500 F g^{-1}	1 A g^{-1}	[109]
Graphene@$NiCo_2S_4$@NiMo	1346 F g^{-1}	1 A g^{-1}	[110]
NiCoMnLDH/rGO	912 F g^{-1}	1 A g^{-1}	[114]
$NiMoO_4$@Ni_3S_2	870 F g^{-1}	0.6 A g^{-1}	[115]
$LaCO_3$-OH-$Ni(OH)_2$@RGO	572.47 F g^{-1}	–	[117]
MnO_2/$Ni(OH)_2$/nickel foam	506 F g^{-1}	16.7 A g^{-1}	[118]
Ni@ Composite	1306 F g^{-1}	2 A g^{-1}	[119]
Ni/Co-LDH	2228 F g^{-1}	1 A g^{-1}	[120]
$MnNiO_3$/Ni_6MnO_8	70.08 mAh g^{-1}	1 A g^{-1}	[121]
Ni-MOF/SnS	1440 C g^{-1}	1 A g^{-1}	[122]

Other 3D flower-like composite materials in energy storage applications: Various other 3D flower-like composites were also prepared by many workers [123-126] and its energy storage properties were tested. The 3D flower like FeS/carbon assembly materials (FeS/C-S) with high capacity reten-sion on increasing the current density was tested for lithium-sulfur battery. In FeS/C-S electrode, there is better sulphur utilization due to the presence of FeS and the strong chemical adsorption of FeS for sulphur in FeS/C-S enhanced the electro-chemical performance. The FeS/C-S composite shows an initial discharge capacity of 870 mAh g^{-1} at 0.1 C [123]. 3D graphene aerogel wrapped 3D flower like Fe_3O_4 (Fe_3O_4/GA) composite that possess the advantages of 3D graphene aerogel and flower like Fe_3O_4 exhibit superior electrochemical lithium storage performance with high specific surface area of 126.4 m^2/g and a high reversible capacity of 797 mAh g^{-1} at 0.2 A g^{-1} [124]. The 3D structure of 3D flower composite can provide an extra room for volume change of electroactive materials, electrolyte transport and electrochemical reaction. The 3D flower like Fe_3O_4/GA composite has high specific surface area (126 m^2/g) due to the introduction of porous 3D graphene nanosheets into the composite that facilitate the electrolyte/charge transport and relieve the volume change during lithium/delithium process. The flowers like Ag@ZnO composite [125] possess the combined advantage of metallic silver and 3D flower like architecture. The Ag additive and the flower like structure of 3D Ag@ZnO composite provided an outstanding electrochemical performance. The 3D flower like Ag@ZnO composite with a stable framework possess high discharge capacity (627 mAh g^{-1}) and long cycle life (830 cycles). The 3D flower like structure with high specific surface area and more electroactive sites in the 3D flower like Ag@ZnO composite improves the cell efficiency. The high electrochemical performance was attributed to the unique flower like structure and the Ag-additive [127-129]. Another type of 3D flower-like $MoSe_2$@N-doped carbon sub-nanocluster ($MoSe_2$@NCSNCs) with more active sites, faster conductivity for lithium ions and reversible discharge capacity of 480 mAh g^{-1} at current density of 4.0 A g^{-1} [130-132]. The microstructure of $MoSe_2$@NCSNCs was stabilized due to the N-doped carbon covered on its surface and would show a good rate performance in lithium-ion batteries. Similarly, 3D Flower composite like $MoSe_2$/N-doped carbon composite ($MoSe_2$/CN) with excellent Na-ion storage performance was ascribed to the coupling effect between $MoSe_2$ and N-doped carbon resulting in outstanding cycle stability of 328.7 mAh g^{-1} after 500 cycles at a high current density of 1.0 A g^{-1} [133]. The N-doped carbon coating increases the rate performance and cycling stability of 3D flower like $MoSe_2$/CN composite.

A novel 3D flower like CuO-TiO_2 composite (3DFCT) assembled from TiO_2 nanospindle supported 2D CuO nanosheets with high reversible capacity and cyclic stability [134, 135]. The 3D FCT maintained a discharge capacity of ~300 mAh g^{-1} after 100 cycles due to the 3D flower like structure of the composite with high surface area and porosity. Also, the TiO_2 nanospindles improve the mechanical support by providing more void space for aggregation of CuO during charging/discharging process. Flower like MoS_2 microstructure with 3D graphene (3DG/MoS_2) was synthesized through hydrothermal method. The MoS_2 nanoflowers on 3D graphene display high specific capacitance of 410 F g^{-1} at a current density of 1 A g^{-1} [136]. The 3D graphene provides more active sites and high electrical conductivity. The 3D structure of graphene and flower like structure of MoS_2 provides good charge transfer network and rapid electrolyte diffusion channels resulting in enhanced electrochemical performance. Novel 3D flower like MoS_2 nanosheet/N-doped 3D graphene (MoS_2/N-3DG) was prepared in a facile process, where flower like MoS_2 was grown on N-doped graphene (N-3DG) [137]. The improved electrochemical performance of MoS_2/N-3DG is due to the efficient electron transfer within the composite and its porous structure.

Some other 3D flower-like composite nanostructures are also found to possess high surface area with more active sites in energy storage applications (Table-3). The high electrochemical performance of this 3D flower like composites is attributed to the flower like structure that provides more space and improves the efficiency of supercapacitor.

TABLE-3
OTHER 3D FLOWER LIKE COMPOSITES
IN BATTERY APPLICATION

3D Flower-like composite materials	Specific capacity	Current density	Ref.
FeS/C-S	870 mAh g^{-1}	0.1 C	[123]
Fe_3O_4/GA	797 mAh g^{-1}	0.2 A g^{-1}	[124]
ZnO@Ag composite	627 mAh g^{-1}	–	[125]
$MoSe_2$@NC SNCs	480 mAh g^{-1}	4.0 A g^{-1}	[130]
$MoSe_2$/CN composite	328.7 mAh g^{-1}	1 A g^{-1}	[133]
CuO/TiO_2 (3DFCT)	~300 mAh g^{-1}	–	[134]
Graphene/MoS_2	410 F g^{-1}	1 A g^{-1}	[136]
MoS_2/N-3DG	301.2 F g^{-1}	0.2 A g^{-1}	[137]

3D Flower composites in photocatalytic applications

Bismuth containing 3D flower composite in photocatalytic applications: Some recent studies on 3D flower-like composites having bismuth compounds in photocatalytic degradation is of significant interest due to its high photodegradation [138-142]. 3D Flower like Bi_2S_3/BiOCl heterostructure which facilitates the separation and transfer of photoinduced electrons and holes exhibit high photocatalytic degradation (~100%) for rhodamine B (RhB) dye under visible light [143]. The high RhB degradation mechanism of 3D flower-like Bi_2S_3/BiOCl heterostructure composite is due to the reactive species h^+ and $^{\bullet}O^{2-}$ and the separation of photogenerated electron hole pairs. 3D Flower like AgI/$Bi_2O_2CO_3$ composite [58] was studied for the degradation of RhB dye under visible light. The 3D flower like AgI/$Bi_2O_2CO_3$ composite also shows 99.1% degradation of rhodamine B (RhB) dye when the amount of AgI in the 3D flower-like composite was controlled at 25% (molar ratio). In AgI/$Bi_2O_2CO_3$ composite, the mesoporous structure and the high charge separation efficiency led to high photocatalytic activity. The high photocatalytic activity of the 3D flower like AgI/$Bi_2O_2CO_3$ composite was attributed to the presence of mesoporous structure and the formation of staggered AgI/$Bi_2O_2CO_3$ heterojunction that resulted in high charge separation efficiency. Another type of 3D flower like BOMCs (BiOI/Fe_3O_4) was synthesized by hydrothermal method as reported by Liu *et al.* [72]. The RhB dye degradation by 3D flower like BOMCs is affected with various Fe_3O_4 doping levels with BiOI/Fe_3O_4 displaying optimum RhB degradation of 98.4%. Moreover, the malachite green dye was permitted for the degradation over $Bi_2O_2CO_3$-$CuBi_2O_4$ (1:1)-SH nanocomposite for 180 min under sunlight irradiation, which retains the high degradation of 91.6% as it's macroporous flower like structure and easy separation of charge because of its heterojunction formation [144].

3D Ultralight graphene/Bi_2WO_6 composite (GA/BW) was synthesized with good photocatalytic activity was compared to pure BW power [88]. The GA/BW composite with 6:8 ratio exhibited superior degradation for rhodamine B (RhB) dye reaching 97.49%. The high photocatalytic degradation of GA/BW composite is due to the electron transfer from BW to the surface of graphene and the high conductivity of graphene resulting in high photocatalytic activity [145]. The 3D-structured flower like bismuth tungstate/mag-graphene nanoplate composite (Bi_2WO_6/Mag-GNPs) exhibit enhanced photocatalytic degradation due to the synergistic effect of Bi_2WO_6, graphene and Fe_3O_4 [146]. Novel 3D structured flower-like Bi_2WO_6/mag-graphene nanoplate composite provides efficient electron transfer channels and enhanced utilization of visible light. The photocatalytic degradation of 3D structured flower like Bi_2WO_6/mag-GNP was efficient towards degradation of ciproflaxin with 97.6% within 1 h. The 3D $Bi_{12}TiO_{20}$/TiO_2 hierarchical heterostructure having $Bi_{12}TiO_{20}$ nanorods decorated with TiO_2 nanoparticles exhibit good photocatalytic degradation efficiency of 96% under visible light [62]. In 3D $Bi_{12}TiO_{20}$/TiO_2 composite the enhanced photocatalytic degradation was attributed to the improved charge separation, the high surface area and efficient inter electron transfer. Another 3D flower like $BiPO_4$/Bi_2WO_6 microsphere composite with 15% $BiPO_4$ showed the highest phtocatalytic activity under visible light with 92% removal of rhodamine B (RhB) dye within 100 min [140]. The surface modification of $BiWO_6$ by $BiPO_4$ nanoparticles facilitates the migration of photogenerated electron holes and resulting in enhanced photocatalytic activity under visible light irradiation. 3D Double layer half open flower $BiVO_4$ and graphene composite (BVO-GS) exhibit superior photocatalytic removal of RhB dye (90%) under visible light irradiation [147]. The high photocatalytic activity of BVO-GS composite was due to the positive synergistic effect between 3D BVO and rGO. Another type of 3D-flower like CeO_2/BiOI composite was analyzed for its photo-catalytic degradation of rhodamine B (RhB) dye under UV light. The 15%CeO_2/BiOI composite exhibits highest photodegra-dation efficiency of 80.29% under visible light for 120 min. The 3D flower like CeO_2/BiOI heterostrucure was synthesized by successfully coupling the p-type BiOI with n-type CeO_2 to build the p-n heterostructure [148]. A novel $BiPO_4$/SnS_2 3D flower heterogeneous composite also exhibit the highest catalytic activity due to heterojuction structure between SnS_2 and $BiPO_4$ and has excellent photocatalytic degradation towards methylene blue dye under visible light. The 3D flower $BiPO_4$/SnS_2 com-posite has improved photocatalytic degradation with 73.16% of methylene blue molecules were decomposed [149]. Li *et al.* [94] prepared novel 3D flower-like Fe_3O_4@C@$(BiO)_2CO_3$ with perfect surface when the content of Fe_3O_4@C was 2.5 wt.%, which could optimally match the amount of $(BiO)_2CO_3$ to provide good catalytic degradation of tetracycline [150]. The mechanistic study on the photocatalytic degradation of tetracycline by 3D flower-like Fe_3O_4@C@$(BiO)_2CO_3$ revealed that $^{\bullet}$OH radicals were the main active species to photodegrade. Jabbar *et al.* [151] designed and prepared of the heterogenous 3D flower like Bi_5O_7I/Bi/Bi_2WO_6 tangled nanoparticles of $NiFe_2O_4$ and was well characterized with XPS, SEM TEM and DRS for band gap further was employed for the photocatalytic destruction of levofloxacin in water. This photocatalyst was well-designed for the S-scheme, which delays the combination of the holes and electrons and requires 75 mg of photocatalyst under the irradiation of 150 W LED lamp and gives 97.5% of the degradation efficiency within 90 min. 3D Porous Bi_2WO_6/graphene hydrogen composite (BWO/GH) was prepared and evaluated for its photocatalytic degradation of methylene blue and 2,4-dichlorophenol (2,4-CDP) under visible light [152]. Further, Salari *et al.* [153] synthesized the 3D flower like composite of MnO_2 embedded on the surface of Bi_2WO_6 nanosheets and was employed for the photocatalytic degradation of methylene blue using 300 W Xe Lamp with UV cutoff filter, which can provide the visible light only for 100 min and degrades dye completely without any change in the morphology of the 3D-flower like photocatalyst.

The high photocatalytic degradation using bismuth compound containing 3D flower like composites is due to the porous structure, high surface area and the migration of photo-generated electron holes that results in enhanced photocatalytic activity. The degradation mechanism reveals that holes (h^+) and superoxide radical ($^{\bullet}O^2$) are the more active species in the degradation of bismuth containing 3D flower-like composites [154]. Table-4 presents some of the 3D flower-like composites having bismuth with varying pollutant degradation percentage in photocatalysis applications.

3D Flower-like composite materials having silver/silver compounds in photocatalytic applications: Various 3D flower-like composites having silver compounds were also prepared and its photocatalytic performance was analyzed by several researchers. Silver containing 3D flower-like composites were found to be very efficient in the photocatalytic degradation [40,97,98]. Some of the 3D flower-like composites synthesized and used are discussed as below.

TABLE-4
3D FLOWER-LIKE COMPOSITE HAVING BISMUTH IN PHOTOCATALYSIS APPLICATIONS

3D Flower-like composite materials	Pollutant	Degradation (%)	Ref.
AgI/$Bi_2O_2CO_3$	RhB	99.1	[58]
$Bi_{12}TiO_{20}$/TiO_2	RhB	96.0	[62]
BiOI/Fe_3O_4 microsphere	RhB	98.4	[72]
$BiPO_4$/Bi_2WO_6	RhB	92.0	[140]
Bi_2S_3/BiOCl	RhB	~ 100.0	[143]
$Bi_2O_3CO_3$-$CuBi_2O_4$ (1:1)	MG	91.6	[144]
Graphene aerogel/Bi_2WO_6	RhB	97.4	[145]
Bi_2WO_6/Mag-GNPs	CIP	96.7	[146]
$BiVO_4$(BVO-GS)	RhB	90.0	[147]
CeO_2/BiOI	RhB	80.29	[148]
$BiPO_4$/SnS_2	MB	73.16	[149]
Fe_3O_4@C@$(BiO)_2CO_3$	TC	–	[150]
Bi_5O_7I/Bi/Bi_2WO_6	LEV	97.5	[151]
Bi_2WO_6/graphene	MB	–	[152]
	2,4-CDP	–	
g-C_3N_4/$CuBi_2O_4$/Bi_2MoO_6	TC and CTC	91.6	[155]
BiOI and BiOCl	RhB	–	[156]
Bi/CuS	MB	55.63	[157]
	MO	45.81	

RhB = rhodamine B, MG = malachite green, CIP = ciproflaxin, MB = methylene blue, TC = tetracycline, LEV = levofloxacin, 2,4-CDP = 2,4-dichlorophenol, CTC = chlortetracycline, MO = methyl orange

A 3D flower like Ag_3PO_4/$SnSe_2$ composite was prepared using Ag_3PO_4 nanoparticles uniformly grown on the surface of 3D flower like $SnSe_2$ to prepare 3D flower like Ag_3PO_4/$SnSe_2$ composite [40]. In 3D flower like Ag_3PO_4/$SnSe_2$ composite, the enhanced photocatalytic degradation was attributed to the efficient separation of photogenerated charge carriers and the strong oxidizing ability of the superoxide radical ($^{\bullet}O^{2-}$). The photocatalytic degradation of RhB dye of the composite with $SnSe_2$ content of 6 wt.% (3D Ag_3PO_4/$SnSe_2$-6 composite) exhibited the highest activity of approximately 100%. Another 3D flower like *g*-C_3N_4/Ag/ZnO nanocomposite [153] with superior optical properties and photocatalytic activity containing silver nanoparticles played a vital role by accelerating the separation of electrons and holes due to surface plasmon resonance effect. The enhanced photocatalytic performance of 3D flower like *g*-C_3N_4/Ag/ZnO nanocomposite towards the degradation of 2,4-dichlorophenol (99.6%) was due to the presence of a hetero-junction which facilitates the efficient separation of electrons and hole. Similarly, Han *et al.* [158] prepared 3D flower like Ag@AgCl/Sn_3O_4 by combining flower like 3D Sn_3S_4 microsphere with Ag@AgCl-QDs and also analyzed the photocatalytic properties under visible light. In this, the introduction of Ag@AgCl nanocrystal on the 3D flower-like Sn_3O_4 increases the surface area and the active sites with improved photocatalytic activity. The presence of metallic silver in the final product initiates the surface plasmon resonance (SPR) effect, resulting in improved photocatalytic activity. The Ag@AgCl (1 wt.%)/Sn_3O_4 achieved an impressive degrading rate of 99.8% and 52.03% with methylene blue and tetracycline hydrochloride under visible light for 180 min. 3D Flower like AgI/$Bi_2O_2CO_3$ composite [58] was also studied for the degradation of RhB dye under the visible light. The high photocatalytic activity of the 3D flower like AgI/$Bi_2O_2CO_3$ composite was attributed to the presence of mesoporous structure and the formation of staggered AgI/$Bi_2O_2CO_3$ heterojunction that resulted in high charge separation efficiency. Similarly, Chen *et al.* [159] prepared 3D flower-like AgBr/CeO_2 composite as photocatalyst by dispersing AgBr particles on the surface of CeO_2. The AgBr fraction in composite was optimized with 40 wt.% AgBr/CeO_2 having excellent photocatalytic degradation ability for rhodamine B, methyl orange and tetracycline with final removal rates of 96%, 93.4% and 77.8%, respectively. Wu *et al.* [160] also prepared a novel type of 3D Fe_3O_4 microflowers, which was successfully loaded with rhombic dodecahedral Cu_2O followed by *in situ* reduction of silver nanocrystals to obtain Cu_2O/Ag-3D Fe_2O_3 microflower composite. In this, the electrons in the conduction band of Cu_2O and the electrons of silver nanocrystals present in 3D Cu_2O/Ag-3D Fe_2O_3 microflower composite were captured by the molecular oxygen absorbed on the photocatalyst. The photodegradation of methyl orange dye under visible light for Cu_2O/Ag-3D Fe_2O_3 microflower composite was above 90% after six-cycles. Similarly, another 3D flower like Ag/ZnO heterostructure composite with large surface area and more active sites also exhibit superior photocatalytic performance as reported by Liang *et al.* [161]. The 3D Ag/ZnO composite was analyzed for its photocatalytic degradation under UV irradiation using RhB dye. The photogenerated electrons due to the surface plasmon resonance (SPR) of silver nanoparticles gets excited from the surface of silver nanoparticles and moves to the conduction band of ZnO followed by diffusion to the surrounding medium to accelerate the photocatalytic process. Another type of 3D flower-like double hydroxide layered Ag_2CO_3/Mg-$AlNO_3$ composites in which Ag_2CO_3 nanoparticles were distributed uniformly on the petals of the MgAl LDHs is also repored in the literature [162]. In this, double hydroxide layered LDHs provide more active sites for the degradation of the dye X-3B and phenol under visible light illumination, which exhibit excellent photocatalytic removal rate of 83% on X-3B within 12 min whereas phenol solution removal was 90% after 1 h.

Zhang *et al.* [163] also prepared 3D flower like Ag@WO_3 nanostructure composite with enhanced adsorption of visible light was evaluated for the degradation of methylene blue (MB) and 2-chlorophenol. The photocatalytic degradation efficiency for methylene blue dye and 2-chlorophenol was 88% within 40 min and 54% within 80 min, respectively. Whereas Zuo *et al.* [164] reported another type of flower like carbon/Ag_3PO_4 composite microspheres (3DFCM/Ag_3PO_4) with enhanced structural stability and efficient photocatalytic degradation of chloramphenicol (90%). The high photocatalytic degradation of chloramphenicol was attributed to the excitation of Ag_3PO_4 in the presence of visible light generating electrons (e^-) and holes (h^+). In the same way, Chen *et al.* [165] prepared 3D Ag/β-$Ni(OH)_2$ microspheres, where silver nanoparticles present on the surface of β-$Ni(OH)_2$ microspheres enhances the separation of photogenerated electron hole pairs resulting in the methylene blue degradation under UV light.

The presence of metallic silver/silver compounds in the 3D flower-like composites initiates the SPR effect and accelerates the photocatalytic degradation process. In the degradation of pollutants by silver/silver containing 3D flower-like composites the more active species are the superoxide radicals ($^{\bullet}O^{2-}$) and holes (h^+) that plays a predominant role in the degradation process. Hence, Ag/Ag compounds containing 3D flower like composites proved efficient in the photocatalytic degradation process. Table-5 presents some of the silver having 3D flower like composites with varying pollutant degradation percentage in photocatalysis applications.

TABLE-5
SILVER/SILVER COMPOUNDS HAVING 3D FLOWER-LIKE COMPOSITE IN PHOTOCATALYTIC APPLICATIONS

3D Flower-like composite materials	Pollutant	Degradation (%)	Ref.
$Ag_3PO_4/SnSe_2$	Rhodamine B	~ 100.0	[57]
$AgI/Bi_2O_2CO_3$	Rhodamine B	99.1	[58]
Ag/ZnO	Rhodamine B	–	[101]
g-C_3N_4/Ag/ZnO	2,4-Dichloro phenol	99.6	[153]
Ag@AgCl/Sn_3O_4	Methylene blue	99.8	[158]
	Tetracycline HCl	52.03	
AgBr/CeO_2	Rhodamine B	96.0	[159]
	Methyl orange	93.4	
	Tetracycline	77.8	
Cu_2O/Ag-3D Fe_3O_4	Methyl orange	> 90.0	[160]
Mg-$AlNO_3$ LDH	Reactive red X-3B	83.0	[162]
	Phenol	90.0	
Ag@WO_3	Methylene blue	~ 88.0	[163]
	2-Chlorophenol	54.0	
Carbon/Ag_3PO_4	Chloramphenicol	90.0	[164]
Ag/β-$Ni(OH)_2$	Methylene blue	–	[165]
Ag/Bi_2WO_6	Rhodamine B	–	[166]
Bi_2S_3/Bi_2WO_6	Tetracycline	91.4	[167]

Graphene containing 3D flower composite in photocatalytic applications: 3D flower-like composites containing graphene in photocatalytic degradation of pollutants was studied by various researchers, due to its high photodegradation [157, 168-172]. Some of the well-known 3D flower-like composites as photocatalysts are discussed as:

A novel 3D flower like TiO_2 microsphere (FT) decorated graphene (GN) (3D FT/GNO) with interfacial contact between GN and FT was synthesized and the photocatalytic activity for the removal of RhB dye under UV light was analyzed [173]. The enhanced photocatalytic activity of 3D FT/GN was due to the unique 3D flower like TiO_2 structure and the introduction of graphene that provides the combined benefit of graphene and FT microsphere. A novel 3D FT/GN with 8% GO mass was prepared (3D FT/8GN) with high removal rate for RhB dye under UV light reaching 99.2% in 80 min. The mechanism of photocatalytic degradation of 3D FT/8GN composite revealed that $^{\bullet}O^{2-}$ and h^+ are the main active species for the decomposition of RhB dye. Similarly, Dong *et al.* [145] synthesized 3D ultralight graphene/Bi_2WO_6 composite (GA/BW) with good photocatalytic activity as compared to pure BW power. The GA/BW composite with 6:8 ratio exhibited superior degradation for RhB dye reaching 97.49%. The high photocatalytic degradation of GA/BW composite is due to electron transfer from BW to the surface of graphene and the high conductivity of graphene. Another type of 3D structured flower like bismuth tungstate/mag-graphene nanoplate composite (Bi_2WO_6/Mag-

GNPs) also exhibit enhanced photocatalytic degradation due to the synergistic effect of Bi_2WO_6, graphene and Fe_3O_4 [146]. The photocatalytic mechanistic study of 3D flower like Bi_2WO_6/Mag-GNPs revealed that h$^+$, $^\bullet$OH and $^\bullet O_2^-$ are the main active species for the decomposition of ciproflaxin with 97.6% within 60 min.

Using graphitic carbon nitride (g-C_3N_4) as a 2D organic metal-free polymer, moreover, CuS, a small band gap p-type semiconductor with high absorption coefficient in UV-infrared light, is a good contender for solar energy absorption.Thus, Khan *et al*. [174] synthesized 3D flower like CuS/g-C_3N_4 composite as the most active photocatalyst and shows excellent photcatalytic degradation of methylene blue dye with solution getting decolorized under visible light after 90 min of irradiation time. Another type of 3D porous graphene as substrate for 20% g-C_3N_4 on which NiO/$Ni_3(BO_3)_2$ was dispersed to obtain z-scheme GACN/NiO/$Ni_3(BO_3)_2$ composite (GACN20/NNB), which exhibits the highest photocurrent intensity with high charge transfer efficiency [175]. The GACN 20/NNB shows high photocatalytic degradation towards methylene blue dye and tetracycline under simulated sunlight reaching 96.9% and 94.0% in 60 and 30 min, respectively. Yang *et al.* [176] also synthesized 3D porous Bi_2WO_6/graphene hydrogen composite (BWO/GH) and evaluated for its photocatalytic degradation of methylene blue dye and 2,4-dichlorophenol under visible light. The high photocatalytic activity of graphene containing 3D flower-like composites is due to the porous nature and efficient electron transfer channels provided by the 3D flower-like structure.

TABLE-6
GRAPHENE HAVING 3D FLOWER-LIKE COMPOSITE IN PHOTOCATALYTIC APPLICATIONS

3D Flower-like composite materials	Pollutant	Degradation (%)	Ref.
Graphene aerogel/Bi_2WO_6	RhB	97.49	[145]
TiO_2/graphene (GN) (3DFT/GN)	RhB	99.2	[173]
CuS/g-C_3N_4	MB	100 (or check for dash)	[174]
GACN/NiO/$Ni_3(BO_3)_2$	MB	96.9	[175]
	TC	94.0	
Bi_2WO_6/Graphene	MB	–	[176]
	2,4-CDP	–	
PANI@MoS_2	Cr(VI)	–	[177]

RhB = rhodamine B, MB = methylene blue, TC = tetracycline, 2,4-CDP = 2,4-dichlorophenol.

3D Flower-like composite having ZnO in photocatalytic applications: Several 3D flower-like composites having ZnO was prepared and its photocatalytic performance was also analyzed [178,179]. ZnO containing 3D flower-like composites were found to be very efficient in photocatalytic degradation, some of the 3D flower-like composites synthesized.

3D Flower like mesoporous Ce-doped ZnO composite was prepared and its photocatalytic performance for the degradation of RhB dye and phenol was studied. The light absorption of ZnO increased by moderate Ce doping with 1% mole ratio of 3D flower like Ce doped ZnO composite exhibited best photocatalytic degradation of 85.1% of RhB dye and 69.6% of phenol was degraded within 125 min and 120 min, respectively. The presence of more electron trapping sites due to the doping of cerium in ZnO lattice enhances the electron-hole separation [180]. Similarly, 3D-nanoflower like ZnO-Au composite was grown on multiwalled carbon nanotubes (MWCNTs) were observed to be in flower form with enhanced photocatalytic degradation of methylene blue dye reaching 98% in 40 min under visible light [181]. The high photocatalytic activity of 3D flower like composites containing ZnO is due to the flower like structure and the presence of more electron trapping sites due to the doping of metal in ZnO lattice, enhances the electron-hole separation. From the photocatalytic mechanistic study of 3D flower-like composites containing ZnO it is evident that holes (h$^+$), hydroxyl radical ($^\bullet$OH) and superoxide radical ($^\bullet O_2^-$) were the main active species to photodegrade under sunlight illumination.

Conclusion

3D Flower-like composites containing graphene/cobalt compounds/nickel compounds were found to have high energy storage characteristics. 3D Flower like composites with porous and high surface area, exhibit superior energy storage and photocatalytic properties. The presence of more active sites due to the unique flower-like architecture in 3D flower-like composites ensures the efficient contact of the electrode/electrolyte. A positive insight in this work will lead to the development of more 3D flower-like composites with unique properties for various applications.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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