1. Introduction

The ever-increasing population and industrialization have led, on one hand, to the depletion of natural energy resources and on the other, to global warming and climatic changes [1–4]. These energy crises and environmental pollution has induced a demand to discover new and eco-friendly energy storage and conversion technologies [5,6]. After lithium-ion batteries, supercapacitors (SC) have emerged as new energy storage devices owing to their high efficiency, unique power density and long cycling ability [7–12].

SCs can be subdivided into electric double-layer capacitors (EDLCs) and pseudocapacitors based on their charge storage mechanism [13,14]. Pseudocapacitors can store energy more efficiently than EDLCs, however, they are expensive and possess less stability as compared to EDLCs. By the use of redox-active electrode materials, the capacity to store charge can be increased for pseudocapacitors [15–17]. Over the decades, various attempts have been made to prepare electrode materials with improved properties because electrode material is the crucial element of SC to boost their performance [18]. Several metal oxides (cobalt oxide, iron oxide, manganese oxide, ruthenium oxide and nickel oxide, etc.) selenides (germanium selenide, tin selenide, etc.) as well as sulphides (cobalt sulfide, molybdenum sulfide, etc.) have been investigated as electrodes for energy storage devices. The structure of rGO/ SrSeO4 nanocomposite was confirmed by x-ray diffraction while the morphology was investigated by scanning electron microscopy. The electrochemical measurements, such as cyclic voltammetry, galvanostatic charge/discharge, electrochemical impedance spectroscopy and cyclic stability, were also carried out. The synthesized nanocomposite showed excellent specific power of 684.16 W/kg with 3.67 Wh/kg specific energy, which is significantly much better than already reported metal selenide materials.
However, non-uniform pore size (from micro to macro pores) reduces its specific capacitance [39]. This may be attributed to the fact that electrolyte ions cannot be accessible to micropores [40] while the surface to volume ratio is very less for macropores that results in poor capacitance [9]. Carbon nanotubes show somewhat better capacitance due to its improved surface area as well as conductivity as compared to activated carbon [41]. The improved surface area, along with excellent conductivity, is required to achieve good specific energy.

Graphene has overcome the shortcomings of other carbon materials due to its fine surface area, improved lattice structure and excellent electrical properties [42,43]. The specific capacitance of 550 F/g with 2675 m²/g surface area can be achieved due to carbon atoms that are sp² hybridized [44]. Thus the incorporation of rGO in SrSeO₄ can be expected to enhance the stability as well as overall electrical performance of the fabricated nanocomposite [45].

Herein, we report an efficient synergetic approach by preparing binder-free SrSeO₄ / rGO nanocomposite to achieve high-energy electrodes. The higher conductivity of rGO as well as better electrical properties of selenium-based materials make them suitable for use in energy storage devices [46]. The rGO was prepared by Hummer’s method [47] while SrSeO₄ as well as nanocomposites were synthesized via hydrothermal route. The higher value of specific power as exhibited by the nanocomposite (i.e. 684.16 W/kg) makes it an excellent candidate for supercapacitor applications as most of the small devices of common use (vehicles and aeronautics) require high specific power [48].

2. Experimental

2.1. Reagents and chemicals

Graphite powder (Daejung), sulphuric acid (Analar, 98%), hydrogen peroxide (Sigma-Aldrich, 30%), potassium permanganate (BDH), strontium nitrate (Sigma-Aldrich), selenium dioxide (Sigma-Aldrich), hydrazine monohydrate (Daejung, > 80%) and potassium sulphide (Daejung) were used as starting materials. All the chemicals were of analytical grade and were used without further treatment.

2.2. Synthesis of reduced graphene oxide

The reduced graphene oxide was synthesized by using the graphite powder via Hummer’s method. For this purpose, 50 mL of H₂SO₄ was poured into a beaker that was already set on the ice bath with a magnetic stirrer. The weighed amount of graphite powder (2 g) was added instantly after the sulphuric acid was poured into the beaker with the temperature of the solution maintained below 20°C throughout. A 6 g of KMnO₄ was added slowly with continuous stirring for 3 h. After the stirring of 3 h, 100 mL of deionized water was poured dropwise in the solution mixture. The temperature of the reaction mixture was kept below 50°C to initiate the oxidation reaction. The dark brown colour of the solution indicated that the graphene oxide was synthesized. Lastly, the reaction was stopped by adding 10 mL of H₂O₂ to the reaction mixture. Afterwards, the solution mixture was centrifuged with HCl and washed with deionized water for several time so as to maintain the pH of reduced graphene oxide solution to neutral. In the end, it was dried in an oven to obtain a powder of reduced graphene oxide.

2.3. Synthesis of strontium selenate (SrSeO₄)

The SrSeO₄ was synthesized by using the hydrothermal method. The 0.1 M solution of strontium nitrate was prepared and stirred for 10 min. Afterwards, 0.22 g of 0.1 M SeO₂ was added to the above solution and stirred for a while so that the selenium dioxide gets dissolved in strontium nitrate. The 2 mL of hydrazine monohydrate was poured in the solution, which act as a reducing agent after which a change in colour from white to light orange color was observed. After being stirred for more 10 min, the solution mixture was transferred to stainless steel autoclave of 100 mL capacity and put in an electric oven at 200°C for 24 h. The autoclave was cooled naturally and the grayish-black crystals of strontium selenate were obtained. The product was centrifuged and washed several times with deionized water to remove the impurities. The product was dried in an oven at 60°C and grounded in agate mortar and pestle and stored for further use.

2.4. Synthesis of composite (rGO/SrSeO₄)

The nanocomposite of SrSeO₄ with rGO was prepared by adding the weighed amount (0.5 g) of already prepared reduced graphene oxide in the strontium nitrate solution with continuous stirring for 15 min. Subsequently, 0.22 g of SeO₂ was added to the above-mentioned mixture. After the complete dissolution of selenium dioxide, 2 mL of hydrazine monohydrate was poured dropwise. The solution thus obtained was then transferred to 100 mL of stainless steel autoclave and given heat treatment of 200°C in an electric oven for 24 h. The resulting solution was centrifuged to remove the impurities by washing with deionized water several times. The blackish needle-like crystals were obtained which were dried in an oven and used as electrode material.

2.5. Characterization

The phase and purity of materials investigated in the present study were carried out by powder X-Ray
Figure 1. Schematic illustration of various steps employed for the growth of SrSeO$_4$ on Nickel foam with pre-deposited rGO thin film.

The synthesized SrSeO$_4$ was verified by powder x-ray diffraction (PXRD) analysis and the respective diffractogram is presented in Figure 2. The peaks observed at the 2$\theta$ values of 25.15, 29.67, 31.44, 35.14, 36.54, 41.33, 43.57, 44.07, 45.33, 47.66, 49.91, 51.68, 65.22, and 73.60° are in accordance with the crystallographic planes (020), (200), (−112), (121), (−212), (−122), (−222), (212), (301), (230), (320), (023), (−303), (041), (−423), and (−424), respectively which crystallize into monoclinic phase. All the peaks (marked as blue with rhombus sign) are well matched with standard pattern ICSD-01-073-1083. The XRD pattern of reduced graphene oxide (rGO) is also shown in Figure 2. The pattern showed two peaks (marked as green with steriks sign) that correspond to (002) and (100) planes, which indicate the successful synthesis of rGO. The XRD pattern of composite (SrSeO$_4$/rGO) showed the peaks for both the materials. The presence of peaks for both the materials indicated the successful formation of a composite as no other peak of impurity was observed. The crystallite size as calculated by the Scherrer formula comes out to be 28.7 nm.

The SEM images of all the synthesized materials are shown in Figure 3(a–c). The reduced graphene oxide has sheet-like morphology, as shown in Figure 3(a). The SEM image of strontium selenite showed rod-shaped morphology with a diameter of 40–50 nm range (Figure 3b). The strontium selenite rods are distributed on the surface of the reduced graphene oxide sheet in the composite as shown in Figure 3(c). The functional groups of graphene oxide, i.e. −OH and −COOH groups, may probably serve as active sites for the adsorption of Sr$^{2+}$, thus enabling the uniform distribution of SrSeO$_4$ on the GO sheets [49].

3. Results and discussion

3.1. Structural analysis

The supercapacitive behaviour of SrSeO$_4$ and its composite with rGO was tested through CV, GCD and EIS
Figure 2. XRD pattern of (a) reduced graphene oxide, (b) strontium selenate (Sr SeO₄) and (c) composite of Sr SeO₄ with reduced graphene oxide.

measurements. Figure 4(a–c) shows the cyclic voltammograms of fabricated nanostructures at various scan rates (5–50 mVs⁻¹) in a potential range of 0–0.5 V. The presence of a pair of redox peaks and non-rectangular shape is indicative of the fact that the prepared materials exhibit pseudocapacitive behavior and charge is stored through Faradic mechanisms [35]. Similar results of cyclic voltammetry curves have also been reported by Kavyashree et al. [50]. According to the previous reports, the material exhibiting pseudocapacitive behaviour may be employed as an electrode material for pseudocapacitor applications [51]. It can also be noticed that with increasing the scan rates (from 5 to 50 mVs⁻¹), the shape of voltammograms does not vary much. Only a minimal shift in peak position is observed, which suggests that rapid electron transfer occurs between electrodes and the electrolyte [52].

The specific capacity of SrSeO₄ and its composite with rGO nanostructures was calculated from the following equation 1 [35] and the values are tabulated in Table 1.

\[
C_{sp} = \frac{\int I dV}{mS\Delta V}
\]

where \(I\) denotes the voltammetric current, \(ν\) represents the scan rate, \(m\) is mass of the used electrode and \(\Delta V\) is the potential window respectively during Faradic reaction employed.

| Scan rate (mVs⁻¹) | \(C_{sp}\) of SrSeO₄ (Fg⁻¹) | \(C_{sp}\) of rGO/ SrSeO₄ (Fg⁻¹) |
|------------------|---------------------------|-------------------------------|
| 5                | 10.80                     | 25.40                         |
| 10               | 10.30                     | 23.86                         |
| 15               | 9.74                      | 22.43                         |
| 20               | 9.51                      | 21.00                         |
| 25               | 7.23                      | 20.32                         |
| 30               | 6.98                      | 19.45                         |
| 50               | 6.55                      | 18.32                         |

An insight into Table 1 tells that specific capacitance \((C_{sp})\) declines with the increment in scan rate. The lower potential of redox peaks (i.e. higher \(C_{sp}\) at lower scan rate attributes to the efficient diffusion of ionic species to the electrode from the electrolyte [53]. It is also evident from the voltammograms that redox peaks appear even at higher scan rates, i.e. 50 mVs⁻¹ which affirms the good electrochemical reversibility of rGO/ SrSeO₄ composite in aqueous KOH electrolyte [54].

GCD tests of the studied electrodes (SrSeO₄ and rGO/SrSeO₄) at various current densities in the range of 0.12–1.6 Ag⁻¹ were carried out and the results are shown in Figure 4(a and b). The well-defined plateau regions in GDC graphs are coincident with the redox peaks as obtained in cyclic voltammograms thus confirming the pseudocapacitive nature of bare as well as rGO/ SrSeO₄ electrodes.
The galvanostatic discharge time as observed from the graph comes out to be 70, 41, 11 and 5 s and 87, 57, 12 and 6 s at a current density of 0.12, 0.2, 0.8 and 1.6 $\text{Ag}^{-1}$ for SrSeO$_4$ and rGO/ SrSeO$_4$ respectively. Clearly discharge time is reduced with an increment of current density. This is probably due to the reason that at lower current density the electrolyte ions acquire adequate time to reach the active material and possess small resistance owing to lower excitation of ions as explained by Faisal et al. [35]. However, at higher current densities the time restraint as well as resistance of electrolyte ions become significant and result in diffusion of inner of the active electrode.

The discharge $C_{sp}$ with varying current densities was calculated using Equation (2) [46] and exhibited in Figure 5 and Table 2.

$$C = \frac{I \Delta t}{m \Delta V}$$

where $I$ represents the discharging current, $t$ is the time and $V$ denotes the potential difference respectively.

Interestingly rGO/ SrSeO$_4$ exhibited high $C_{sp}$ value of 30 Fg$^{-1}$ at a current density of 0.12 $\text{Ag}^{-1}$ as compared to bare SrSeO$_4$ (23 Fg$^{-1}$) at the same current density. This may be ascribed to the fact that larger surface area and higher conductivity of GO favour the good rate transfer of electrons at the electrode–electrolyte interface thus ensuring the prepared electrodes suitable for supercapacitors applications. Moreover, the binder-free preparations of studied electrode material make it more fascinating for use as a supercapacitor because it possesses the ability to reduce the contact resistance which is found in the electrolyte [55].

Some essential parameters for supercapacitors, e.g. specific energy and specific power, were also deduced from GCD profile as indicated in the Ragone plot (Figure 5d) by using Equations (3) and (4) respectively [56,57].

$$E = \frac{1}{2} C (\Delta V)^2$$

$$P = \frac{E}{t}$$

where $C$ represents specific capacitance, $\Delta V$ denotes the potential window while $t$ is the discharge time respectively.
Figure 4. CV profile of (a) rGO, (b) SrSeO₄, (c) rGO/SrSeO₄ at various scan rates and (d) effect of scan rate on specific capacitance of rGO and rGO/SrSeO₄ nanocomposite.

Table 2. Specific capacitance specific energy and specific power of SrSeO₄ and rGO/SrSeO₄ at varying current densities.

| Current density | SrSeO₄ electrode | rGO/SrSeO₄ electrode |
|-----------------|------------------|---------------------|
| (Ag⁻¹)          | Cₛ (Fg⁻¹)        | E (Whkg⁻¹)          | P (Wkg⁻¹) |
| 0.12            | 23               | 1.30                | 290       | 30        | 3.57 | 70      |
| 0.2             | 21               | 1.28                | 360       | 27        | 3.10 | 100     |
| 0.8             | 17               | 1.23                | 410       | 20        | 2.85 | 340     |
| 1.6             | 14.5             | 1.00                | 470       | 15        | 2.58 | 684.16  |

The measured specific energy and power values are provided in Table 2. As indicated from the Ragone plot-specific energy declines while an increment in specific power is observed due to an increase in current density. This may be attributed to the fact that at higher current densities some hindrance in flow of charge carriers occurs which results in increased polarization of electrode material [51]. Moreover, specific power is observed to be greater as compared to the previously reported value for various chalcogenides [58,59]. The larger value of specific power might be ascribed to the enhanced surface area as well as electrical conductivity of rGO/SrSeO₄ [49,60]. The higher value of specific power as exhibited by the nanocomposite (i.e. 684.16 W/Kg) makes it an excellent candidate for supercapacitor applications as most of the small devices of common use (vehiciles and aeronautics) require high specific power [48].

The cyclic life of supercapacitor is an important parameter for its practical application. The electrochemical stability of nanocomposite was explained by the capacitance retention curve. For this purpose, the active material electrode undergone CV measurements in 2M
Figure 5. GCD profile of (a) SrSeO$_4$, (b) rGO/SrSeO$_4$ composite at various current densities, (c) effect of current densities on specific capacitance of SrSeO$_4$ and rGO/SrSeO$_4$ composite and (d) Ragone plot of SrSeO$_4$ and rGO/SrSeO$_4$ nanocomposite.

Figure 6. (a) Cycling stability of rGO/SrSeO$_4$ over 1000 cycles and (b) Nyquist plot of SrSeO$_4$ and rGO/ SrSeO$_4$ nanostructures.

KOH at 100 mVs$^{-1}$ for 1000 cycles. The cyclic plot (Figure 6a) depicts that initially capacitance is increased with the number of cycles which then becomes stable. This initial increase may be observed owing to the reason that the active materials are not consumed initially [61]. The constant capacitance reveals the robust stability of our prepared composite electrode material and makes it a potential candidate to be used in energy storage devices.

3.3. EIS measurements

To confirm the electrical conductivity, electrochemical impedance spectroscopic studies of SrSeO$_4$ and rGO
/SrSeO₄ were carried out in the frequency range of 100 kHz to 0.01 Hz with an AC voltage at 0.5 mV amplitude. The corresponding Nyquist plots are revealed in Figure 6(b) with an inset of equivalent circuit model. Generally, four types of electrochemical resistances are found in electrode materials: $R_{ct}$ (charge transfer resistance), $R_{ct}$ (contributions of ionic resistance of the electrolyte intrinsic resistance and contact resistance between the active material and the current collector), $Z_w$ (the Warburg impedance) and $C_F$ (the electrochemical capacitance) [62].

The more vertical slope of the composite electrode as compared to SrSeO₄ suggested that the composite possesses lower ion diffusion resistance. The semicircle region is related to the faradaic redox reactions and its diameter exhibits $R_{ct}$ [63]. Here the semicircle is smaller in rGO/SrSeO₄ nanocomposite (12 ohm) than SrSeO₄ (14 ohm) indicating lower value of the semicircle region is related to the faradaic redox reactions and its diameter exhibits the $R_{ct}$ in the nanocomposite as compared to bare SrSeO₄. The Warburg section for rGO-based SrSeO₄ composite is less than bare SrSeO₄ thus illustrating that the diffusion of ions through pores becomes swift in our rGO-based nanocomposite. This enhanced electrical conductivity of GO-based SrSeO₄ nanocomposite may be a consequence of the increased surface area of the nanocomposite due to the incorporation of graphene in it as well as complete coverage of rGO-based SrSeO₄ on nickel foam.

4. Conclusion

Strontium selenite composite with reduced graphene oxide has been successfully synthesized by hydrothermal synthesis on nickel foam substrate. The synthesized rGO/SrSeO₄ composite indicated the $C_{sp}$ value of 30 F/g at 0.12 A/g current density as tested by galvanostatic charge/discharge measurements. The high specific power 684.16 W/kg with 3.67 Wh/kg specific energy is observed by this composite which is significantly better than some already reported metallic selenides. The stability test performed at 0.1 V/s for 1000 cycles exhibited that initially $C_{sp}$ increases gradually with the increase in several cycles and then becomes almost constant until 1000 cycles. This observed trend may be ascribed to the slow activation of electrode material as well as good access of electrolytic ions to the electrode surface with the increment in number of cycles. All these results make our fabricated rGO based composite a suitable material for supercapacitors applications.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by Bahauddin Zakariya University: [Grant Number R&D354/20]; King Khalid University: [Grant Number R.G.P. 2/199/42]; Deanship of Scientific Research at King Khalid University Saudi Arabia: [Grant Number R.G.P.2/3/42].

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References

[1] Armand M, Endres F, macFarlane DR, et al. Ionic-liquid materials for the electrochemical challenges of the future. Nat Mater. 2009;8:621–629.
[2] Yuan C, Gao B, Su L, et al. Interface synthesis of mesoporous MnO₂ and its electrochemical capacitive behaviors. J Colloid Interface Sci. 2008;322(2):545–550.
[3] Zhao B, Liu P, Zhuang H, et al. Hierarchical self-assembly of microscale leaf-like CuO on graphene sheets for high-performance electrochemical capacitors. J Mater Chem A. 2013;1(2):367–373.
[4] Nam K-W, Kim K-B. A study of the preparation of NiO x electrode via electrochemical route for supercapacitor applications and their charge storage mechanism. J Electrochem Soc. 2002;149(3):A346–A354.
[5] Javed M, Shah SSA, Najam T, et al. Achieving high-energy density and superior cyclic stability in flexible and lightweight pseudocapacitor through synergic effects of binder-free Co₃O₄ 2D-hexagonal nanoplates. Nano Energy. 2020;77:105276.
[6] Tabassum H, Mahmood A, Wang Q, et al. Hierarchical cobalt hydroxide and B/N co-doped graphene nanohybrids derived from metal-organic frameworks for high energy density asymmetric supercapacitors. Sci Rep. 2017;7(1):1–12.
[7] Kötz R, Carlen M. Principles and applications of electrochemical capacitors. Electrochim Acta. 2000;45(15–16):2483–2498.
[8] Zhang Y, Feng H, Wu X, et al. Progress of electrochemical capacitor electrode materials: A review. Int J Hydrogen Energy. 2009;34(11):4889–4899.
[9] Burke A. R&D considerations for the performance and application of electrochemical capacitors. Electrochim Acta. 2007;53(3):1083–1091.
[10] Ghenaatian H, Mousavi M, Rahmani M. High performance battery–supercapacitor hybrid energy storage system based on self-doped polyaniline nanofibers. Synth Met. 2011;161(17-18):2017–2023.
[11] Conway BE, Birss V, Wojtowicz J. The role and utilization of pseudocapacitance for energy storage by supercapacitors. J Power Sources. 1997;66(1-2):1–14.
[12] Shi J-L, Du W-C, Yin Y-X, et al. Hydrothermal reduction of three-dimensional graphene oxide for binder-free flexible supercapacitors. J Mater Chem A. 2014;2(28):10830–10834.
[13] Chu A, Braatz P. Comparison of commercial supercapacitors and high-power lithium-ion batteries for power-assist applications in hybrid electric vehicles: I. initial characterization. J Power Sources. 2002;112(1):236–246.
[14] Chen T, Dai L. Flexible supercapacitors based on carbon nanomaterials. J Mater Chem A. 2014;2(28):10756–10775.
[15] Mitchell E, Gupta RK, Mensah-Darkwa K, et al. Facile synthesis and morphogenesis of superparamagnetic iron oxide nanoparticles for high-performance supercapacitor applications. New J Chem. 2014;38(9):4344–4350.

[16] Mitchell E, De Souza F, Gupta R, et al. Probing on the hydrothermally synthesized iron oxide nanoparticles for ultra-capacitor applications. Powder Technol. 2015;272:295–299.

[17] Wang H, Wang Y, Wang X. Pulsed laser deposition of large-area manganese oxide nanosheet arrays for high-rate supercapacitors. New J Chem. 2013;37(4):869–872.

[18] Javed MS, Dai S, Wang M, et al. High performance solid state flexible supercapacitor based on molybdenum sulfide hierarchical nanospheres. J Power Sources. 2015;285:63–69.

[19] Chen J, Huang K, Liu S. Hydrothermal preparation of octadecahedral Fe$_3$O$_4$ thin film for use in an electrochemical supercapacitor. Electrochim Acta. 2009;55(1):1–5.

[20] Yang L, Wang S, Mao J, et al. Hierarchical mos2/polyaniline nanowires with excellent electrochemical performance for lithium-ion batteries. Adv Mater. 2013;25(8):1180–1184.

[21] Qian L, Gu L, Yang L, et al. Direct growth of NiCo$_2$O$_4$ nanorods on conductive substrates with enhanced electrocatalytic activity and stability for methanol oxidation. Nanoscale. 2013;5(16):7388–7396.

[22] Patil U, Kulkarni S, Jamadade V, et al. Chemical synthesis of Fe$_3$O$_4$ thin films for supercapacitor application. J Alloys Compd. 2011;509(5):2567–2571.

[23] Wang J-G, Yang Y, Huang Z-H, et al. Interface synthesis of mesoporous MnO$_2$/polyaniline hollow spheres and their application in electrochemical capacitors. J Power Sources. 2012;204:236–243.

[24] Jin W-H, Cao G-T, Sun J-Y. Hybrid supercapacitor based on MnO$_2$ and columned FeOOH using Li$_2$SO$_4$ electrolyte solution. J Power Sources. 2008;175(1):686–691.

[25] Yan X, Tong X, Wang J, et al. Synthesis of mesoporous NiO nanoflake array and its enhanced electrochemical performance for supercapacitor application. J Alloys Compd. 2011;509(5):1677–1682.

[26] Kulal P, Dubal D, Lokhande C, et al. Chemical synthesis of Fe$_3$O$_4$ thin films for supercapacitor application. J Alloys Compd. 2011;509(5):2567–2571.

[27] Wang J-G, Yang Y, Huang Z-H, et al. Interface synthesis of mesoporous MnO$_2$/polyaniline hollow spheres and their application in electrochemical capacitors. J Power Sources. 2012;204:236–243.

[28] Arul NS, Han JI. Facile hydrothermal synthesis of hexapod-like two dimensional dichalcogenide NiSe$_2$ for supercapacitor. Mater Lett. 2016;181:345–349.

[29] Chen H, Chen S, Fan M, et al. Bimetallic nickel cobalt selenides: a new kind of electroactive material for high-power energy storage. J Mater Chem A. 2015;3(47):23653–23659.

[30] Naglajiu G, Cha SM, Sekhar SC, et al. Metallic layered polyester fabric enabled nickel selenide nanosheets as highly conductive and binderless electrode with superior energy storage performance. Adv Energy Mater. 2017;7(4):1601362.

[31] Tabassum H, Zhi C, Hussain T, et al. Encapsulating trogitalite Co$_2$Se$_2$ nanobuds into BCN nanotubes as high storage capacity sodium ion battery anodes. Adv Energy Mater. 2019;9(39):1901778.

[32] Wang X, Liu B, Wang Q, et al. Three-dimensional Hierarchical GeSe$_2$ nanostructures for high performance flexible all-solid-state supercapacitors. Adv Mater. 2013;25(10):1479–1486.

[33] Zhang C, Yin H, Han M, et al. Two-dimensional tin selenide nanostructures for flexible all-solid-state supercapacitors. ACS Nano. 2014;8(4):3761–3770.

[34] Yang P, Chen Y, Yu X, et al. Reciprocal alternate deposition strategy using metal oxide/carbon nanotube for positive and negative electrodes of high-performance supercapacitors. Nano Energy. 2014;10:108–116.

[35] Iqbal MF, Ashiq MN, Hassan M-U, et al. Excellent electrochemical behavior of graphene oxide based aluminum sulfide nanowalls for supercapacitor applications. Energy. 2018;159:151–159.

[36] Byrne A. Ultracapacitors: why how and where is the technology. J Power Sources. 2000;91(1):37–50.

[37] Qu D. Studies of the activated carbons used in double-layer supercapacitors. J Power Sources. 2002;109(2):403–411.

[38] Fernández J, Morishita T, Toyoda M, et al. Performance of mesoporous carbons derived from poly (vinyl alcohol) in electrochemical capacitors. J Power Sources. 2008;175(1):675–679.

[39] Wang Y, Xia Y. Recent progress in supercapacitors: from materials design to system construction. Adv Mater. 2013;25(37):5336–5342.

[40] Liu C, Yu Z, Neff D, et al. Graphene-based supercapacitor with an ultrahigh energy density. Nano Lett. 2010;10(12):4863–4868.

[41] Pan H, Li J, Feng Y. Carbon nanotubes for supercapacitor. Nanoscale Res Lett. 2010;5(3):654–668.

[42] Wang J, Wu Z, Hu K, et al. High conductivity graphene-like MoS$_2$/polyaniline nanocomposites and its application in supercapacitor. J Alloys Compd. 2015;619:438–43.

[43] Iqbal MF, Razaq A, Ashiq MN, et al. Effect of graphene oxide thin film on growth and electrochemical performance of hierarchical zinc sulfide nanoweb for supercapacitor applications. ChemElectroChem. 2018;5(18):2636–2644.

[44] Saranya P, Selladurai S. Facile synthesis of NiSnO$_3$/graphene nanocomposite for high-performance electrode towards asymmetric supercapacitor device. J Mater Sci. 2018;53(23):16022–16046.

[45] Iqbal MZ, Faisal MM, Sulman M, et al. Facile synthesis of strontium oxide/polyaniline/graphene composite for the high-performance supercapattery devices. J Electroanal Chem. 2020;879:114812.

[46] Gohar RS, Ahmad I, Shah A, et al. Fabrication of transition-metal oxide and chalcogenide nanostructures with enhanced electrochemical performances. J Energy Storage. 2020;31:101621.

[47] Sun X, Liu Z, Welscher K, et al. Nano-graphene oxide for cellular imaging and drug delivery. Nano Res. 2008;1(3):203–212.

[48] Uma K, Chong S, Mohan SC, et al. Multi-functional RGO-MoS$_2$ nanocomposites and its application in supercapacitor. Mater Lett. 2016;181:345–349.

[49] Kirubasankar B, Murugadoss V, Lin J, et al. In situ grown nickel selenide on graphene nanohybrid electrode for high energy density asymmetric supercapacitors. Nanoscale. 2018;10(43):20414–20425.

[50] Raut SS, Sankapal BR, Pandey S. Tuberose surface architecture of Sr (OH)$_2$ film as supercapacitive electrode. Electrochim Acta. 2017;258:34–42.

[51] Iqbal MF, Ashiq MN, Razaq A, et al. Excellent electrochemical performance of graphene oxide based strontium...
sulfide nanorods for supercapacitor applications. Electrochim Acta. 2018;273:136–144.

[52] Tomar AK, Singh G, Sharma RK. Charge storage characteristics of mesoporous strontium titanate perovskite aqueous as well as flexible solid-state supercapacitor cell. J Power Sources. 2019;426:223–232.

[53] Parveen S, Raut SS, Tiwari MK, et al. Flexible iron-doped Sr (OH)2 fibre wrapped tuberose for high-performance supercapacitor electrode. J Alloys Compd. 2019;781:831–841.

[54] Wu S, Hu Q, Wu L, et al. One-step solvothermal synthesis of nickel selenide nanoparticles as the electrode for high-performance supercapacitors. J Alloys Compd. 2019;784:347–353.

[55] Iqbal MF, Ashiq MN, Iqbal S, et al. High specific capacitance and energy density of synthesized graphene oxide based hierarchical Al2S3 nanorambutan for supercapacitor applications. Electrochim Acta. 2017;246:1097–1103.

[56] Bibi N, Hussain MZ, Hussain S, et al. Excellent electrochemical performance of SrZrO3 nanorods as supercapacitor electrode in aqueous electrolytes. Appl Surf Sci. 2019;495:143587.

[57] Zhang L, Gong H. Partial conversion of current collectors into nickel copper oxide electrode materials for high-performance energy storage devices. ACS Appl Mater Interfaces. 2015;7(28):15277–15284.

[58] Peng H, Ma G, Sun K, et al. A novel aqueous asymmetric supercapacitor based on petal-like cobalt selenide nanosheets and nitrogen-doped porous carbon networks electrodes. J Power Sources. 2015;297:351–358.

[59] Ramasamy K, Gupta RK, Palchoudhury S, et al. Layer-structured copper antimony chalcogenides (CuSbSe x S2–x): stable electrode materials for supercapacitors. Chem Mater. 2015;27(1):379–386.

[60] Nagarani S, Sasikala G, Satheesh K, et al. Synthesis and characterization of binary transition metal oxide/reduced graphene oxide nanocomposites and its enhanced electrochemical properties for supercapacitor applications. J Mater Sci: Mater Electron. 2018;29(14):11738–11748.

[61] Zhang J, Zhang Z, Jiao Y, et al. The graphene/lanthanum oxide nanocomposites as electrode materials of supercapacitors. J Power Sources. 2019;419:99–105.

[62] Zhao L, Qiu Y, Yu J, et al. Carbon nanofibers with radially grown graphene sheets derived from electrospinning for aqueous supercapacitors with high working voltage and energy density. Nanoscale. 2013;5(11):4902–4909.

[63] Packiaraj R, Devendran P, Venkatesh K, et al. Electrochemical investigations of magnetic Co3O4 nanoparticles as an active electrode for supercapacitor applications. J Supercond Novel Magn. 2019;32:2427–2436.