

Summary and Conclusions

The present work explores the preparation of carbon from *P. juliflora* biomass (anode) and Zinc cobaltite and doped Zinc cobaltite (cathode) by sol-gel method. The prepared anode and cathode materials are used to assemble the devices in symmetric and asymmetric mode. The key results are listed here.

Anodes

- In Anodic materials, S-Carbon and B-Carbon have been prepared from the stick and bark of *Prosopis juliflora* by conventional heating method. Then, high performance biomass i.e., bark of *Prosopis juliflora* has been chosen for synthesis of PB-Carbon by plasma firing without using any activating agents.
- XRD analysis confirms the presence of microcrystallite graphite that are randomly oriented across the S-Carbon, B-Carbon and PB-Carbon.
- The morphological characterization shows that the prepared materials are exhibiting the porous nature. Compared to all the prepared anodes, B-Carbon exhibits porous morphology in FESEM analysis and are verified by HRTEM analysis. The long range ordered graphite is dominant in the B- Carbon owing to the best performance.
- Elemental analysis shows that the atomic weight percentage of carbon in B-Carbon is 91.44% which is higher than the S-Carbon and PB-Carbon.
- Surface area analysis of B-Carbon shows the specific surface area of $703 \text{ m}^2\text{g}^{-1}$ which is higher than the S-Carbon and B-Carbon. Higher surface area is realized due to the long-range disordered graphite that has formed a mesh like structure allowing more pores in between offering larger surface area for electrochemical activity contributing to the high capacitance value.
- Compared to all the anodes, B-Carbon, when evaluated in a half cell, exhibits higher specific capacitance of 198 Fg^{-1} at the current density of 1 Ag^{-1} due to its high surface area and low charge transfer resistance of the electrochemical cell. After 500 consecutive charge discharge cycles, the cyclic stability of 77% is

achieved. It is attributed to the increase in charge transfer resistance of the sample and is confirmed by Electrochemical impedance analysis. Though the cyclic stability of B- Carbon is less than S- Carbon (94%) and PB-Carbon (82%), the internal resistance contributed by B-Carbon is low thus qualifying for better performance. Capacity fading occurred in the case of B-Carbon is well correlated to the impurities of electrolyte and not with the working electrode prepared due to the high half-cell performance observed.

Cathodes

- Pristine and doped ZnCo_2O_4 exhibits spinel cubic structure and is confirmed by the Rietveld refinement analysis. When doping the Ni, Cr and Fe, Cr in the host matrix, the positional co-ordinates of Zn has been shifted from their position which is verified by the obtained crystal structure using Vesta software.
- Compared to pristine ZnCo_2O_4 , Raman peaks observed for Fe,Cr: ZnCo_2O_4 and Ni,Cr: ZnCo_2O_4 got shifted due to change in positional occupation of atoms in the unit cell of the pristine material.
- Octahedral morphologies are seen in FESEM analysis of ZnCo_2O_4 and doped ZnCo_2O_4 samples. The crystallite size of the Ni,Cr: ZnCo_2O_4 sample is lower than the pristine sample which decreases the particle size of the sample and is shown in FESEM analysis
- Out of all the prepared cathodes and the analysis with the half-cell analysis of electrochemical performance, Ni,Cr: ZnCo_2O_4 sample exhibits higher specific capacitance of 575 Fg^{-1} at the current density of 1 Ag^{-1} in the half cell configuration. The material is quite stable as it exhibits 90% of capacitance retention after 2000 cycles at 5 Ag^{-1} current density. Due to the lower charge-transfer resistance, as seen in EIS spectra analysed before and after cycling, the movement of ionic species is favoured thereby bringing a decrease in the internal resistance of the Ni, Cr-doped samples. Hence, in conclusion, Ni, Cr doped ZnCo_2O_4 performs better than the other two samples.

Symmetric devices

- The capacitive contribution of the symmetric device fabricated with B-Carbon exhibits higher value of 72% compared to the other symmetric devices constructed. It is attributed to the high carbon content (at.wt % - 91.44%), high surface area of B-Carbon, presence of long range disordered graphite and the absence of impurity.
- From all the prepared symmetric supercapacitor devices, the symmetric device assembled with B-carbon from the bark of *P. juliflora* by conventional heating method exhibits higher performance than other symmetric devices with an areal energy density of $137\mu\text{Wh}/\text{cm}^2$ (15.16 Wh Kg^{-1}) and an areal power density of $5452\text{ Wh}/\text{cm}^2$ (375 W Kg^{-1}) that would favor the miniaturization of devices when utilized for development of product.

Asymmetric devices

- Compared to all the prepared asymmetric supercapacitor devices, the device fabricated with B-carbon from the bark of *P. juliflora* and Ni,Cr:ZnCo₂O₄ exhibits higher performance with specific capacitance - 126.27 Fg^{-1} , areal energy density of $113\mu\text{Wh}/\text{cm}^2$ (gravimetric - 34 Wh Kg^{-1}) and areal power density of $5594\mu\text{W}/\text{cm}^2$ (gravimetric- 1695 W Kg^{-1}).
- The best performing device, B-Carbon/PVA-KOH/Ni, Cr: ZnCo₂O₄, is analysed at various bending states. It is observed that the electrochemical performance experienced no apparent change which is more favourable for portable and flexible electronic devices of lower power demand.

FUTURE SCOPE OF THE RESEARCH WORK

- ✚ To improve the overall performance of the S-Carbon and PB-Carbon for supercapacitor application.
- ✚ To improve the performance of the B Carbon in terms of cycling stability by using more reliant electrolyte.
- ✚ To analyse the oxidation state of the transition metal oxides before and after cycling for better understanding on the role of charge storage mechanism in the fabricated asymmetric devices.
- ✚ To prepare the composite material using ZnCo_2O_4 and Carbon material to develop the performance of the device.
- ✚ To improve on the design of the device by selection of more suitable polymer for the electrolyte and current collector.
- ✚ To develop fabric-based device with the prepared electrodes.
- ✚ To bring down the cost of the device
- ✚ To explore the device towards wearable and portable electronic devices.