IJCPS Vol. 9, No. 3 , May-June 2020
www.ijcps.org
DOI Prefix:10.30731/ijcps

International Journal of Chemical and Physical Sciences
(Peer-Reviewed Journal)
ISSN:2319-6602

Metal Oxides and its Nano Composite as Electrode Materials for Supercapacitor: A Review

K.D. Jagtap[1], R.V. Barde[2]*, S.A. Waghuley[3], K.R. Nemade[4]

[1] Department of Physics, Indira Gandhi Kala Mahavidyalaya Ralegaon, Yavatmal, Maharashtra, India
[2] Department of Physics and Electronics, Govt. Vidarbha Institute of Science and Humanities, Amravati, Maharashtra, India
[3] Department of Physics, Sant Gadge Baba Amravati University, Amravati, Maharashtra, India
[4] Department of Physics, Indira Mahavidyalaya Kalamb, Yavatmal, Maharashtra, India
***Corresponding Author E-Mail:** rajeshbarde1976@gmail.com

Received: 09.04.2020 ***Accepted: 23.05.2020*** ***Published Online 15.06.2020***

Abstract

Supercapacitor is the most efficient potential energy storing systems because of its extraordinary power density, low weight, eco-friendly nature, etc. In future, Supercapacitor will widely use in fusion electric automobiles, power devices and may more systems. The possessions of supercapacitor come from the interface of their interior materials. Especially the mixture of electrode materials and the types of electrolyte regulate the functionality and thermal and electrical features of the capacitors. The electrode materials play the important role to improve the precise capacitance, power and energy densities of the supercapacitor. For this, it requires to develop methods to fabricate such materials for advanced electrode. In current years have seen giant interest in such materials and their building method. In this reviews paper, we overview on types of supercapacitor and mainly focused on all the metal oxide and its nano composite as an electrode materials for supercapacitor.

Keywords: Supercapacitors, EDLC, Pseudocapacitors, Metal oxide and its Nano composites and electrode materials

Introduction:

Among all the energy resources, the global energy necessities are mostly dependent on the fossil fuel. Due to the limitation of reservoirs a fossil fuel and increasing population and industrialization, in future we will face the problem of energy crisis. To overcome such problem, it is necessary to develop sustainable energy model. Energy storage has an equal significance as energy manufacture. In the recent years there has been notable amount of interest in emerging energy storing method to avoid energy challenges. Currently battery and supercapacitor are the major energy storage devices. But due to lack of advanced power and energy densities, higher number of charge and discharge cycle and higher rates of charging and discharging, battery limits its application. Our modern society demands light weight, flexible, inexpensive and ecologically approachable energy storing system. The limitation of battery can be overcome by using supercapacitor. Supercapacitor with their significant features such as extraordinary energy density, great power density, low weight, speedy charging discharging rate and long life span is better energy storage system than the battery.

Classification of Supercapacitor:

Supercapacitor is a extraordinary capacity capacitor over a capacitance significance much greater than other capacitors in smaller voltage limits, that bond the break between supercapacitors and rechargeable batteries. Supercapacitor can be classified into three types such that electrochemical double layer capacitors (EDLCs), pseudo capacitor and hybrid capacitor which is the mixture of EDLC and pseudo capacitor.

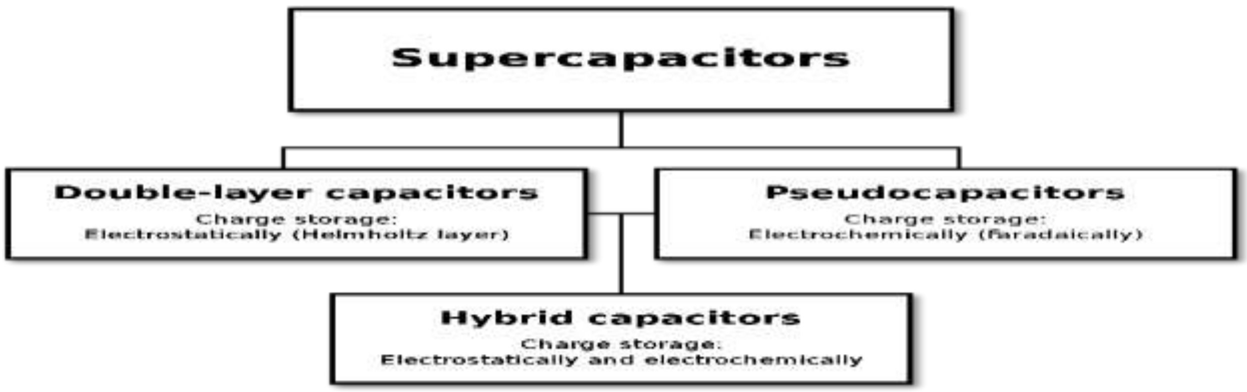

Fig.1: Supercapacitor Types

Electrochemical double layer capacitors (EDLCs):

Every electrochemical capacitor has two electrodes, mechanically alienated by a separator, which are ionically linked to each other via the electrolyte. The electrolyte is a grouping of positive and negative ions disbanded in a solvent like as water. At every of the two electrode surfaces generate a space in which the liquid electrolyte associates the conductive metallic surf ace of the electrode. This boundary forms a mutual borderline among two different states of material, such as an unsolvable dense electrode surface and a head-to-head fluid electrolyte. In this boundary happens a very unusual occurrence of the double layer consequence.

Pseudocapacitance:

In this type of capacitor, electrical energy stored through faradaic redox reactions through transfer of charge .When the voltage applied to terminals of capacitor, electrolyte ions transfer to the reverse diverged electrode and forms a double-layer. In between this double layer, a solitary layer of solvent molecules doings as separator. Pseudocapacitance will initiate when precisely adsorbed ions of the electrolyte present the double-layer. The mechanism of revocable faradaic redox reactions is take place on the apparent of appropriate electrodes through an electric double-layer.

Hybrid capacitors:

Out of two electrods of Hybrid capacitor, one show mostly electrostatic and further typically electrochemical capacitance, like as lithium-ion capacitors. Double-layer capacitance and pseudocapacitance together contribute the whole capacitance value of an electrochemical supercapacitor, a accurate explanation of these capacitors merely can be agreed beneath the universal term. The perception of supercapattery and supercabattery has been afresh suggested to healthier epitomize those fusion devices that effort extra like the supercapacitor and the rechargeable battery, respectively. The precise capacitance of hybrid supercapacitor is higher in association to the present electric double layer capacitor (EDLC) and pseudocapacitors. Generally, the uneven performance of cross supercapacitors which is the grouping of EDLC and pseudocapacitor deeds as a garnish in its corresponding capacitance values.

Electrodes:

Generally thin coatings are applied to electrodes of Supercapacitor and electrically linked to a conductive current collector. For better value of capacitance, the supercapacitor electrodes essentially have decent conductivity, great temperature constancy, high corrosion resistance, long-term chemical stability, and great surface regions per unit volume and mass. Also other necessities comprise eco-friendly and low cost. The quantity of double-layer as healthy as pseudocapacitance stowed per unit voltage in a supercapacitor is mostly a task of the electrode surface space. Therefore, supercapacitor electrodes are usually made of absorbent, spongy material with an extremely great particular surface area, such as activated carbon. Furthermore, the capability of the electrode material to accomplish faradaic charge transfers increases the over-all capacitance.

Electrodes for EDLCs:

The utmost usually used electrode material for super capacitors is carbon in different form like as activated carbon, carbon fibre-cloth, carbide-derived carbon, carbon aerogel, graphite, graphane and carbon nanotubes.

Activated carbon:

Activated carbon was the leading material selected for EDLC electrodes. Even however its electrical conductivity is about 0.0029% that of metals (1,252 to 2,001 S/m), it is enough for supercapacitors. Activated carbon is an exceptionally absorbent type of carbon with an extraordinary precise surface area. The majority form recycled in electrodes is small density with several pores, generous great double-layer capacitance. Solid triggered carbon, also named consolidated amorphous carbon is the most preferred electrode material for supercapacitors and may be inexpensive than former carbon products. It is created from stimulated carbon powder constrained into the preferred shape, making a slab with a comprehensive dissemination of pore extents. An electrode of a surface space of nearby 1000 m2/g outcomes in a typical double-layer capacitance of around 10 μF/cm2 and a specific capacitance of 100 F/g.

Activated carbon fibres:

Activated carbon fibres are formed from activated carbon and have a usual diameter of 10 μm. They can have micropores with a very thin pore-size distribution that can be readily controlled. The surface area of ACF merged into a fabric is about 2500 m^2/g. Benefits of ACF electrodes contain small electrical resistance beside the fibre axis and worthy contact to the collector. For example activated carbon electrodes show mainly double layer capacitance through a minor quantity of pseudocapacitance owed to their microspores.

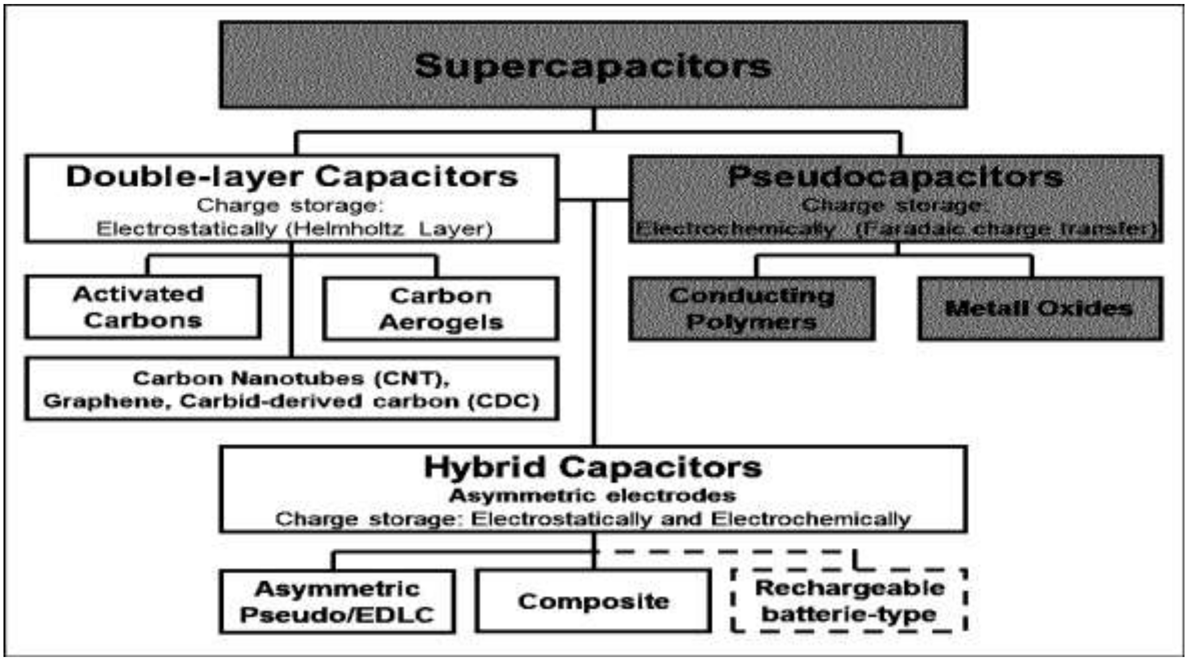

Fig.2: Family tree of supercapacitor types: Double-layer capacitors, pseudocapacitors as well as hybrid capacitors are defined over their electrode designs.

Carbon aerogel:

Carbon aerogel is a extremely porous, artificial, ultra light resulting since an organic gel in which the liquid constituent of the gel has been exchanged with a gas. Aerogel electrodes are manufactured via pyrolysis of resorcinol-formaldehyde aerogels and are additional conductive than greatest activated carbons. They permit shrill and mechanically steady electrodes with a width in the variety of numerous hundred micrometres (µm) and with unchanging pore extent. Aerogel electrodes similarly deliver mechanical and vibration constancy for supercapacitors used in extraordinary vibration surrounds. Researchers have designed a carbon aerogel electrode through specific densities of around 400–1200 m^2/g and volumetric capacitance of 104.1 F/cm^3, giving a specific energy of 325.1 kJ/kg (90.1 Wh/kg) and specific power of 20.1 W/g. The typical aerogel electrodes display mainly double-layer capacitance. Aerogel electrodes that include composite material can add a extraordinary amount of pseudo capacitance.

Carbide derived carbon:

Carbide derived carbon (CDC), also identified as tuneful nanoporous carbon, is a group of carbon materials resulting from carbide precursors, as dualistic silicon carbide and titanium carbide, that are converted into pure carbon through physical or chemical processes. Carbide derivative carbons can reveal great surface space and tuneful pore diameters to exploit ion confinement, increasing pseudo capacitance through faradaic H_2 adsorption action. CDC electrodes with handmade pore structure offer as much as 75% superior specific energy than traditional activated carbons.

Graphene:

Graphene is a crystal like allotrope of carbon with 2 D properties. Its carbon atoms are compactly crowded in a steady hexagonal pattern. Graphene has a hypothetical specific surface area of 2630 m^2/g

which can hypothetically give a capacitance of 550.2 F/g. Also, benefit of graphene over activated carbon is its greater electrical conductivity. As a new improvement used graphene sheets straightly by way of electrodes deprived of collectors for moveable uses. In one personification, a graphene centered supercapacitor practices bowed graphene panes that do not heap face-to-face, creating mesopores that are reachable to and being wet by ionic electrolytes at potential near to 4 V. A precise energy of 85.63 Wh/kg (308.2 kJ/kg) is attained at room temperature equaling that of a conservative nickel metal hydride battery, but with 100-999 times superior precise power. The 2D structure of graphene advances charging and discharging. Charge carriers in vertically concerned with sheets can rapidly travel into or out of the unlimited arrangements of the electrode, therefore increasing currents. Such capacitors might be appropriate for 101/121 Hz filter solicitations, which are out-of-the-way for super capacitors consuming other carbon materials.

Carbon nanotubes:

Carbon nanotube (CNTs), are carbon molecules with a cylindrical nanostructure. They have a echoing structure with walls shaped by one atom dense panes of atomic number 6. These panes are rolled at precise and distinct angles, and also the mixture of chiral angle and radius gear stick possessions like electrical physical phenomenon, electrolyte wettability and ion admittance. Nanotubes are classified as single-walled nanotubes or multi-walled nanotubes. The second have one or additional outer tubes in turn close a SWNT, very similar to the Russian matryoshka toys. SWNTs take diameters in between 1 and 3 nm. MWNTs have denser concentric walls, parted by positioning (0.341 nm) that is nearby to graphene's inter layer distance. Nanotubes will cultivate precipitously on the collector ubstrate, like a Si wafer. Distinctive lengths are 21 to 110 µm. Carbon nanotubes can significantly advance capacitor presentation, due to the extremely wet surface area and extraordinary conductivity. A SWNT based super capacitor with binary compound solution was consistently studied, for the primary time, revealed that the ion extent result and also the electrode-electrolyte wettability are the leading factors moving the chemistry behavior of versatile SWCNTs-supercapacitors in numerous one molar aqueous electrolytes through dissimilar anions and cations. The experimental results additionally showed for versatile supercapacitor that it's advised to place enough pressure between the 2 electrodes to enhance the binary compound solution CNT supercapacitor.

Electrodes for pseudocapacitors:

MnO2 and RuO2 are distinctive materials castoff as electrodes for pseudo capacitors, meanwhile they need the chemistry signature of a electrical phenomenon conductor as well as showing faradaic behaviour. Additionally, the charge storing creates from electron transferal tools instead of accumulation of ions within the double layer. Pseudo capacitors were formed through faradaic chemical reaction reactions that occur among the active conductor materials. More analysis was targeted on transition-metal oxides like MnO2 since transition-metal oxides have a lower price compared to metallic element oxides like RuO2.

Metal oxides:

Brian Evans Conway's study represented electrodes of transition metal oxides that revealed great amounts of pseudo capacitance. Oxides of transition metals together in metal (RuO2), metal (IrO2), iron(Fe3O4), atomic number 25 (MnO2) or compounds like metal sulfide (TiS2) alone or together generate sturdy faradaic electron–transferring reactions collective with small resistance. Metal oxide together with H2SO4 solution delivers precise capacitance of 721 F/g and a great specific energy of twenty 6.71 Wh/kg (96.119 kJ/kg).

Conductive polymers:

Another approach uses electron-conducting polymers as pseudocapacitive material. Although automatically weak, semiconducting polymers have high conduction, leading to an occasional ESR and a comparatively high capacitance.Such conducting polymers include polyaniline, polythiophene, polypyrrole and polyacetylene. Such electrodes conjointly use chemical science doping of the polymers through anions and cations. Electrodes prepared of or coated with semiconducting polymers have prices cherish carbon electrodes. Conducting compound electrodes usually suffer from restricted athletics stability. Though, polyacene electrodes deliver up to 10,000 cycles, considerable superior than batteries.

Electrodes for hybrid capacitors:

All commercial hybrid supercapacitors are asymmetric. They mix Associate in ursing conductor with high quantity of pseudocapacitance with Associate in nursing conductor with a high quantity of double-layer capacitance. In such systems the faradaic pseudo capacitance conductor through their greater capacitance delivers extraordinary specific energy whereas the non-faradaic EDLC conductor allows high specific power. A benefit of the hybrid type super capacitors associated with symmetrical EDLC's is their advanced precise capacitance amount with their greater rated voltage and consistently their advanced specific energy.

Composite electrodes:

Complex electrodes for hybrid type super capacitors are considered from carbon created material with combined pseudo capacitive vigorous materials similar metal oxides and conducting polymers. As per 2013 most analysis for super capacitors discovers composite electrodes. CNTs provide strength for a standardised distribution of metal chemical compound or electrically conducting polymers (ECPs), producing decent pseudocapacitance and good double-layer capacitance. These electrodes come through advanced capacitances than whichever clean carbon or clean metal chemical compound or polymer centred electrodes. This is recognised to the availability of the nanotubes' twisted carpet structure, which permits an unbroken covering of pseudo capacitive materials and 3D charge dissemination. The method to produce pseudo capacitve materials sometimes uses a hydrothermal process. However, a recent man of science, Li et al., from the University of Delaware initiate a superficial and accessible tactic to precipitate MnO2 on a SWNT film to make an organic-electrolyte based super capacitor. Another way to boost carbon nanotube electrodes is by nobbling with a pseudo capacitive dopant such as in lithium-ion capacitors. In this situation the comparatively minor lithium atoms insert among the strata of carbon. The anode is prepared of lithium doped carbon, which allows lesser negative potential with a cathode finished of activated carbon. This leads to a bigger voltage of 3.9-4 V that avoids electrolyte oxidation. As of 2007 that they had attained capacitance of 551 F/g. and touch a selected energy up to fourteen Wh/kg (50.41 kJ/kg).

Table 1: Metal Oxides And its Nano Composite As Electrode materials:

Sr. No.	Materials	Method of synthesis	Electrolyte	High Sp. Capacitance	Retention	Max. energy density	Max. power density	Year
1	MnMoO4 nanoparticles	Solvothermal method	2 M KOH	654.8 F/g at 1 A/g	-	-	-	2018
2	Ag/Nio Honeycomb structured	Surfactant-assisted hydrothermal route	2 M KOH	824C/g at 2.5A/g	-	63.75W h kg-1	2812.5W kg-1	2019
3	(Co, Mn)3O4 spinel structure	Co-precipitation	6M KOH	2701f/g at 5A/g	76.4%.	-	-	2017
4	Co3O4 Nanoparticles	Traditional chemical reflux	2 M KOH	1413 Fg-1 At 1 Ag-1	98.4% after 1000 cycles.	-	-	2018
5	CoO-modified NiMoO4	Two-step hydrothermal reaction	6 M KOH	2332 F/g At $2mA/cm^2$	87.1% after 2000 cycle	71.4 Wh/Kg	750 W/Kg	2019
6	Cubic Cu2O	Solvothermal method	2 M KOH	402 F/g At 0.75A/g	89.5 % after 2500 cycles	7.5 Wh/Kg.	2678.5 W/Kg	2019
7	Cu–O thin films	RF magnetron sputtering	-	350 F g-1 At 1A/g	67% after 1000 cycles.	-	-	2017
8	CuMoO4 Nanosheets with Graphene	hydrothermal method	2 M LiOH	2342 F/g At 1.8 A/g	98% after 4000 cycles	50.6 Wh kg-1	3875 W kg-1	2018
9	CuCo2O4 arrays on Ni foam	facile hydrothermal routes.	6 M HCl	1227.8 F g1 at 5 mA cm2	95.4% after 1000 cycles)	16.7 W h /kg	4134 W /kg	2019
10	(rGO/MnFe2o 4/Ppy	modified Hummer's	1 M H_2SO_4	232 F/g At 5 mV/s	-	32.3 Wh/Kg	581 W/Kg	2019
11	Hierarchical Fe2O3 and NiO	wet chemical process	0.05 M $FeCl_3$ 6 M NaOH	81.9 mAh/g 119.7	85.2 % retention after 5000	48 Wh kg-1	2089 W kg-1	2019
12	GF-CNT@400 Fe2O3	Atomic layer deposition	2M KOH	580.6 F/g At 5 A/g	111.2 % after 5000 cycles	-	-	2017
13	Fe3O4@CNF Mn	magnetic stirring	0.1 M H_2SO_4	306 F/g at 1 A/g	85% after 2000	13 Wh/kg	65 W/Kg	2017
14	PPy/GO|PPy/ MnO2	electrochemical deposition	1 M Na_2SO_4	786.6 F/g At 25mV/s	86.1 % after 1000 cycles	53.2 Wh/Kg	1392.9 W/kg	2019
15	Ni/NiO@rGO	modified Hammers	1 M KOH.	335 C/g	100 % after 1000 cycles	-	-	2017
16	Co3O4 and La2O3	chemical bath method.	1 M KOH	415 and 288 F g 5 mV/s	92% after 2000 cycles	42.9 Wh kg1	108.2 W kg1,	2017
17	LiMn2O4/CC s	hydrothermal method	0.5 M Li2SO4	451 F/g at 0.5 A/g	95% after 3000	-	-	2019
18	MnCo2O4/3D G	modified Hummers'	3 M KOH	503 F g1 at 1 A g1	97.4%After 5000	-	-	2019
19	MnO2-deposited graphene	current deposition method	1 M Na2SO4	1231mF/cm2 At 0.5 mA/cm2	82.8% After 10000	0.27 mFmWh/ cm3	0.02 W/cm3	2017
20	MnO2 and Fe2O3	-	1 M Na2SO4	92 Fg-1	91% After 3000 cycle	41.8Wh kg-1	-	2015
21	ZnCo 2O4/MnO2	facile solvothermal method.	6M aqueous KOH	286 F/g	98.5% after 1500 cycles	16.94 W h/kg	750 W/kg	2018

22	WO3 nanorod	hydrothermal method	1 M H2SO4	538F/g At 5mV/s	85 % after 2000 cycles	48 Wh/kg	1385 W/Kg	2018
23	TiO2 nanotube arrays/C/MnO 2	anodization, carbon deposition and electro deposition .	0.5 M NaSO4	492 mF/cm2	98% after 3000 cycles	465 mWh/m2	f2.5 W/m2	2019
24	SnO2@NiCo2 O4/N-MWCNTs	Thermal reduction	6 M KOH	728 Fg1 at 4 A/g	92 % After 5000 cycles	-	-	2019
25	Nb2O5	magnetic stirring	2 M KOH	258 F/g at 0.5 A/g	90.5% after 5000 cycles	-	-	2019

Conclusions:

In this paper, we have reviewed some of the latest works on certain metal oxides and its composite electrodes which can be used as supercapacitor electrodes. The composite electrodes offer better specific capacitance and higher power density than the authentic counterpart. Further research is desirable for extraordinary performance supercapacitors electode which can be concurrently guarantee great capacitance, cyclic constancy and outstanding rate. The issue with the natural metal oxide electrodes is that they've terrible charge and cyclic capability. The strength density is not great sufficient as related to that of battery. The capacitance attained is very irrelevant in comparison to their hypothetical values. The drawbacks of metallic oxides may be minimized via use of other cloth to shape a complex electrode. Incorporating using nanostructures in creation of complex electrodes in addition complements the electrodes performance. The better unique capacitance had been discovered in complex electrodes through nano structuring. Construction of ternary complex electrodes is attainment momentum. However, rational preference of electrode materials and Electrolytes will have a huge impact at the performance. Enhancing of stacking amount of active materials desires interest while getting ready the composite. The metallic oxides composite electrode has shown a specific capacitance in range of 92 to786 fg^{-1}. The metallic oxides complex on Ni foam have reached better capacitances as much as 1227fg^{-1}. The nano composite metal oxides with graphenes and spinel shape have been additionally capable of acquire precise capacitance in 2342 to 2700 fg^{-1} range. The Author believed that further study should be focused on different Nano complex materials made up of metal oxides for fabricating high performance supercapacitor electrodes. By forming the nano composite of metal oxide with graphens, conducting polymers so it can minimize particle size, induce porosity, enhance specific surface area, prevent particles from agglomerating, expanding active sites, refining cycling stability and providing additional pseudocapacitance. Also it is important to advance synthesis parameter and materials properties for all capability exploration of the supercapacitor electrode materials. We particularly note that special care must be taken to provide good electrode electrolyte match in order to achieve good capacitance. A proper materials selection must be done captivating into interpretation the requirement for final application such as cycle life, specific energy and power, energy and power density, calendar life. In mandate to advance the electrochemical enactment of metal oxide and its nano compsites the following aspects may be considered: optimisation of the morphology of metal compounds in the composite, finding out the best metal combination and simple and practical preparation method, synthesis of composite material of multi-metal oxide and its nano composites.

Acknoledgment:

The authors are thankful to the department of Physics and Electronics, Goverment Vidarbha Institute of science and Humanities, Amravati, Maharashtra.

References:

[1] B. Saravanakumar, S. P. Ramachandran, G. Ravi, V. Ganesh, A. Sakunthala, R. Yuvakkumar,Transition mixed-metal molybdates (MnMoO4) as an electrode for energy storage applications, Applied Physics A (2019) 125:6

[2] Sadayappan Nagamuthu & Kwang-sun Ryu, Synthesis of Ag/Nio Honeycomb structured Nanoarrays as the electrode Material for High performance Asymmetric supercapacitor Devices, scientific Reports(2019) 9:4864

[3] Qinghua Tian, Xiang Wang, Guoyong Huang, and Xueyi Guo, Nanostructured (Co, Mn)3O4 for High Capacitive Supercapacitor Applications, Nanoscale Research Letters (2017) 12:214

[4] R. Packiaraj & P. Devendran & K. S. Venkatesh & S. Asath bahadur & A. Manikandan & N. Nallamuthu, 'Electrochemical Investigations of Magnetic Co3O4 Nanoparticles as an Active Electrode for Supercapacitor Applications' Journal of Superconductivity and Novel Magnetism(2018)

[5] P. Li, C. Ruan, J. Xu, Y. Xie, Enhanced capacitive performance of CoOmodified NiMoO4 nanohybrid as advanced electrodes for asymmetric supercapacitor, Journal of Alloys and Compounds (2019)

[6] Abdullah Aljaafari , Nazish parveen, Faheem Ahmad, Mir Waqas Alam & sajid Ali Ansari, 'self-assembled Cube-like Copper oxide Derived from a Metalorganic Framework as a Highperformance electrochemical supercapacitive electrode Material' scientific Reports (2019) 9:9140

[7] B Purusottam Reddy, K Sivajee Ganesh, S-H Park and O M Hussain, 'RF-sputter deposited flexible copper oxide thin films for electrochemical energy storage', 'Indian J Phys'(2017)

[8] F. Bahmani, S.H. Kazemi, H. Kazemi, M.A. Kiani, S.S. Yoones Feizabadi, Nanocomposite of copper–molybdenum–oxide nanosheets with graphene as high-performance materials for supercapacitors, Journal of Alloys and Compounds (2019)

[9] Qi Gao, Jinxing Wang, Jingfeng Wang, 'Morphology-controllable synthesis of CuCo2O4 array on nickel foam as advanced electrode for Supercapacitor, 'Journal of Alloys and Compounds 789' (2019) 193-200.

[10] Saira Ishaq, Mahmoud Moussa, Farah Kanwal, Muhammad ehsan, Muhammad saleem, Truc Ngo Van & Dusan Losic, 'Facile synthesis of ternary graphene nanocomposites with doped metal oxide and conductive polymers as electrode materials for high performance supercapacitors', 'Scientific Reports' (2019) 9:5974

[11] J. Lin, Y. Yan, H. Wang, X. Zheng, Z. Jiang, Y. Wang, J. Qi, J. Cao, W. Fei, J. Feng, Hierarchical Fe2O3 and NiO nanotube arrays as advanced anode and cathode electrodes for high-performance asymmetric supercapacitors, Journal of Alloys and Compounds (2019)

[12] Cao Guan, Jilei Liu, Yadong Wang, Lu Mao, Zhanxi Fan, Zexiang Shen, Hua Zhang, John Wang, 'Iron Oxide-Decorated Carbon for Supercapacitor Anodes with Ultrahigh Energy Density and Outstanding Cycling Stability', 'ACS Nano 9(5)(2015), 5198-5207

[13] Nousheen Iqbal, Xianfeng Wang, Aijaz Ahmed Babar, Ghazala Zainab, Jianyong Yu & Bin Ding, 'Flexible Fe3O4@Carbon Nanofibers Hierarchically Assembled with MnO2 Particles for High-Performance Supercapacitor Electrodes', 'Scientific RepORts'(2017) 7: 15153

[14] Shalini Kulandaivalu, Nadhrah suhaimi & Yusran Sulaiman, 'Unveiling high specific energy supercapacitor from layer-by-layer assembled polypyrrole/graphene oxide|polypyrrole/manganese oxide electrode material', 'Scientific RepoRts' (2019) 9:4884

[15] Himadri Tanaya Das, Kamaraj Mahendraprabhu, Thandavarayan Maiyalagan & Perumal Elumalai 'Performance of Solid-state Hybrid Energy-storage Device using Reduced Graphene-oxide Anchored Sol-gel Derived Ni/NiO Nanocomposite', 'SciEnTific REPORTS(2017) 7: 15342

[16] Yadav A.A.,Lokhande A.C., Kim J.H., Lokhande C.D., 'High electrochemical performance asymmetric supercapacitor based on La2O3//Co3O4, 'Journal of Industrial and Engineering Chemistry 56(2017) 90-98

[17] Chunhong Mu a, Shuai Lou a, Rashad Ali a, Huajing Xiong a, Shiyu Liu a, Hong Wang a, Weirong Huo a, Liangjun Yin a, Ruonan Jia a, Yifan Liu a, Xian Jian a, b, 'Carbon-decorated LiMn2O4 nanorods with enhanced performance for supercapacitors', 'Journal of Alloys and Compounds' 805 (2019) 624-630

[18] Hongzhi Wang, Chen Shen, Jin Liu, Weiguo Zhang, Suwei Yao, 'Three-dimensional MnCo2O4/graphene composites for supercapacitor with promising electrochemical properties', 'Journal of Alloys and Compounds' 792 (2019) 122-129

[19] Lanshu Xu, Mengying Jia, Yue Li, Xiaojuan Jin & Fan Zhang, 'High-performance MnO2-deposited graphene/activated carbon film electrodes for flexible solid-state supercapacitor', 'SCiEntiFiC REPORts (2017) 7: 12857

[20] Girish S. Gund, Deepak P. Dubal, Nilesh R. Chodankar, Jun Y. Cho, Pedro GomezRomero, Chan Park & Chandrakant D. Lokhande, 'Low-cost flexible supercapacitors with high-energy density based on nanostructured MnO2 and Fe2O3 thin films directly fabricated onto stainless steel', 'Scientific RepoRts' (2015) 5:12454

[21] Huanhuan Li1 • Lei Wang1 • Yuming Guan1 • Yibo Su1 • Jingbo Mu1 • Hongwei Che1 • Aifeng Liu1 • Zengcai Guo1. 'Facile solvothermal synthesis of ZnCo2O4/MnO2 nanosheets composite with enhanced

[22] P.A. Shinde, A.C. Lokhande, A.M. Patil, C.D. Lokhande, Facile synthesis of self-assembled WO3 nanorods for high-performance electrochemical capacitor, Journal of Alloys and Compounds (2018)

[23] Zhirong Zhang 1, Zhiming Xu 1, Zhongping Yao, Yanqiu Meng, Qixing Xia, Dongqi Li, Zhaohua Jiang, 'Ultrahigh capacitance of TiO2 nanotube arrays/C/MnO2 electrode for supercapacitor', 'Journal of Alloys and Compounds' 805 (2019) 396-403

[24] Sivalingam Ramesh a, Dhanasekaran Vikraman b, K. Karuppasamy b, Hemraj M. Yadav c, Arumugam Sivasamy d, Hyun-Seok Kim b, Joo-Hyung Kim e,, Heung-Soo Kim a, 'Controlled synthesis of SnO2@NiCo2O4/nitrogen doped multiwalled carbon nanotube hybrids as an active electrode material for supercapacitors', 'Journal of Alloys and Compounds' 794 (2019) 186-194

[25] Jingqiang Liu, Kaixiong Xiang, Wei Zhou, Yirong Zhu, Li Xiao, Wenhao Chen, Han Chen, 'Preparation of Nb2O5 with an air filter-like structure and its excellent electrochemical performance in supercapacitors', 'Journal of Alloys and Compounds' 802 (2019) 668-674'