

Dedication

I dedicate this work to my wife for her unconditional love and support and have always been there for me.

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Shibsankar Dutta
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Signature of the Candidate with date

Abstract

Two dimensional (2-D) nanomaterials have drawn considerable attention to the evolution of supercapacitor electrodes for high performance flexible energy storage device applications due to their high electro-active sites, high specific surface area, macro mechanical flexibility, well-behaved electrical properties etc. The thesis entitled “**2-D Nano Materials and their Hybrids as Supercapacitor Electrodes for Energy Storage Applications**” encompasses a detail report on the development of some 2-D nanomaterials through different synthesis routes and their applications in supercapacitor energy storage. More precisely, this dissertation highlights the successful synthesis of some 2-D transition metal oxides (TMOs) like MoO_3 , MnO_2 , RuO_2 , metal dichalcogenides (MoS_2), BiOCl nanoplates, vanadyl phosphate (VOPO_4) and their composites with graphene, single and multi-wall carbon nanotubes (SWCNT, MWCNT) etc. and their applications as supercapacitor energy storage devices. The prepared samples have been thoroughly characterized by FESEM, TEM, XRD, XPS, AFM BET, Raman and etc.

In this work, a facile large scale production of TMOs nanosheets by exfoliation in ethanol-water mixed solvent instead of using highly toxic organic solvents has been demonstrated. After optimization, this method gives high concentration (0.42 mg/ml, 0.47 mg/ml and 0.40 mg/ml for MoO_3 , MnO_2 and RuO_2 respectively) stable dispersion of TMOs nanosheets. Thin flexible solid state supercapacitors based on SWCNT /TMOs nanosheets composites showing a large specific capacitance and high energy density. In addition, a planner supercapacitor based on SWCNT/ MnO_2 shows an improved electrochemical performance with excellent stability under different bending condition. Thin flexible films of BiOCl /MWCNT composites have been prepared with varying the weight percentage. Among various compositions, 60% BiOCl loaded electrodes delivers superior electrochemical performance. Instead of gold we have used SWCNT network as a current collector which will be helpful to make transparent flexible supercapacitor with high energy density for future application BiVO_4 /rGO hybrid nanostructure based symmetric supercapacitor exhibits better performance in solid electrolyte. MoS_2 /rGO hybrids thin film supercapacitor and MWCNT/ VOPO_4 hybrid supercapacitor are also deliver improved energy storage performance.

Publications

1. Mixed Solvent Exfoliated Transition Metal Oxides Nanosheets Based Flexible Solid State Supercapacitor Devices Endowed with High Energy Density, **Shibsankar Dutta**, Shreyasi Pal and Sukanta De, *New J. Chem.*, **2019**, 43, 12385-12395.
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List of Abbreviations

0D, 1D, 2D, 3D Zero, One, Two, Three Dimensional

	A		FESEM	Field emission scanning electron microscope
AFM Microscope	Atomic Force		Fe ₃ O ₄ , Fe ₂ O ₃	Iron Oxide
	B		FSSSC	Flexible solid state symmetric supercapacitor
BiVO ₄	Bismuth vanadate			
BiOCl	Bismuth oxychloride		G	
	C		GA	Graphene analogue
CV	Cyclic voltammetry		GO	Graphene oxide
CNTs	Carbon nanotubes		GCD	Galvanometric charging discharging
CMG graphene	Chemically modified			
Co ₃ O ₄	Cobalt oxide		H	
	D		HRTEM	High-resolution Transmission Electron Microscope
DMSO	Dimethyl sulfoxide		HSP	Hansen solubility parameter
DMF	Dimethylformamide		HSCs	Hybrid supercapacitors
	E		H ₂ SO ₄	Sulphuric acid
EDLC capacitor	Electric double layer		I	
ESPW	Electrochemical stable potential window		IHP	Inner Helmholtz plane
ESR	Equivalent series resistance		IrO ₂	Iridium (IV) oxide
EDX	Energy dispersive X-ray		K	
EIS impedance spectroscopy	Electrochemical		KCl	Potassium Chloride
ECS supercapacitor	Electrochemical		KI	Potassium Iodide
	F		KOH	Potassium hydroxide
			L	
			LIB	Lithium ion battery

	M		R_{ct}	Charge transfer resistance
MoO ₃	Molybdenum Trioxide		S	
MnO ₂	Manganese (IV) Oxide		SWCNT nanotube	Single wall carbon
MWCNT nanotube	Multiwall Carbon		SCs	Supercapacitors
MXenes and/or nitrides	Transition metal carbides and/or nitrides		SDS	Sodium dodecylsulphate
	N		SNAP	Spin-on nano imprinting
Na ₂ SO ₄	Sodium sulfate		T	
NiO	Nickel oxide		TMOs	Transition metal oxides
NMP	N-Methyl-2-pyrrolidone		TMDCs	Transition metal dichalcogenides
NaOH	Sodium Hydroxide		U	
	O		UV-Vis-NIR	Ultraviolet-visible-near infrared spectrophotometer
OHP	Outer Helmholtz plane		V	
	P		VS ₂	Vanadium disulfide
PET Terephthalate	Polyethylene		VOPO ₄	Vanadium phosphate
PSCs	Pseudo supercapacitor		V ₂ O ₅	Vanadium pent oxide
PVA	Polyvinyl Alcohol		W	
PVP	Polyvinylpyrrolidone		WS ₂	Tungsten disulfide
PEO	Polyethylene glycol		X	
PAA	Polypolyacrylate		XPS	X-ray photoelectron spectroscopy
PVDF	Polyvinylidene fluoride		XRD	X-Ray Diffractometer
PEDOT: PSS Poly(3,4- Ethylenedioxythiophene):Poly(Styrene- Sulfonate)				
	R			
rGO	Reduced graphene oxide			
RuO ₂	Ruthenium (IV) Oxide			

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