

Review

Electrospun Nanomaterials for Energy Applications: Recent Advances

Saveria Santangelo

Dipartimento di Ingegneria Civile, dell'Energia, dell'Ambiente e dei Materiali, Università
"Mediterranea", 89122 Reggio Calabria, Italy

Correspondence: saveria.santangelo@unirc.it; Tel.: +39-0965-169-2305

Supporting Information

Table 1. ENMs for SIB cathodes and preparation conditions. Acronyms: ADHP (ammonium dihydrogen phosphate), AV (ammonium vadanate), Ac₂O (acetic anhydride), CAc (citric acid), CrNit₃ (chromium(III) nitrate), DIW (deionized water), EtOH (etanol), FeNit₃ (iron (III) nitrate), GNHs (graphitic nanohorns), NaAc (sodium acetate), NaDHP (sodium dihydrogen phosphate), NaF (sodium fluoride), NaNit (sodium nitrate), MnAc₂ (manganese (II) acetate), MnNit₂ (manganese (II) nitrate), NiNit₂ (nickel(II) nitrate), OxAc (oxalic acid), PEO (polyethylene oxide), PVAc (polyvinylacetate), PVP (polyvinyl pyrrolidone), SDBS (sodium dodecyl benzene sulfonate), VITP (vanadium(V) oxytripropoxide).

ENM type	Spinnable solution			Spinning conditions			Heat treatment(s)		Ref.
	Polymer	Solvent(s)	Precursor(s)	Feeding rate (mL/h)	Applied voltage (kV)	Distance (cm)	Oxidation (°C/h)	Annealing (°C/h/gas)	
Na _{2/3} (Fe _{1/2} Mn _{1/2})O ₂	PVP	EtOH+DMF	NaAc+FeNit ₃ +MnAc ₂	0.8	20	11	350/2 500/2 900/2	--	[S1]
Na _{0.44} MnO ₂	PVAc	DIW	NaAc+MnNit ₂	--	15	12	120/4 400–900/1	--	[S2]
NaCrO ₂	PVP	EtOH+DIW	NaNit+CrNit ₃	1.08	15	16	450	900/Ar	[S3]
Na ₃ V ₂ (PO ₄) ₃ /C	PEO	DIW	NaDHP+AV+CAc	--	--	--	--	500/Ar 800/Ar	[S4]
Na ₃ V ₂ (PO ₄) ₃ /C	PVP	DIW	NaDHP+AV+CAc	--	15	18	--	300/3/Ar 800/8/Ar	[S5]
NaVPO ₄ F/C	PVP	DIW+OxAc	NaF+AV+ADHP	1.08	15	18	400/2	700–800/2–8/Ar	[S6]
Na ₃ V ₂ (PO ₄) ₃ /C	PVP	EtOH+OxAc DIW	Na ₂ CO ₃ +V ₂ O ₅ +ADHP	0.6	30	--	--	150/2/Ar 750–900/6/Ar	[S7]
VO ₂ /C	PVAc	EtOH+Ac ₂ O	VITP ¹	0.5	28	20	--	700/3/Ar 300–350/0.5–3/Ar+air	[S8]

¹ Graphitic nanohorns (GNHs) are incorporated in the spinnable solution as a conductive additive.

Table 2. Main parameters describing the performance of cathode ENMs in SIBs. Acronyms: CB (carbon black), HC (hard carbon), PVDF (polyvinylidene fluoride).

ENM type	Ref.	Electrode composition or specifics	Specific capacity (mAh/g)	Current density	Rate capability (mAh/g)	Current density	Capacity retention (%)	After cycles
$\text{Na}_{2/3}(\text{Fe}_{1/2}\text{Mn}_{1/2})\text{O}_2$	[S1]	$\text{Na}_{2/3}(\text{Fe}_{1/2}\text{Mn}_{1/2})\text{O}_2 + \text{CB} + \text{PVDF}$ 80:10:10	195	0.1C	167	0.1C	86.4	80
$\text{Na}_{0.44}\text{MnO}_2$	[S2]	$\text{Na}_{0.44}\text{MnO}_2 + \text{CB} + \text{PVDF}$ 80:10:10	69.5	10C	120	1C	--	140
NaCrO_2	[S3]	$\text{NaCrO}_2/\text{HD full cell}$	108.8	10	--	--	--	--
			87.2	50				
			112.8	0.1C				
$\text{Na}_3\text{V}_2(\text{PO}_4)_3/\text{C}$	[S4]	--	103	0.1C	77	2C	--	--
		--			20	20C		
$\text{Na}_3\text{V}_2(\text{PO}_4)_3/\text{C}$	[S5]	$\text{Na}_3\text{V}_2(\text{PO}_4)_3/\text{C} + \text{CB} + \text{PVDF}$ 80:10:10	115.0	0.1C	106.2 103.0	0.2C 2C	95.7	--
$\text{NaVPO}_4\text{F}/\text{C}$	[S6]	Binder- and collector-free	126.3	1	61.2	50C	96.5	1000 at 2C
$\text{Na}_3\text{V}_2(\text{PO}_4)_3/\text{C}$	[S7]	Binder- and collector-free	76.9	100	112.0	1C	94.1	100
					101.4	5C		
					92.1	20C		
VO_2/C	[S8]	Binder-free	107	--	--	--	--	--

Table 3. ENMs for SIB anodes and preparation conditions. Acronyms: AcA (acetic acid), CoAc₂ (cobalt(II) acetate), DMF (*N,N*-dimethylformamide), EtOH (etanol), FeAc₂ (iron(II) acetate), FeAcAc₃ (iron(III) acetylacetonate), FeNit₃ (iron(III) nitrate), HC (hard carbon), MnAc₂ (manganese (II) acetate), PAN (polyacrylonitrile), PMMA (polymethyl methacrylate), PVP (polyvinyl pyrrolidone), RFuA (refined fulvic acid), SnCh (tin chloride), SUR (thiourea), TEOS (tetraethyl orthosilicate), TBT (tetrabutyl titanate), vac (vacuum).

ENM type	Spinnable solution			Spinning conditions			Heat treatment(s)		Ref.
	Polymer	Solvent(s)	Precursor(s)	Feeding rate (mL/h)	Applied voltage (kV)	Distance (cm)	Oxidation (°C/h)	Annealing (°C/h/gas)	
Co ₃ O ₄	PAN	DMF	CoAc ₂	1.41	15	11	600/2	--	[S9]
γ-Fe ₂ O ₃ :Si	PAN	DMF	FeAc ₂ +TEOS	1.41	15	11	600/2	--	[S10]
γ-Fe ₂ O ₃ /C	PAN+PMMA	DMF	FeAcAc ₃	0.9	20	15	280/3	600/3/N ₂	[S11]
TiO ₂ /C	PVP	EtOH	TBT	8.5	10	--	--	550/3/Ar	[S12]
TiO ₂ -Sn/C	PVP	DMF+AcA	TBT+SnCh	0.38	15	15	200/2	600/4/Ar+H ₂	[S13]
SnS ₂ /N-S-C	PVP	DMF	SnCh	0.3	16	15	250/2	250/2/vac (1:4 SUR) ¹ 580/8/vac	[S14]
SnS/C	PVP	DMF	SnCh	0.3	18	15	280/2	250/2/Ar+H ₂ (1:5 SUR)	[S15]
Sn/N-C	PAN+PMMA	--	SnCh	--	15	--	250/5	700/1/N ₂	[S16]
MnFe ₂ O ₄ @C	PAN	DMF	MnAc ₂ +FeNit ₃	1.2	15	15	280/2 ²	250/1/N ₂ 700/1/N ₂	[S17]
HC	PAN+RFuA	DMF	--	1	25	20	280/1	800–1500/0.5/N ₂	[S18]

¹ Sulfidation step in vacuum.

² After treatment upon N₂ atmosphere.

Table 4. Main parameters describing the performance of cathode ENMs in SIBs. Acronyms: CB (carbon black), CMC-Na (carboxymethyl cellulose Na), ECFs (electrospun carbon fibers), HC (hard carbon), PAA (polyacrylic acid), PVDF (polyvinylidene fluoride).

ENM type	Ref.	Electrode composition or specifics	Specific capacity (mAh/g)	Current density	Rate capability (mAh/g)	Current density	Capacity retention (%)	After cycles
Co ₃ O ₄ (CoO)	[S9]	Co ₃ O ₄ +CB+PAA 75:17:8	724 (576)	0.9mA/g	--	--	71	30
γ-Fe ₂ O ₃ :Si	[S10]	γ-Fe ₂ O ₃ :Si+CB+PAA 60:30:10	400	C/20	350	C/20	85	70
γ-Fe ₂ O ₃ /C	[S11]	-- γ-Fe ₂ O ₃ NPs+ECFs+PVDF 55:25:20	290 ~150	0.1C 0.1C	230 --	2C --	78 <30	50 50
TiO ₂ /C	[S12]	TiO ₂ /C+CB+PAA 80:15:10	165	2A/g	240	200mA/g	100	1000
TiO ₂ -Sn/C	[S13]	TiO ₂ -Sn/C+CB+PVDF 70:20:10	255	50mA/g	190.8	1A/g	95.4	1000
SnS ₂ /N-S-C	[S14]	SnS ₂ /N-S-C+CB+CMC-Na 70:20:10	631	50mA/g	380 311	0.5A/g 4A/g	74	200
SnS/C	[S15]	Binder- and collector-free	563	50mA/g	230	2A/g	90.2	100
Sn/N-C	[S16]	Binder- and collector-free	633	200mA/g	483	2A/g	--	1300
MnFe ₂ O ₄ @C	[S17]	Binder- and collector-free	504	100mA/g	305	10A/g	90	4200
HC	[S18]	Binder- and collector-free	248	100mA/g	--	--	91	100

Table 5. Electrode ENMs for supercapacitors and preparation conditions. Acronyms: AcA (acetic acid), CNTs (carbon nanotubes), DMAc (dimethyl acetamide), CHlF (chloroform), DIW (deionized water), DMF (*N,N*-dimethylformamide), EtOH (etanol), GNPs (graphene nanoplatelets), HCSA (camphorsulfonic acid), MnAc₂ (manganese (II) acetate), MnAcAc₂ (manganese (II) acetylacetonate), PAN (polyacrylonitrile), PANI (polyaniline), PBI (polybenzimidazol), PEO (polyethylene oxide), PInd (polyindole), PPy (polypyrrole), PSF (polysulfone), p-TSA (p-toluenesulfonic acid), PVP (polyvinyl pyrrolidone), VOAcAc₂ (vanadyl acetylacetonate).

ENM type	Spinnable solution			Spinning conditions			Heat treatment(s)		Ref.
	Polymer	Solvent(s)	Additive(s)	Feeding rate (mL/h)	Applied voltage (kV)	Distance (cm)	Oxidation (°C/h)	Annealing (°C/h/gas)	
Porous C	PAN	DMF	--	--	10–25	--	280/1	700–800/0.5/N ₂	[S19]
Porous C	PAN+PVP	DMF	--	1.0	15	12	280/5	500–970/3/Ar 850/1/CO ₂	[S20]
Porous C	PAN+PVP	DMF	--	--	20	15	300/2	300–500/5/N ₂ 500–970/1/N ₂ 850/1.5/CO ₂	[S21]
Porous C	PBI	DMAc	--	--	--	--	--	700–850/0.5/N ₂	[S22]
Porous N-C	PAN+PVP	DMF	--	1.5	20	20	300/3	850/3/N ₂	[S23]
Porous N-C	PAN+PVP	DMF	SiO ₂	--	15	15	--	250/1/N ₂ 800/2/N ₂ ¹	[S24]
Porous C A3-size	PAN	DMF	ZnCl ₂	--	25	20	280/1	800/1/Ar	[S25]
Porous C	PAN	DMF	Biochar	1.0	18	25	280/6	1200/2/Ar	[S26]
Porous C-GNPs	PAN	DMF	GNPs	--	15	--	280/1	800/1/inert	[S27]
PANI-CNTs	PANI+PEO	HCSA+CHlF	CNTs	0.6	5	25	--	--	[S28]
PInd/CNTs	PInd+PEO	CHlF+p-TSA	CNTs	0.5	15	15	--	--	[S29]
PANI-coated C/CNTs	PAN	DMF	CNTs	1	15	15	250/1	800/2/N ₂	[S30]
CNY@PPy@rGO	PAN	DMF	PPy+GO (subsequently)	1.8	18	15	280/5	1000/2/Ar	[S31]
V ₂ O ₅	PVP	AcA+EtOH	VOAcAc ₂	0.2	10	10	300–500/0.25	--	[S32]
MnO ₂	PVP	Alcohol+DIW	Mn(CH ₃ COO) ₂	0.3	10–15	8	--	480/3/Ar	[S33]
Porous C-MnO	PAN	DMF	MnAcAc ₂	--	10	17.5	80/8 290/2	550/2/N ₂ 850/2/N ₂	[S34]

¹ Followed by SiO₂ etching.

Table 6. Main parameters describing the performance of electrode ENMs in supercapacitors. Acronyms: AE (aqueous electrolyte ,2 M KCl), CB (cabon black), PTFE (polytetrafluoroethylene, OE (organic electrolyte, 1 M LiClO₄ in PC), PVDF (polyvinylidene fluoride).

ENM type	Ref.	Electrode composition or specifics	Specific capacitance (F/g)	Current density (A/g)	Scan rate (mV/s)	Capacity retention (%)	After cycles	Energy capability (Wh/kg)
Porous C	[S19]	Self-standing	120	1	--	--	--	--
Porous C	[S20]	Self-standing	148–222			99.6–99.8	1000	13.1–33.6
Porous C	[S21]	Self-standing	221	--	--	--	--	--
Porous C	[S22]	Self-standing	35–202	--	--	--	--	--
Porous N-C	[S23]	Self-standing	148–198	1	--	104	5000	--
Porous N-C	[S24]	Self-standing	242	0.2	--	99	5000	--
Porous C A3-size	[S25]	Self-standing	120–140	--	10	--	--	--
Porous C	[S26]	Self-standing	37.6	0.5	--	--	--	--
Porous C-GNP	[S27]	Self-standing	86.1			90	1000	--
PANI-CNTs	[S28]	Self-standing	385 259	0.5	-- 100	81.4 --	1000 --	--
PInd/CNTs	[S29]	Self-standing	476	1	--	95	2000	17
PANI-coated C/CNTs	[S30]	Self-standing	1119 748	1 10		98	2000	
CNY@PPy@rGO	[S31]	Self-standing	~93	--	2	86	10000	--
V ₂ O ₅	[S32]	V ₂ O ₅ +CB+PVDF 80:10:10	190 (AE) 250 (OE)	0.1	5	--	--	5 78
MnO ₂	[S33]	On flexible support	645	0.5	--	95	2000	--
Porous C-MnO	[S34]	PAN separator	200		2.5			

Table 7. Electrospun photo-catalysts for WS and preparation conditions. Acronyms: AcA (acetic acid), AcAc (acetylacetone), AmT (ammonium tungstate), CEHX (copper-2-ethylhexanoate), FeAc₂ (iron(II) acetate), FeNit (iron(III) nitrate nonahydrate), DMAc (*N,N*-dimethylacetamide), DMF (*N,N*-dimethylformamide), EtOH (ethanol), GC (gold(III) chloride), MeOH (methanol), PAN (polyacrylonitrile), PVA (polyvinyl alcohol), PVAc (polyvinylacetate), PVP (polyvinyl pyrrolidone), TEHX (tin-2-ethylhexanoate), TEOS (tetraethyl orthosilicate), TIP (titanium (IV) isopropoxide), TBT (tetrabutyl titanate), TB (titanium(IV) butoxide).

ENM type	Spinnable solution			Spinning conditions			Heat treatment	Ref.
	Polymer	Precursor(s)	Solvent(s)	Feeding rate (mL/h)	Applied voltage (kV)	Distance (cm)	Temperature (°C)	
TiO₂	PVP	TB	AcAc+MeOH	--	15	15	400–700	[S35]
TiO ₂	PVP	TIP	AcA+EtOH	2.5	12	12	600	[S36]
TiO ₂ /ITO	PVA	TIP	AcA+DMF	0.25	8	9	300, 500, 700	[S37]
N-TiO ₂ /TiO ₂ @FTO	PVAc	TIP+urea	AcA+DMAc	1	30	10	450	[S38]
TiO ₂ -CuO	PVP	TBT+CEHX	AcA+EtOH	0.3	19	18	450	[S39]
TiO ₂ -SnO ₂	PVP	TBT+TEHX	AcA+EtOH	--	19	--	450	[S40]
TiO ₂ -WO ₃ -Au	PVP	TBT+AmT+GC	AcA+EtOH	--	15	15	520	[S41]
CNT-TiO ₂ /FTO	PVAc	TIP	AcA+DMAc	1	30	10	450	[S42]
C-Co-TiC	PVP	TIP	AcA+EtOH	--	--	--	950	[S43]
Fe ₂ O ₃ /FTO	PVA	FeNit	water	0.2–5	15–21	20	450–600	[S44]
Fe ₂ O ₃ :Si/FTO	PAN	FeAc ₂ +TEOS	DMF	1.41	15	11	600	[S45]

References

- S1. Kalluri, S.; Seng, H.K.; Pang, W.K.; Guo, Z.; Chen, Z.; Liu, H.K.; Dou, S.X. Electrospun P2-type $\text{Na}_{2/3}(\text{Fe}_{1/2}\text{Mn}_{1/2})\text{O}_2$ hierarchical nanofibers as cathode material for sodium-ion batteries. *ACS Appl. Mater. Interfaces* **2014**, *6*, 8953–8958, doi: 10.1021/am502343s.
- S2. Fu, B.; Zhou, X.; Wang, Y. High-rate performance electrospun $\text{Na}_{0.44}\text{MnO}_2$ nanofibers as cathode material for sodium-ion batteries. *J. Power Sources*, **2016**, *310*, 102–108, doi: 10.1016/j.jpowsour.2016.01.101.
- S3. Liang, L.; Sun, X.; Denis, D.K.; Zhang, J. ; Hou, L.; Liu, Y.; Yuan, C. Ultralong layered NaCrO_2 nanowires: a competitive wide temperature-operating cathode for extraordinary high-rate sodium-ion batteries. *ACS Appl. Mater. Interfaces* **2019**, doi: 10.1021/acsami.8b20149.
- S4. Liu, J. ; Tang, K.; Song, K.; van Aken, P. A.; Yu, Y.; Maier, J. Electrospun $\text{Na}_3\text{V}_2(\text{PO}_4)_3/\text{C}$ nanofibers as stable cathode materials for sodium-ion batteries. *Nanoscale*, **2014**, *6*, 5081–5086. DOI: 10.1039/C3NR05329F
- S5. Li, H.; Bai, Y.; Wu, F.; Li, Y.; Wu, C. Budding willow branches shaped $\text{Na}_3\text{V}_2(\text{PO}_4)_3/\text{C}$ nanofibers synthesized via an electrospinning technique and used as cathode material for sodium ion batteries. *J. Power Sources*, **2015**, *273*, 784–792, doi: 10.1016/j.jpowsour.2014.09.153.
- S6. Jin, T.; Liu, Y.; Li, Y.; Cao, K.; Wang, X.; Jiao, L. Electrospun NaVPO_4C nanofibers as self-standing cathode material for ultralong cycle life Na-ion batteries. *Adv. Energy Mater.* **2017**, *7*, 1700087, doi:10.1002/aenm.201700087.
- S7. Yang, L.; Wang, W.; Hu, M.; Shao, J. ; Lv, R. Ultrahigh rate binder-free $\text{Na}_3\text{V}_2(\text{PO}_4)_3/\text{carbon}$ cathode for sodium-ion battery. *J. Energy Chemistry* **2018**, *27*, 1439–1445, doi: 10.1016/j.jchem.2017.08.021.
- S8. Tolosa, A.; Fleischmann, S.; Grobelsek, I.; Presser, V. Electrospun hybrid vanadium oxide/carbon fiber mats for lithium-and sodium-ion battery electrodes. *ACS Appl. Energy Mater.* **2018**, *1*, 3790–3801, doi:10.1021/acsaem.8b00572.
- S9. Santangelo, S.; Fiore, M.; Pantò, F.; Stelitano, S.; Marelli, M.; Frontera, P.; Antonucci, P.; Longoni, G.; Ruffo, R. Electro-spun Co_3O_4 anode material for Na-ion rechargeable batteries. *Solid State Ionics* **2017**, *309*, 41–47, doi:10.1016/j.ssi.2017.07.002.
- S10. Fiore, M.; Longoni, G.; Santangelo, S.; Pantò, F.; Stelitano, S.; Frontera, P.; Antonucci, P.L.; Ruffo, R. Electrochemical characterization of highly abundant, low cost iron(III) oxide as anode material for sodium-ion rechargeable batteries. *Electrochim. Acta* **2018**, *269*, 367–377, doi: 10.1016/j.electacta.2018.02.161.
- S11. Chen, Y.; Yuan, X.; Yang, C.; Lian, Y.; Razzaq, A.A.; Shah, R.; Shah, R.; Guo, J. ; Zhao, X.; Peng, Y.; Deng, Z. $\gamma\text{-Fe}_2\text{O}_3$ nanoparticles embedded in porous carbon fibers as binder-free anodes for high-performance lithium and sodium ion batteries. *J. Alloys Comp.* **2019**, *777*, 127–134, doi: 10.1016/j.jallcom.2018.10.371.
- S12. Xiong, Y.; Qian, J. ; Cao, Y.; Ai, X.; Yang, H. Electrospun TiO_2/C nanofibers as a high-capacity and cycle-stable anode for sodium-ion batteries. *ACS Appl. Mater. Interfaces* **2016**, *8*, 16684–16689, doi:10.1021/acsami.6b03757.
- S13. Nie, S.; Liu, L.; Liu, J. ; Xia, J. ; Zhang, Y.; Xie, J. ; Li, M.; Wang, X. $\text{TiO}_2\text{-Sn}/\text{C}$ composite nanofibers with high-capacity and long-cycle life as anode materials for sodium ion batteries. *J. Alloys Comp.* **2019**, *772*, 314–323, doi:10.1016/j.jallcom.2018.09.044.
- S14. Xia, J. , J iang, K., Xie, J. , Guo, S., Liu, L., Zhang, Y., Ne, S.; Yuan, Y.; Yan, H.; Wang, X. Tin disulfide embedded in N-, S-doped carbon nanofibers as anode material for sodium-ion batteries. *Chem. Eng. J.* **2019**, *359*, 1244–1251, doi: 10.1016/j.cej.2018.11.053.
- S15. Xia, J. ; Liu, L.; J amil, S.; Xie, J. ; Yan, H.; Yuan, Y.; Zhang, Y.; Nie, S.; Pan, J. ; Wang, X.; Cao, G. SnS/C nanofiber anodes for ultralong cycle-life lithium-ion batteries and sodium-ion batteries. *Energy Storage Materials* **2019**, doi: 10.1016/j.ensm.2018.08.005.
- S16. Liu, Y.; Zhang, N.; J iao, L.; Chen, J. . Tin nanodots encapsulated in porous nitrogen-doped carbon nanofibers as a free-standing anode for advanced sodium-ion batteries. *Adv. Mater.* **2015**, *27*, 6702–6707, doi:10.1002/adma.201503015.
- S17. Liu, Y.; Zhang, N.; Yu, C.; J iao, L.; Chen, J. . MnFe/C nanofibers as high-performance anode for sodium-ion batteries. *Nano Lett.* **2016**, *16*, 3321–3328, doi:10.1021/acs.nanolett.6b00942.
- S18. Zhao, P.Y.; Zhang, J. ; Li, Q.; Wang, C.Y. Electrochemical performance of fulvic acid-based electrospun hard carbon nanofibers as promising anodes for sodium-ion batteries. *J. Power Sources* **2016**, *334*, 170–178, doi:10.1016/j.jpowsour.2016.10.029.
- S19. Kim, C.; Yang, K.S. Electrochemical properties of carbon nanofiber web as an electrode for supercapacitor prepared by electrospinning. *Appl. Phys. Lett.* **2003**, *83*, 1216–1218, doi: 10.1063/1.1599963.

- S20. He, T.; Fu, Y.; Meng, X.; Yu, X.; Wang, X. A novel strategy for the high performance supercapacitor based on polyacrylonitrile-derived porous nanofibers as electrode and separator in ionic liquid electrolyte. *Electrochim. Acta* **2018**, *282*, 97–104, doi: 10.1016/j.electacta.2018.06.029.
- S21. Niu, H.; Zhang, J.; Xie, Z.; Wang, X.; Lin, T. Preparation, structure and supercapacitance of bonded carbon nanofiber electrode materials. *Carbon* **2011**, *49*, 2380–2388, doi: 10.1016/j.carbon.2011.02.005.
- S22. Kim, C. Electrochemical characterization of electrospun activated carbon nanofibers as an electrode in supercapacitors. *J. Power Sour.* **2005**, *142*, 382–388, doi: 10.1016/j.jpowsour.2004.11.013.
- S23. Li, X.; Zhao, Y.; Bai, Y.; Zhao, X.; Wang, R.; Huang, Y.; Liang, Q.; Huang, Z. A non-woven network of porous nitrogen-doping carbon nanofibers as a binder-free electrode for supercapacitors. *Electrochim. Acta* **2017**, *230*, 445–453, doi: 10.1016/j.electacta.2017.02.030.
- S24. Fan, L.; Yang, L.; Ni, X.; Han, J.; Guo, R.; Zhang, C.J. Nitrogen-enriched meso-macroporous carbon fiber network as a binder-free flexible electrode for supercapacitors. *Carbon* **2016**, *107*, 629–637, doi:10.1016/j.carbon.2016.06.067.
- S25. Kim, C.; Ngoc, B.T.N.; Yang, K.S.; Kojima, M.; Kim, Y.A.; Kim, Y.J.; Endo, M.; Yang, S.C. Self-sustained thin webs consisting of porous carbon nanofibers for supercapacitors via the electrospinning of polyacrylonitrile solutions containing zinc chloride. *Adv. Mater.* **2007**, *19*, 2341–2346, doi: 10.1002/adma.200602184.
- S26. Nan, W.; Zhao, Y.; Ding, Y.; Shende, A.R.; Fong, H.; Shende, R. Mechanically flexible electrospun carbon nanofiber mats derived from biochar and polyacrylonitrile. *Mater. Lett.* **2017**, *205*, 206–210, doi:10.1016/j.matlet.2017.06.092.
- S27. Chee, W.K.; Lim, H.N.; Zainal, Z.; Harrison, I.; Andou, Y.; Huang, N.M.; Altarawneh, M.; Jiang, Z.T. Electrospun graphene nanoplatelets-reinforced carbon nanofibers as potential supercapacitor electrode. *Mater. Lett.* **2017**, *199*, 200–203, doi: 10.1016/j.matlet.2017.04.086.
- S28. Simotwo, S.K.; Del Re, C.; Kalra, V. Supercapacitor Electrodes Based on High-Purity Electrospun Polyaniline and Polyaniline–Carbon Nanotube Nanofibers. *ACS Appl. Mater. Interfaces* **2016**, *8*, 21261–21269, doi:10.1021/acsami.6b03463.
- S29. Tebyetekerwa, M.; Yang, S.; Peng, S.; Xu, Z.; Shao, W.; Pan, D.; Ramakrishna, S.; Zhu, M. (2017). Unveiling polyindole: freestanding as-electrospun polyindole nanofibers and polyindole/carbon nanotubes composites as enhanced electrodes for flexible all-solid-state supercapacitors. *Electrochim. Acta* **2017**, *247*, 400–409, doi:10.1016/j.electacta.2017.07.038.
- S30. Agyemang, F.O.; Tomboc, G.M.; Kwofie, S.; Kim, H. Electrospun carbon nanofiber-carbon nanotubes coated polyaniline composites with improved electrochemical properties for supercapacitors. *Electrochim. Acta* **2018**, *259*, 1110–1119, doi: 10.1016/j.electacta.2017.12.079.
- S31. Chen, L.; Li, D.; Chen, L.; Si, P.; Feng, J.; Zhang, L.; Li, Y.; Lou, J.; Ci, L. Core-shell structured carbon nanofibers yarn@polypyrrole@graphene for high performance all-solid-state fiber supercapacitors. *Carbon* **2018**, *138*, 264–270, doi: 10.1016/j.carbon.2018.06.022.
- S32. Wee, G.; Soh, H.Z.; Cheah, Y.L.; Mhaisalkar, S.G.; Srinivasan, M. Synthesis and electrochemical properties of electrospun V_2O_5 nanofibers as supercapacitor electrodes. *J. Mater. Chem.* **2010**, *20*, 6720–6725, doi:10.1039/c0jm00059k.
- S33. Li, X.; Wang, G.; Wang, X.; Li, X.; Ji, J. Flexible supercapacitor based on MnO_2 nanoparticles via electrospinning. *J. Mater. Chem. A*, **2013**, *1*, 10103–10106, doi: 10.1039/c3ta11727h.
- S34. Liu, X.; Marlow, M.N.; Cooper, S.J.; Song, B.; Chen, X.; Brandon, N.P.; Wu, B. Flexible all-fiber electrospun supercapacitor. *J. Power Sour.* **2018**, *384*, 264–269, doi: 10.1016/j.jpowsour.2018.02.081.
- S35. Chuangchote, S.; Jitputti, J.; Sagawa, T.; Yoshikawa, S. Photocatalytic activity for hydrogen evolution of electrospun TiO_2 nanofibers. *ACS Appl. Mater. Interf.* **2009**, *1*, 1140–1143, doi: 10.1021/am9001474.
- S36. Regonini, D.; Teloeke, A. C.; Alves, A. K.; Berutti, F. A.; Gajda-Schranz, K.; Bergmann, C. P.; Graule, T.; Clemens, F. Electrospun TiO_2 fiber composite photoelectrodes for water splitting. *ACS Appl. Mater. Interf.* **2013**, *5*, 11747–11755, doi: 10.1021/am403437q.
- S37. Mali, M.G.; An, S.; Liou, M.; Al-Deyab, S.S.; Yoon, S.S. Photoelectrochemical solar water splitting using electrospun TiO_2 nanofibers. *Appl. Surf. Science*, **2015**, *328*, 109–114, doi: 10.1016/j.apsusc.2014.12.022.
- S38. Babu, V.J.; Kumar, M.K.; Nair, A.S.; Kheng, T.L.; Allakhverdiev, S.I.; Ramakrishna, S. Visible light photocatalytic water splitting for hydrogen production from N- TiO_2 rice grain shaped electrospun nanostructures. *Int. J. Hydrogen En.* **2012**, *37*, 8897–8904, doi: 10.1016/j.ijhydene.2011.12.015.

- S39. Lee, S.S.; Bai, H.; Liu, Z.; Sun, D.D. Novel-structured electrospun TiO₂/CuO composite nanofibers for high efficient photocatalytic cogeneration of clean water and energy from dye wastewater. *Water research*, **2013**, *47*, 4059–4073, doi: 10.1016/j.watres.2012.12.044.
- S40. Lee, S.S.; Bai, H.; Liu, Z.; Sun, D.D. Electrospun TiO₂/SnO₂ nanofibers with innovative structure and chemical properties for highly efficient photocatalytic H₂ generation. *Int. J. Hydrogen En.* **2012**, *37*, 10575–10584, doi:10.1016/j.ijhydene.2012.04.098.
- S41. Gao, H.; Zhang, P.; Zhao, J.; Zhang, Y.; Hu, J.; Shao, G. Plasmon enhancement on photocatalytic hydrogen production over the Z-scheme photosynthetic heterojunction system. *Appl. Catalysis B* **2017**, *210*, 297–305, doi:10.1016/j.apcatb.2017.03.050.
- S42. Veluru, J. B.; Manippady, K.K.; Rajendiren, M.; Mya, K.M.; Rayavarapu, P.R.; Appukuttan, S.N.; Seeram, R. Photocatalytic hydrogen generation by splitting of water from electrospun hybrid nanostructures. *Int. J. Hydrogen En.* **2013**, *38*, 4324–4333, doi: 10.1016/j.ijhydene.2013.01.134.
- S43. Al-Enizi, A.M.; Brooks, R.M.; Abutaleb, A.; El-Halwany, M.M.; El-Newehy, M.H.; Yousef, A. Electrospun carbon nanofibers containing Co-TiC nanoparticles-like superficial protrusions as a catalyst for H₂ gas production from ammonia borane complex. *Ceramics International* **2017**, *43*, 15735–15742, doi:10.1016/j.ceramint.2017.08.135.
- S44. Saveh-Shemshakia, N.; Latifia, M.; Bagherzadehb, R.; Malekshahi Byranvandc, M.; Naserid, N.; Dabirian, A. Synthesis of mesoporous functional hematite nanofibrous photoanodes by electrospinning. *Polym. Adv. Technol.* **2016**, *27*, 358–365, doi: 10.1002/pat.3647.
- S45. Santangelo, S.; Frontera, P.; Pantò, F.; Stelitano, S.; Marelli, M.; Patanè, S.; Malara, F.; Dal Santo, V.; Antonucci, P. Effect of Ti-or Si-doping on nanostructure and photo-electro-chemical activity of electro-spun iron oxide fibres. *Int. J. Hydrogen En.* **2017**, *42*, 28070–28081, doi: 10.1016/j.ijhydene.2017.03.204.



© 2019 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).