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Supplementary Information

Hybrid niobium-based oxide with bio-based porous carbon as efficient electrocatalyst in photovoltaics: A general strategy for understanding catalytic mechanism

Chen Wang,[a] Sining Yun,[*a] Qingyang Fan,[b] Ziqi Wang,[a] Yangliang Zhang,[a] Feng Han,[a] Yiming Si,[a] and Anders Hagfeldt [c]

[a] Functional Materials Laboratory (FML), School of Materials Science and Engineering, Xi'an University of Architecture and Technology, Xi'an, Shaanxi, 710055

[b] School of Information and Control Engineering, Xi'an University of Architecture and Technology, Xi'an, Shaanxi, 710055

[c] Laboratory of Photomolecular Science, Institute of Chemical Sciences and Engineering, Ecole Polytechnique Federale de Lausanne (EPFL), Lausanne 1015, Switzerland.

Corresponding Author

* E-mail: alexsyun1974@aliyun.com; yunsining@xauat.edu.cn

Details for the preparation of BPC, $ZnNb_2O_6$, and $ZnNb_2O_6$/BPC

Niobium chloride ($NbCl_5$, 0.287 g) and zinc nitrate nonahydrate ($Zn(NO_3)_2{\cdot}9H_2O$, 0.516 g) was added to 20 mL deionized water and stirred until the metal salts was completely dissolved. 10 mL hydrazine hydrate was slowly added to the solution and stirred for 30 min. The obtained solution was transferred into a Teflon-lined stainless steel autoclave (200 mL). Subsequently, the autoclave was subjected to hydrothermal treatment at 120 °C for 12 h in an oven and was then cooled naturally. The hydrothermal precursor was processed by centrifuging with alcohol and deionized water and dried in an oven at 80 °C for 12 h, then the white powder was achieved. Finally, the dried product was annealed in a tubular furnace for 2 h under nitrogen flow at 800 °C, which resulted in the expected niobium-based oxide $ZnNb_2O_6$.

Aloe peel was used as raw material to prepare bio-based porous carbon (BPC). The aloe peel was dried at 105 °C and crushed into powder. The powder was added into 20 mL deionized water and stirred for 4h, then transferred into the autoclave to proceed a hydrothermal carbonization process at 120 °C for 12 h. The obtained black precipitate was dipped into 1 mol/L KOH, then stirred thoroughly to perform a chemical activation process. The mixture was dried at 90 °C and then sintered at 800 °C under an N_2 atmosphere for 2 h in a tubular furnace. Subsequently, the obtained black product was repeatedly washed by 1 mol/L HCl, deionized water and absolute ethanol until the pH value of solution was neutral, and dried to finally achieve the target material BPC. More details on this type of bio-based carbon can be found in our previous literatures.[1-3]

In terms of the preparation of $ZnNb_2O_6$/BPC (a molar ratio of 1: 4) nanohybrid, the two metal salts ($NbCl_5$ 0.287 g and $Zn(NO_3)_2·9H_2O$, 0.516 g) and BPC (0.048 g) were dispersed in 20 mL ethyl alcohol, respectively, and stirred for 4 h. Then the mixed solution was conducted hydrothermal process at 120 °C for 12 h to obtaining a gray sediment. The colloidal product was dried at 80 °C for 12 h. Finally, the target nanohybrid $ZnNb_2O_6$/BPC would be obtained after a 800 °C annealing process for 2 h.

X-ray diffraction peak assignments of the catalytic materials

Chemical composition, crystal structures, space groups, JCPDS Card number and lattice parameters of the $ZnNb_2O_6$ were summarized in Table S1.

Table S1 Details of the XRD patterns of $ZnNb_2O_6$.

Chemical formula	Crystal structures	JCPDS Card [a]	a (nm)	b(nm)	c(nm)
$ZnNb_2O_6$	Orthorhombic	PDF#37-1371	5.031	14.187	5.723

[a] PDF-2 database.

The diffraction peaks at 24.407°, 25.107°, 30.251°, 31.226°, 35.670°, 36.100°, 38.016°, 40.547°, 41.068°, 43.670°, 48.103°, 49.989°, 51.626°, 53.411°, 60.707°, 62.887°, 64.306°, 68.055° can be indexed to the (031), (040), (131), (002), (200), (102), (060), (230), (132), (202), (062), (033), (260), (162), (331), (191), (233), (104) reflection of the $ZnNb_2O_6$ crystalline structure (PDF#37-1371), respectively.

Tafel polarization

Tafel polarization is shown in Figure S1 and Equation S1-S10, the Tafel curve can be divided into three zones.[4, 5] The part at low potential is attributed to the polarization zone (|U|<116 mV), in which the over potential (V) reveals a linear function of current density (J). The slope of the cross point of polarization and curve is the charge resistance (R_{ct}), which is inversely proportional to the exchange current density (J_0) and can be regarded as a crucial indicator to evaluate the electrochemical reaction activity, based on the Equation S5. The part at the middle potential is attributed to the Tafel zone, in which the potential (V) is a linear function of the logarithmic current density (lg$J$) according to Equation S2. The curve at high potential ascribes to the diffusion zone, which is on account of the redox couple transmission.

Based on the Tafel zone and diffusion zone, the exchange current density (J_0) and the limiting diffusion current density (J_{lim}) can be obtained, which are closely related to the catalytic activity of electrocatalyst. Based on Equation S2, the Tafel zone J_0 can be acquired through extending the line to the potential as zero and the current density (J) obtained there. In Tafel zone, the intersection of the equilibrium potential line and the cathodic can be considered as the J_0. The steeper curve means the higher J_0 value, which also indicates a better catalytic activity. In terms of the diffusion zone, J_{lim} depends on the diffusion capability of redox couple and the counter electrode catalyst. The J_{lim} can be obtained through the intersection of the cathodic branch with the Y axis. A higher J_{lim} means a larger diffusion coefficient at the same potential and higher diffusion velocity of redox couple in the electrolyte. Seen from the Equation S2, S5 and S6, it can be found that the J_0 is inversely proportional to R_{ct} whereas J_{lim} is proportional to D. More detailed on the Tafel polarization, please consult our previous papers.[4, 6-8]

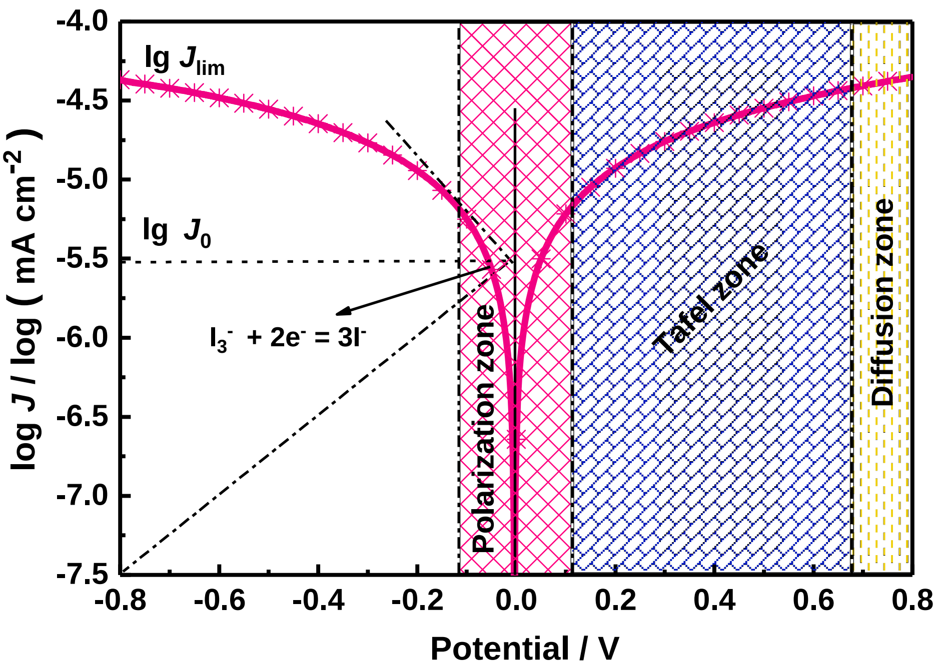

Figure S1 Annotation of Tafel curves.

$$V = a + b \lg J \quad \text{(Equation-S1)}$$

$$V = \frac{2.3RT(lgJ - lgJ_0)}{\alpha nF} \quad \text{(Equation-S2)}$$

$$a = -\frac{2.3RT}{\alpha nF} \lg J_0 \quad \text{(Equation-S3)}$$

$$b = \frac{2.3RT}{\alpha nF} \quad \text{(Equation-S4)}$$

$$J_0 = \frac{RT}{nFR_{ct}} \quad \text{(Equation-S5)}$$

$$D = \frac{l}{2nFC} J_{lim} \quad \text{(Equation-S6)}$$

The Nernst impedance describes the diffusion of the triiodide in the electrolyte, and can be expressed as follows:

$$Z_N = \frac{W}{\sqrt{iw}}\tanh(\sqrt{\frac{iw}{K_N}}) \qquad \text{(Equation-S7)}$$

$$W = \frac{kT}{n^2e^2CA\sqrt{D}} \qquad \text{(Equation-S8)}$$

$$J_{lim} = \frac{2neDCN_A}{l} \qquad \text{(Equation-S9)}$$

$$K_N = D/\delta^2 \qquad \text{(Equation-S10)}$$

where a and b are the constants, V is the overpotential, J is the polarization current density, R is the gas constant, T is the temperature, D is the diffusion coefficient of the triiodide, F is the Faraday constant, C is the triiodide concentration, n is the number of electrons exchanged in the reaction at the electrolyte-electrode interface, δ is the thickness of the diffusion layer, e is the elementary charge, k is the Boltzmann constant, A is the electrode active area, l is the distance between the electrodes (the spacer thickness), α is the distribution coefficient or symmetrical coefficient, N_A is the Avogadro constant , R_{ct} is the charge-transfer resistance, Z_N is the Nernst diffusion impedance, W is the Warburg parameter, J_0 is the exchange current density, and J_{lim} is the limiting diffusion current density.

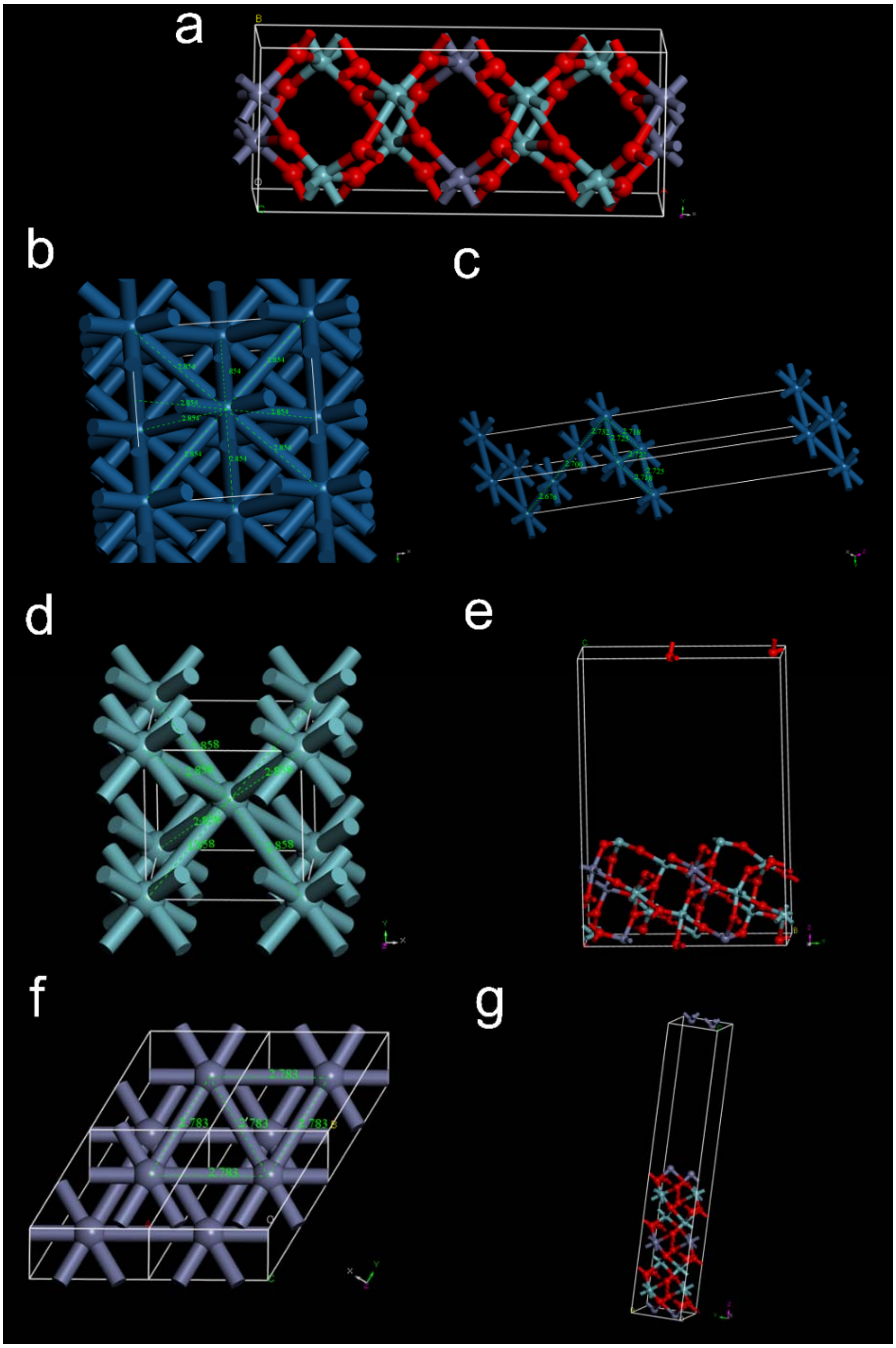

Figure S2 Geometric models (a) $ZnNb_2O_6$ of the *Pbcn* phase, (b) bulk Pt, (c) (111) surface of Pt, (d) bulk Nb, (e) (110) surface of $ZnNb_2O_6$, (f) bulk Zn and (g) (100) surface of $ZnNb_2O_6$.

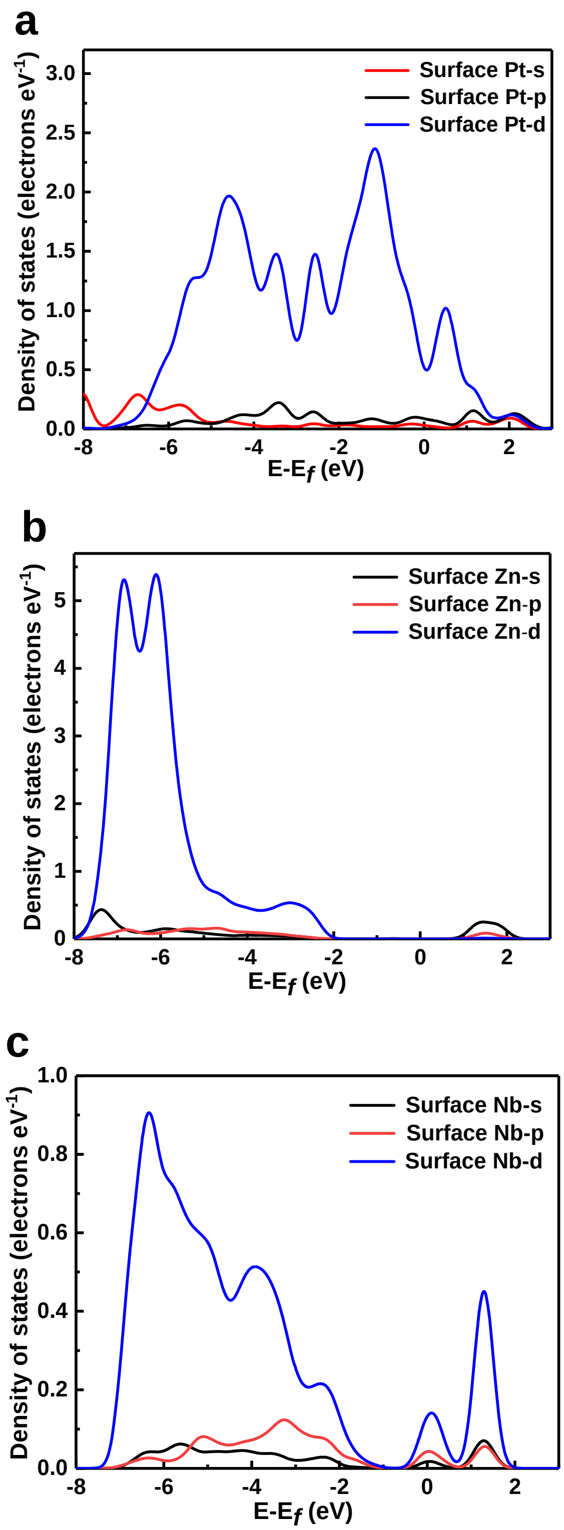

Figure S3 Projected density of states of (a) Pt atom in (111) surface of Pt, (b) Zn atom in (100) surface of $ZnNb_2O_6$, (c) Nb atom in (110) surface of $ZnNb_2O_6$.

Table S2 Photovoltaic parameters of DSSCs using transition metal compounds/carbon nanohybrid CEs. (AM 1.5, 100 mW cm^{-2}).

Transition metal compounds/Carbon nanohybrids									
CEs	**J_{sc} (mA cm^{-2})**	**V_{oc} (mV)**	**FF**	**PCE (%)**	**Area (cm^2)**	**Dye**	**Electrolyte**	**Year**	**Ref.**
Pt	12.48	730	0.65	**6.40**	0.20	Z907	I^-/I_3^-	2009	**9**
TiO_2/Carbon	12.53	700	0.57	**5.50**	0.24				
Pt	12.83	735	0.60	**5.68**	0.25	N719	I^-/I_3^-	2010	**10**
TiN	9.28	660	0.35	**2.12**					
CNTs	8.55	705	0.52	**3.53**					
TiN/CNTs	12.74	750	0.57	**5.41**					
Pt	13.71	780	0.71	**7.55**	0.16	N719	I^-/I_3^-	2011	**11**
WO_2	12.69	807	0.65	**6.69**					
MC	14.54	799	0.60	**7.01**					
WO_2/MC	13.55	808	0.71	**7.76**					
WC	41.01	650	0.56	**5.10**	0.16	N719	T_2/T^-	2011	**12**
WC/MC	14.45	650	0.57	**5.34**					
Pt	15.23	807	0.64	**7.89**	0.16	N719	I^-/I_3^-	2011	**13**
MoC/MC	15.50	787	0.68	**8.34**					
WC/MC	14.59	804	0.70	**8.18**					
CoS/MWCNTs	15.96	720	0.64	**6.96**	0.283	N719	I^-/I_3^-	2011	**14**
MoC/MC	15.50	787	0.68	**8.34**	0.16	N719	I^-/I_3^-	2011	**13**
WC/MC	14.59	804	0.70	**8.18**					
Mo_2C/P25/CD	15.25	796	0.67	**8.14**					
WC/P25/CD	14.93	787	0.68	**8.34**					
Pt	10.12	765	0.6508	**5.03**	1.00	N719	I^-/I_3^-	2011	**15**
TiN/NG	12.34	728	0.6433	**5.78**					
Pt	14.08	783	0.68	**7.50**	0.16	N719	I^-/I_3^-	2012	**16**
VC/MC	13.11	808	0.72	**7.63**					
Pt	15.00	808	0.66	**8.00**	0.25	N719	I^-/I_3^-	2012	**17**
TiO_2/MC	15.20	800	0.55	**6.69**					

TiN/MC	15.30	820	0.67	**8.41**					
Pt	15.44	652	0.33	**3.32**			T_2/T^-		
TiN/MC	14.36	697	0.67	**6.71**					
MC	14.54	800	0.60	**7.01**	0.16	N719	I^-/I_3^-	2012	**18**
Ni_5P_4/C	13.85	780	0.69	**7.54**					
Ni_5P_4	13.84	770	0.54	**5.71**					
MoP	12.79	760	0.51	**4.92**					
MC	12.88	630	0.54	**4.40**	0.16	N719	T_2/T^-		
Ni_5P_4/C	11.81	630	0.64	**4.75**					
Ni_5P_4	11.40	630	0.54	**3.87**					
Pt	13.33	782	0.63	**6.59**	1.00	N719	I^-/I_3^-	2012	**19**
C_b	12.80	760	0.61	**5.93**					
TiN	10.06	741	0.48	**3.59**					
TiN/C_b	14.29	791	0.70	**7.92**					
Pt	13.12	744	0.62	**6.08**	0.20	N719	I^-/I_3^-	2012	**20**
graphene	12.88	701	0.52	**4.70**					
$Ni_{12}P_5$	12.24	727	0.44	**3.94**					
graphene/$Ni_{12}P_5$	12.86	727	0.61	**5.70**					
Pt	15.86	740	0.63	**7.35**	0.20	N719	I^-/I_3^-	2012	**21**
MoN	13.71	670	0.61	**5.57**					
MoO_2	12.52	515	0.43	**2.79**					
MoO_2/CNTs	13.67	725	0.44	**4.34**					
MoN/CNTs	14.40	735	0.64	**6.74**					
Pt	13.24	740	0.66	**6.41**	0.28	N719	I^-/I_3^-	2012	**22**
MoS_2	11.25	720	0.61	**4.99**					
MWCNTs	9.11	650	0.58	**3.53**					
MoS_2/MWCNTs	13.69	730	0.65	**6.45**					
Pt	12.43	750	0.67	**6.23**	0.20	N719	I^-/I_3^-	2012	**23**
MoS_2/graphene	12.41	710	0.68	**5.98**					
Pt	12.47	730	0.71	**6.48**	0.25	N3	I^-/I_3^-	2012	**24**
Carbon/SnO_2/TiO_2	12.98	740	0.64	**6.15**					
Pristine graphene	11.0	670	0.171	**1.27**	----	N719	I^-/I_3^-	2012	**25**
CoS/graphene	12.8	720	0.364	**3.42**					

Pt	13.23	760	0.75	**7.54**	0.20	N719	I^-/I_3^-	2012	**26**
WS_2	11.72	720	0.63	**5.32**					
MWCNT	10.77	660	0.61	**4.34**					
WS_2/MWCNT	13.63	750	0.72	**7.36**					
$Hf_7O_8N_4/HfO_2/C$ HfO_2/C HfO_2	14.13 12.96 12.63	800 770 730	0.70 0.67 0.40	**7.85** **6.71** **3.73**	0.16	N719	I^-/I_3^-	2013	**27**
Pt	6.47	580	0.44	**1.87**	0.25	N719	Co^{2+}/Co^{3+}	2013	**28**
Ag nanowire	5.32	540	0.36	**1.09**					
Ag nanowire/GNP	6.45	550	0.52	**1.61**					
Pt	13.73	835	0.69	**7.91**	0.25	FNE29	Co^{2+}/Co^{3+}	2013	**29**
TaON	11.35	773	0.29	**2.54**					
graphene	12.33	814	0.46	**4.62**					
graphene/TaON	13.38	829	0.69	**7.65**					
Pt	15.75	739	0.70	**8.15**	0.25	N719	I^-/I_3^-	2013	**30**
NiS_2	14.42	738	0.66	**7.02**					
graphene	10.98	716	0.40	**3.14**					
RGO/NiS_2	16.55	749	0.69	**8.55**					
Pt	13.38	828	0.685	**7.59**	0.25	FNE29	Co^{2+}/Co^{3+}	2013	**31**
Ta_3N_5	11.69	783	0.316	**2.89**					
graphene	12.41	819	0.448	**4.55**					
graphene/Ta_3N_5	13.53	837	0.693	**7.85**					
Pt (FTO)	9.92	730	0.69	**5.00**	----	N719	I^-/I_3^-	2013	**32**
graphene(SiO_2)	8.68	691	0.3234	**1.94**					
NiS/graphene(SiO_2)	10.31	724	0.7036	**5.25**					
NiS(FTO)	9.42	707	0.6288	**4.19**					
CoS/graphene(SiO_2)	10.03	725	0.6928	**5.04**					
CoS(FTO)	9.01	708	0.6161	**3.93**					
Pt	13.98	730	0.66	**6.74**	0.20	N719	I^-/I_3^-	2013	**33**
MoS_2	11.66	730	0.63	**5.36**					
MoS_2/C	15.07	750	0.68	**7.69**					

Pt	13.98	720	0.64	**6.40**	0.12	N719	I^-/I_3^-	2013	**34**
Graphitic Carbon(GC)	12.71	710	0.53	**4.75**					
Fe_3C/GC	13.77	700	0.63	**6.04**					
Pt	12.95	750	0.66	**6.41**	0.20	N719	I^-/I_3^-	2013	**35**
Graphene flake	10.96	690	0.48	**3.63**					
MoS_2	10.56	670	0.58	**4.10**					
MoS_2/graphene	13.27	750	0.61	**6.07**					
Pt	13.12	763	0.62	**6.24**	0.28	N719	I^-/I_3^-	2013	**36**
MoS_2	12.92	701	0.46	**4.15**					
Graphene nanosheets	11.99	754	0.30	**2.68**					
MoS_2/graphene	12.79	773	0.59	**5.81**					
Pt	12.46	751	0.68	**6.36**	0.28	N719 Ti foil	I^-/I_3^-	2013	**37**
MWCNT	7.83	591	0.33	**1.53**					
NiS	13.25	752	0.71	**7.07**					
NiS/MWCNT	14.18	753	0.74	**7.90**					
Pt	12.35	750	0.69	**6.39**	0.28	N719 Ti foil	I^-/I_3^-	2013	**38**
MWCNT	8.25	376	0.41	**1.27**					
CoS	13.88	750	0.71	**7.38**					
CoS/MWCNT	14.69	751	0.73	**8.05**					
Pt	13.23	740	0.67	**6.56**	0.20	N719	I^-/I_3^-	2013	**39**
WS_2	11.28	720	0.59	**4.79**					
MWCNT	10.77	660	0.61	**4.34**					
5wt.% MWCNT/WS_2	13.51	730	0.65	**6.41**					
Pt	13.80	540	0.41	**3.06**	0.16	Quantum QDSSC	polysulide electrolyte	2013	**40**
MWCNT	13.40	510	0.35	**2.39**					
CZTSe	16.36	530	0.44	**3.06**					
MWCNT/CZTSe	17.04	530	0.51	**4.60**					
Pt	15.18	710	0.68	**7.32**	0.16	N719	I^-/I_3^-	2013	**41**

MC	14.45	770	0.64	**7.19**					
TaO/MC	14.97	800	0.68	**8.09**					
TaC/MC	14.51	800	0.68	**7.93**					
Pt	13.99	750	0.68	**7.19**	0.16	N719	I^-/I_3^-	2013	**27**
HfO_2	12.63	730	0.40	**3.73**					
HfO_2/C	12.96	770	0.67	**6.71**					
$Hf_7O_8N_4/HfO_2$/C	14.13	800	0.70	**7.85**					
Rosin carbon	14.41	795	0.61	**7.00**	0.16	N719	I^-/I_3^-	2013	**42**
Carbon/Fe_3O_4	16.01	750	0.68	**8.11**					
HfO_2/MC	14.36	800	0.67	**7.75**	0.16	N719	I^-/I_3^-	2014	**43**
	10.45	590	0.60	**3.69**			T_2/T^-		
SnS_2/C	17.47	745	0.619	**8.06**	0.16	N719	I^-/I_3^-	2014	**44**
Cu/PACF	8.49	720	0.52	**3.20**	0.16	N719	I^-/I_3^-	2014	**45**
Cu/PACF/CNF	11.12	750	0.54	**4.36**					
WC/C	15.35	760	0.67	**7.77**	0.25	N719	I^-/I_3^-	2014	**46**
	13.96	630	0.66	**5.85**			T_2/T-		
Bi_2S_3/RGO	12.20	750	0.60	**5.5**	0.25	N719	I^-/I_3^-	2014	**47**
CNTs/MoS_2	14.93	650	0.47	**4.51**	0.25	N719	I^-/I_3^-	2014	**48**
CNTs/MoS_2/carbon	16.44	790	0.57	**7.23**					
CoS	11.78	670	0.61	**4.79**	3.75	N719	I^-/I_3^-	2014	**49**
CoS/FGN	12.91	670	0.64	**5.54**					
MWCNT	14.83	700	0.56	**5.81**	0.25	N3	I^-/I_3^-	2014	**50**
TiO_2/MWCNT	15.71	720	0.68	**7.69**					
Pt	16.25	635	0.66	**6.84**	0.2	N3	I^-/I_3^-	2014	**51**
Mn_3O_4/RGO	15.20	635	0.61	**5.90**					
Pt	16.00	710	0.60	**6.82**	0.25	N719	I^-/I_3^-	2014	**52**
$NiSe_2$/RGO	15.82	730	0.61	**6.94**					
TiC/SiC/C	11.13	782	0.654	**5.7**	----	N719	I^-/I_3^-	2014	**53**
Pt	14.77	751	0.62	**6.92**	0.25	N719	I^-/I_3^-	2014	**54**
$CuInS_2$/RGO	16.61	782	0.58	**6.96**					
Bi_2S_3	15.34	690	0.438	**4.78**	----	N719	I^-/I_3^-	2014	**55**
Bi_2S_3/RGO (9wt%)	15.33	740	0.609	**6.91**					
ZnO/GNs	21.70	765	0.671	**8.12**	----	N719	I^-/I_3^-	2015	**56**
$CoNi_2S_4$/carbon fibers	15.3	680	0.677	**7.03**	----	N719	I^-/I_3^-	2015	**57**

Pt RuO_2/G	17.10 16.13	780 766	0.62 0.67	**8.16** **8.32**	----	N719	I^-/I_3^-	2015	**58**
CoS_2/RGO	12.87	670	0.63	**5.43**	----	Z907	I^-/I_3^-	2015	**59**
CoS/GR	15.07	748	0.56	**6.31**	0.20	N719	I^-/I_3^-	2015	**60**
CdS/RGO	14.81	760	0.656	**7.39**	0.25	N719	I^-/I_3^-	2015	**61**
SnO_2/RGO	14.25	720	0.66	**6.78**	----	N719	I^-/I_3^-	2015	**62**
TiO_2/C	4.0	710	0.622	**1.9**	1	N719	I^-/I_3^-	2015	**63**
Cu-Ni/GR	13.35	660	0.623	**5.46**	0.16	N719	I^-/I_3^-	2015	**64**
SnS_2/RGO	14.80	718	0.67	**7.12**	0.25	N719	I^-/I_3^-	2015	**65**
CoTe/RGO	17.41	770	0.685	**9.18**	----	N719	I^-/I_3^-	2015	**66**
MoS_2/MWCNT	16.71	737	0.608	**7.50**	0.15	N719	I^-/I_3^-	2015	**67**
MoS_2/G	15.64	685	0.67	**7.18**	----	N719	I^-/I_3^-	2015	**68**
PtO/MWCNTs	17.93	763	0.633	**8.67**	0.25	N719	I^-/I_3^-	2015	**69**
AuNP/RGO	7.27	355.2	0.50	**1.30**	0.49	N719	I^-/I_3^-	2015	**70**
CoS/$RGO_{0.2}$	19.42	764	0.633	**9.39**	----	N719	I^-/I_3^-	2015	**71**
NiCo/CNFs	11.12	740	0.54	**4.47**	0.25	N719	I^-/I_3^-	2015	**72**
NiO/MWCNT	18.54	644	0.639	**7.63**	0.15	N719	I^-/I_3^-	2015	**73**
TiO_{2-x}/CNT	12.36	700	0.66	**5.71**	----	N719	I^-/I_3^-	2015	**74**
$NiCo_2O_4$/G	16.12	750	0.67	**8.10**	0.28	N719	I^-/I_3^-	2015	**75**
NiO/acetylene black	16.28	780	0.61	**7.75**	0.15	N719	I^-/I_3^-	2015	**76**
CoS/G	15.07	748	0.56	**6.31**	0.20	N719	I^-/I_3^-	2015	**60**
CoS/G	17.02	770	0.63	**8.34**	0.30	N719	I^-/I_3^-	2015	**77**
Ni_3S_2/C	20.75	750	0.62	**9.64**	----	N719	I^-/I_3^-	2015	**78**
$Ni_{0.75}Cu_{0.25}$/G	10.35	750	0.65	**5.1**	0.25	N719	I^-/I_3^-	2015	**79**
$Ni_{0.6}Cu_{0.4}$/G	10.03	720	0.39	**2.87**					
$Cu_{0.75}Ni_{0.25}$/G	7.44	518	0.32	**1.24**					
Fe_2O_3	13.60	711	0.61	**5.89**	0.16	N719	I^-/I_3^-	2016	**80**
Fe_2O_3/GFs	15.05	728	0.68	**7.45**					
Pt	14.89	719	0.68	**7.29**					
g-C_3N_4	8.8	540	0.41	**1.95**	0.2	N3	I^-/I_3^-	2016	**81**
MWCNT	12.6	640	0.53	**4.27**					
g-C_3N_4/MWCNT	14.2	720	0.62	**6.34**					
Pt	14.6	710	0.66	**6.84**					
CoS	17.028	766	0.651	**8.49**	0.12	N719	I^-/I_3^-	2016	**82**
CoS/$rGO_{0.10}$	18.903	767	0.677	**9.82**					

rGO	15.368	733	0.013	**2.01**					
Co/RGO	14.22	750	49.6	**5.29**	----	N719	I^-/I_3^-	2016	**83**
$Pt_{0.1}Co_{0.9}$/RGO	14.66	745	68.1	**7.44**					
Pt/RGO	14.79	730	65.4	**7.06**					
CoS/G	12.09	630	0.71	**5.41**	0.16	Z907	I^-/I_3^-	2016	**84**
CoS	10.93	610	0.61	**4.07**					
RGO	10.21	620	0.35	**2.22**					
Nb_2O_5	12.27	683	0.59	**4.95**	0.16	N719	T_2/T^-	2016	**85**
	15.18	868	0.63	**8.29**			Co^{2+}/Co^{3+}		
Nb_2O_5/C	13.39	689	0.66	**6.11**			T_2/T^-		
	15.68	861	0.73	**9.86**			Co^{2+}/Co^{3+}		
MoS_2/G	16.1	660	0.67	**7.1**	0.16	N719	I^-/I_3^-	2016	**86**
TiO_2/C_a	15.83	705	0.55	**6.04**	----	N719	I^-/I_3^-	2016	**87**
Ni/GO	17.8	750	0.62	**8.30**	0.16	N719	I^-/I_3^-	2016	**88**
$La_{0.65}Sr_{0.35}MnO_3$/RGO	12.53	780	0.67	**6.57**	----	N719	I^-/I_3^-	2016	**89**
g-C_3N_4/CCB	13.21	688	0.56	**5.09**	0.2	N3	I^-/I_3^-	2016	**90**
Ni–Co/CNFs	9.78	730	0.64	**4.57**	0.2	N719	I^-/I_3^-	2016	**91**
10wt%CNFs-TiC	9.71	720	0.64	**4.5**	0.25	N719	I^-/I_3^-	2016	**92**
MnO_2+6wt% RGO	15.97	705	0.509	**5.77**	0.25	N719	I^-/I_3^-	2016	**93**
$NiCo_2O_4$/RGO	14.92	690	0.599	**6.17**	----	N719	I^-/I_3^-	2016	**94**
PbSe/RGO	15.24	570	0.65	**6.5**	0.25	N719	I^-/I_3^-	2016	**95**
PbSe	4.62	570	0.45	**1.2**					
ZnSe	6.14	540	0.43	**1.44**	---	N719	I^-/I_3^-	2016	**96**
ZnSe/RGO	15	780	0.57	**6.61**					
CoS_2	4.11	530	0.53	**1.18**	0.25	N719	I^-/I_3^-	2016	**97**
CoS_2/RGO	15.2	770	0.55	**6.49**					
Bi_2Se_3	7.02	550	0.46	**1.86**	0.25	N719	I^-/I_3^-	2016	**98**
Bi_2Se_3/RGO	16.36	750	0.57	**7.09**					
Pt	15.65	680	0.59	**6.47**					
rGO	4.35	695	0.2447	**0.74**	---	N719	I^-/I_3^-	2016	**99**
Co_9S_8	14.74	669	0.5821	**5.74**					
Co_9S_8/rGO	15.24	703	0.6627	**7.10**					
Pt	15.68	693	0.6856	**7.45**					
MnO_x	2.99	700	0.45	**0.77**	---	N719	I^-/I_3^-	2016	**100**
CNT	6.12	750	0.42	**2.40**					
CNT/MnO_x	3.93	740	0.48	**1.39**					
CNT/MnO_x/CNT	4.67	780	0.55	**2.01**					
In_2O_3	1.82	250	0.30	**0.14**	---	N719	I^-/I_3^-	2016	**101**

In_2O_3-MWCNTs	9.45	370	0.37	**1.29**					
ACs	15.01	730	0.60	**6.57**	0.15	N719	I^-/I_3^-	2016	**102**
Nano-Si@ACs	15.50	760	0.67	**8.01**					
Pt	15.20	740	0.64	**7.20**					
MoS_2	8.15	610	0.21	**1.04**	0.2	N3	---	2016	**103**
MoS_2/AB	10.27	640	0.20	**1.31**					
MoS_2/VC	10.81	640	0.43	**2.97**					
MoS_2/CNT	12.43	620	0.4	**3.08**					
MoS_2/CNF	10.33	580	0.53	**3.17**					
MoS_2/RHA	10.95	600	0.32	**2.10**					
$In_{2.77}S_4$@Cc	17.34	750	0.67	**8.71**	0.16	N719	I^-/I_3^-	2016	**104**
$In_{2.77}S_4$	15.06	680	0.47	**4.81**					
Cc	16.56	740	0.63	**7.72**					
Pt	19.19	760	0.60	**8.75**					
CNT/TiO_2	15.96	770	0.57	**7.00**	0.25	N719	I^-/I_3^-	2016	**105**
TiO_2	15.68	770	0.54	**6.51**					
In_2O_3	4.83	320	0.38	**0.59**	1.5	N719	I^-/I_3^-	2016	**106**
In_2O_3-MWCNTs$_{(0.1\%)}$	4.28	430	0.40	**0.74**					
In_2O_3-MWCNTs$_{(0.2\%)}$	5.23	480	0.41	**1.03**					
In_2O_3-MWCNTs$_{(0.3\%)}$	5.63	510	0.43	**1.23**					
In_2O_3-MWCNTs$_{(0.4\%)}$	4.92	450	0.41	**0.91**					
In_2O_3-MWCNTs$_{(0.5\%)}$	4.62	400	0.40	**0.74**					
Fe_3O_4	11.26	511	0.31	**2.1**	0.25	N719	I^-/I_3^-	2016	**107**
Carbon Black	5.84	655	0.47	**2.2**					
Fe_3O_4–CB (1:1)	14.14	660	0.49	**5.8**					
Fe_3O_4–CB (1:2)	14.40	665	0.51	**6.1**					
Fe_3O_4–CB (2:1)	12.55	650	0.50	**5.0**					
Pt	9.33	675	0.52	**4.1**					
$NiSe_2$ nanoparticles	13.96	750	0.62	**6.49**	---	N719	I^-/I_3^-	2016	**108**
$NiSe_2$+3 wt% graphene	14.86	750	0.62	**6.91**					
$NiSe_2$+6 wt% graphene	16.32	750	0.61	**7.47**					
$NiSe_2$+9 wt% graphene	14.67	760	0.64	**7.14**					
Pt	15.25	760	0.63	**7.28**					
Pt	13.0	720	0.69	**6.47**	0.25	---	I^-/I_3^-	2016	**109**
Sb_2Se_3	11.3	640	0.43	**3.08**					
CNP	12.4	700	0.57	**4.97**					
Sb_2Se_3-CNP	12.7	730	0.68	**6.26**					
$CoSe_2$/C-NG	17.51	730	0.67	**8.41**	0.24	N719	I^-/I_3^-	2016	**110**
$CoSe_2$/C-NR	15.98	730	0.67	**7.83**					
$CoSe_2$/C-NCW	18.03	730	0.67	**8.92**					

Pt	16.43	740	0.67	**8.25**					
$Ni_{0.85}Se$	17.86	743	0.675	**8.96**(Front)	0.11	N719	I^-/I_3^-	2016	**111**
	9.51	715	0.772	**5.25**(Rear)					
$Ni_{0.85}Se/RGO_{0.05}$	18.66	751	0.666	**9.75**(Front)					
	8.06	720	0.696	**3.97**(Rear)					
$Ni_{0.85}Se/RGO_{0.1}$	19.94	751	0.652	**9.75**(Front)					
	7.87	717	0.702	**3.97**(Rear)					
$Ni_{0.85}Se/RGO_{0.15}$	18.13	765	0.641	**8.89**(Front)					
	6.90	715	0.713	**3.52**(Rear)					
Pt	16.51	746	0.662	**8.15**(Front)					
	1.19	683	0.664	**0.54**(Rear)					
NiS	17.08	680	0.52	**6.04**	0.16	N719	I^-/I_3^-	2016	**112**
NiS/Ca	15.56	720	0.61	**6.83**					
NiS/Cc	18.18	760	0.59	**8.15**					
Pt	16.03	750	0.69	**8.29**					
MoS_2	6.76	640	0.50	**2.18**	---	---	I^-/I_3^-	2016	**113**
MoS_2/graphene	16.64	760	0.58	**7.31**					
graphene	18.92	770	0.46	**6.72**					
FeN	14.02	690	0.70	**6.79**	0.20	N719	I^-/I_3^-	2016	**114**
N-doped graphene	16.13	730	0.74	**8.71**					
FeN/N-doped graphene	18.83	740	0.78	**10.86**					
Pt	16.98	750	0.78	**9.93**					
MoS_2	15.95	720	0.599	**6.89**	---	N719	I^-/I_3^-	2016	**115**
MoS_2/graphene	16.96	720	0.657	**8.01**					
Pt	16.86	730	0.6672	**8.21**					
RGO	9.32	720	0.4098	**2.75**	---	---	I^-/I_3^-	2016	**116**
Co_3O_4	7.43	660	0.2447	**1.20**					
Co_3O_4@RGO	11.91	790	0.6154	**5.79**					
Pt	11.65	790	0.6693	**6.16**					
Pt	15.289	743	0.683	**7.76**	0.28	Z907	I^-/I_3^-	2016	**117**
Graphene	12.085	706	0.612	**5.22**					
NiS	12.836	717	0.651	**5.99**					
NiS/Gr	14.244	727	0.678	**7.02**					
NiS/Ag	14.909	735	0.654	**7.17**					
NiS/Gr-Ag	16.205	753	0.685	**8.36**					
NiS/AB(acetyleneblack)	14.01	720	0.67	**6.75**	0.2	N3	I^-/I_3^-	2016	**118**
NiS	12.71	680	0.69	**5.96**					
Pt	17.32	660	0.63	**7.20**					
NiSe-Ni_3Se_2/RGO-HD	16.31	750	0.64	**7.83**	---	N719	I^-/I_3^-	2016	**119**

NiSe/RGO-NP	13.80	750	0.60	**6.21**					
NiSe-Ni_3Se_2/RGO-NP	14.41	750	0.65	**7.02**					
NiSe-Ni_3Se_2/RGO-SD	14.03	750	0.64	**6.73**					
NiSe-Ni_3Se_2/RGO-HD-10h	15.48	760	0.63	**7.41**					
Pt	15.25	760	0.63	**7.28**					
Pt	16.45	780	0.48	**6.08**	---	N719	I^-/I_3^-	2017	**120**
$MoSe_2$/rGO	17.11	770	0. 50	**6.56**					
Pt	14.83	740	0.65	**7.15**	0.28	N719	I^-/I_3^-	2017	**121**
MoS_2	14.44	740	0.64	**6.81**					
CNTs	13.33	750	0.62	**6.15**					
MoS_2/CNTs	16.65	740	0.66	**7.83**					
Pt	18.34	716	0.5514	**7.23**	---	N719	I^-/I_3^-	2017	**122**
MoS_2-graphene aerogel (MG)	17.24	714	0.6383	**7.86**					
MoS_2	13.64	780	0.2045	**2.20**					
Pt	12.79	720	0.675	**6.22**	0.25	$(Bu_4N)_2[Ru(Hdcbpy)_2(NCS)_2]$	I^-/I_3^-	2017	**123**
MoS_2/GP	13.34	696	0.698	**6.48**					
GP	9.61	667	0.395	**2.53**					
Pt	15.58	784	0.68	**8.27**	---	N719	I^-/I_3^-	2017	**124**
CNFs	12.58	777	0.62	**6.11**					
MnO_2/CNFs-1	14.43	786	0.65	**7.42**					
MnO_2/CNFs-2	15.29	782	0.68	**8.09**					
MnO_2/CNFs-3	16.15	783	0.70	**8.86**					
MnO_2/CNFs-4	15.18	779	0.66	**7.77**					
NiS	14.007	692	0.721	**6.98**	0.25	N719	I^-/I_3^-	2017	**125**
NiS-G0.2	14.398	698	0.696	**6.99**					
NiS-G0.4	14.586	712	0.727	**7.54**					
NiS-G0.6	15.814	715	0.724	**8.18**					
NiS-G0.8	15.600	704	0.691	**7.59**					
Pt	15.606	711	0.726	**8.05**					
Graphene	12.461	703	0.344	**3.02**					
$CoSe_{0.85}$	14.182	687	0.666	**6.49**	0.25	N719	I^-/I_3^-	2017	**126**
$CoSe_{0.85}$-G25	14.218	691	0.695	**6.83**					
$CoSe_{0.85}$-G50	14.342	711	0.722	**7.36**					
$CoSe_{0.85}$-G75	15.789	715	0.724	**8.17**					
$CoSe_{0.85}$-G90	15.581	703	0.694	**7.60**					
RGO	13.24	686	0.38	**3.47**	---	N719	I^-/I_3^-	2017	**127**
CoS_2	14.13	693	0.56	**5.48**					
CoS_2/RGO	16.35	702	0.67	**7.69**					
Pt	15.51	706	0.67	**7.38**					

RGO	8.86	721	0.16	**1.01**	---	N719	I^-/I_3^-	2017	**128**
$Co_{0.85}Se$	14.51	706	0.52	**5.34**					
$Co_{0.85}Se$/RGO	16.01	706	0.69	**7.81**					
Pt	15.44	707	0.69	**7.55**					
Pt	14.52	740	0.76	**8.12**	0.25	---	I^-/I_3^-	2017	**129**
$Ni_2P_2O_7$-NiO/C5	2.41	650	0.08	**0.13**					
$Ni_2P_2O_7$-Ni_3P-Ni/C5	6.16	650	0.16	**0.64**					
$Ni_2P_2O_7$-$Ni_{12}P_5$-Ni_8P_3/C5	12.34	720	0.61	**5.44**					
Ni_2P/C2.5	13.53	750	0.76	**7.81**					
Ni_2P/C5	14.78	770	0.77	**8.82**					
Ni_2P/C10	14.89	780	0.83	**9.57**					
Ni_2P/C20	13.95	770	0.78	**8.38**					
Ni_2P/C40	13.42	770	0.76	**7.91**					
$Ni_{12}P_5$/C10	13.88	760	0.75	**7.94**					
Pt	15.77	700	0.65	**7.19**	0.16	N719	I^-/I_3^-	2018	**130**
Ta/Co-N-C	18.11	650	0.68	**7.96**					
Co-N-C	13.02	720	0.67	**6.25**					

Abbreviation used:

FTO	fluorine-doped tin oxide
TMCs	transition metal compounds
C_a	activated carbon
C_b	carbon black
C_c	conductive carbon
C_f	carbon fiber
CD	carbon dye
C_p	discarded toner of a printer
C60	fullerene
MC	mesoporous carbon
CNTs	carbon nanotubes
CNP	carbon nanoparticle
CNFs	carbon nanofires
NG	nanograin
NR	nanorock
NP	nanoparticle
AB	acetylene black
VC	vulcan carbon
RHA	rice husk ash
NCW	nanoclimbing-wall
GNP	graphene nanoplatelets
GO	graphene oxide

RGO	reduced graphene oxide
SWCNTs	single-wall CNTs
MWCNTs	multi-wall CNTs
GNP	graphene nanoplatelets
NG	N-doped rGO

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