

Electronic Supplementary Information

A Strategy for Preparing High-efficiency and Economical Catalytic Electrodes toward Overall Water Splitting

Dongxue Yao^{#a}, Lingling Gu^{#a}, Bin Zuo^a, Shuo Weng^a, Shengwei Deng^b, Weiju Hao^{*a}

^aUniversity of Shanghai for Science and Technology, Shanghai 200093, P. R. China.

^bCollege of Chemical Engineering, Zhejiang University of Technology, Hangzhou, Zhejiang 310014, P. R. China.

E-mail: wjhao@usst.edu.cn

Table S1. The overpotential of NF-based catalytic electrodes in alkaline media at the current density of 10 mA cm⁻² in recent years.

Catalysts	HER (mV)	OER (mV)	References
NiFe LDH/NF	210	240	<i>Science</i> , 2014, 345 , 1593–1596
Ni ₃ S ₂ /NF	223	260	<i>J. Am. Chem. Soc.</i> , 2015, 137 , 14023-14026
Ni ₃ S ₂ /AT-Ni foam	200	217	<i>Electrochim. Acta</i> , 2015, 174 , 297-301
NiS-Ni(OH) ₂ @aMoS _{2+x} /NF	226	417	<i>Adv. Funct. Mater.</i> , 2016, 26 , 7386-7393
FNHNs/NF	140	290	<i>Small</i> , 2017, 13 , 1602637
CoS-Co(OH) ₂ @aMoS _{2+x} /NF	92	255	<i>Adv. Funct. Mater.</i> , 2016, 26 , 7386-7393
Ni _{0.75} Fe _{0.25} LDHs/NF	169	140	<i>Int. J. Hydrog. Energy</i> , 2017, 42 , 5560-5568
NF/Ni ₃ Se ₂ /Ni	203	239	<i>Nano Energy</i> , 2016, 24 , 103-110
SNCF-NR/NF	262	390	<i>Adv. Energy Mater.</i> , 2017, 7 , 1602122
VOOH-NF	164	270	<i>Angew. Chem., Int. Ed.</i> , 2017, 56 , 573-577
Ni@NiCo ₂ O ₄ /NF	87	270	<i>ChemNanoMat</i> , 2018, 4 , 124-131
Co ₃ O ₄ /CoMoO ₄ /NF	143	244	<i>Appl. Surf. Sci.</i> , 2018, 433 , 256-263
Ni _x Co _{3-x} S ₄ /Ni ₃ S ₂ /NF	136	160	<i>Nano Energy</i> , 2017, 35 , 161-170
Ni ₃ S ₂ /NF	123	222	<i>J. Energy Chem.</i> , 2017, 26 , 1217-1222
NiSe/NF	137	271	<i>J. Energy Chem.</i> , 2017, 26 , 1217-1222
Ni-Co ₃ O ₄ /NF	170	310	<i>ACS Appl. Energy Mater.</i> , 2018, 1 , 6279-6287
Co _{0.85} Se/NF	129	232	<i>J. Solid State Electro.</i> , 2018, 22 , 1785-1794
p-MoS ₂ /Ni ₃ S ₂ /NF	99	185	<i>ACS Appl. Energy Mater.</i> , 2018, 1 , 3929-3936
CoB/NF	110	315	<i>Int. J. Hydrog. Energy</i> , 2018, 43 , 6076-6087
P-Co/NF	62	320	<i>Int. J. Hydrog. Energy</i> , 2018, 43 , 10448-10457
NiCo ₂ O ₄ @NiCo ₂ O ₄ /NF	61	180	<i>Nanoscale</i> , 2019, 11 , 22820-22831
Mo ₂ Co@N-CNS/CNT	99	300	<i>Chinese J. Catal.</i> , 2019, 40 , 1352-1359

CCH@CoSe/NF	128	255	<i>Energy Technol.</i> , 2019, 7 , 1800741
Ni ₃ S ₂ @GF/NF	99	240	<i>Energy Technol.</i> , 2019, 7 , 1900063
Ir-Co _x Ni _{1-x} O/NF	53	260	<i>Chinese J. Catal.</i> , 2019, 40 , 1576-1584
CuO–NiO/NF	38	172	<i>Dalton Trans.</i> , 2020, 49 , 1776-1784
NiFeP–MoO ₂ /NF	56	143	<i>Chem. Eng. J.</i> , 2021, 409 , 128161
Ni ₂ P/RGO@NF	83	366	<i>Electrochim. Acta</i> , 2020, 362 , 137172
Cu ₂ S–Ni ₃ S ₂ /NF	149	329	<i>ChemistrySelect</i> , 2020, 5 , 2455-2464
NiFe/NF	100	230	<i>J. Mater. Sci.</i> , 2020, 55 , 15140-15151
MoS ₂ /NiS/NF	87	216	<i>Int. J. Hydrog. Energy</i> , 2020, 45 , 17329-17338

Table S2. The overpotential of C-based catalytic electrodes in alkaline environment at the current density of 10 mA cm⁻² in recent years.

Catalysts	HER (mV)	OER (mV)	Reference
CoOx@CN	232	260	<i>J. Am. Chem. Soc.</i> , 2015, 137 , 2688-2694
CP/CTs/CoS	190	306	<i>ACS Nano</i> , 2016, 10 , 2342-2348
NiCoFe LTHs/CFC	200	230	<i>ACS Energy Lett.</i> , 2016, 1 , 445-453
NiFe DHNAs/CFC	330	260	<i>ACS Energy Lett.</i> , 2016, 1 , 445-453
CoFe DHNAs/CFC	290	290	<i>ACS Energy Lett.</i> , 2016, 1 , 445-453
NiCo DHNAs/CFC	350	330	<i>ACS Energy Lett.</i> , 2016, 1 , 445-453
Fe SHNAs/CFC	370	490	<i>ACS Energy Lett.</i> , 2016, 1 , 445-453
Co SHNAs/CFC	270	310	<i>ACS Energy Lett.</i> , 2016, 1 , 445-453
Ni SHNAs/CFC	400	350	<i>ACS Energy Lett.</i> , 2016, 1 , 445-453
Co-NMC/NC	220	350	<i>Small</i> , 2016, 12 , 3703-3711
N, S-CNT	450	360	<i>Adv. Energy Mater.</i> , 2017, 7 , 1602068
ONPPGC/OCC	410	466	<i>Energy Environ. Sci.</i> , 2016, 9 , 1210-1214
Co-PNCNFs	249	285	<i>J. Mater. Chem. A</i> , 2016, 4 , 12818
CoP/CC	95	281	<i>ChemSusChem</i> , 2016, 9 , 472-477
CoP ₃ NSs/CC	121	291	<i>J. Alloys Compd.</i> , 2017, 729 , 203-209
CoNPs@C/CC	153	270	<i>ACS Appl. Mater. Interfaces</i> , 2017, 9 , 31913-31921
Ni ₃ FeN-NPs/CC	238	241	<i>Electrochim. Acta</i> , 2017, 247 , 666-673
NiCo diselenide/CC	108	258	<i>Electrochim. Acta</i> , 2017, 225 , 503-513
CoP NA/CC	52	300	<i>ChemElectroChem</i> , 2017, 4 , 1840-1845
NiCoN NWs/CC	145	360	<i>Energy Technol.</i> , 2017, 5 , 1908-1911
CoN-400/CC	97	251	<i>Electrochim. Acta</i> , 2018, 273 , 229-238

Co ₃ O ₄ /CC	229	341	<i>Electrochim. Acta</i> , 2018, 273 , 229-238
N-doped cotton cloth	233	251	<i>Surf. Coat. Tech.</i> , 2018, 347 , 407-413
Ni ₃ FeN/CC	105	190	<i>ACS Appl. Mater. Interfaces</i> , 2018, 10 , 3699-3706
Ni ₃ N-NiMoN/CC	31	277	<i>Nano Energy</i> , 2018, 44 , 353-363
MoS ₂ @CoO/CC	173	325	<i>J. Phys. Chem. C</i> , 2019, 123 , 5833-5839
Co-CoO/Co(OH) ₂ /CC	195	340	<i>Int. J. Hydrog. Energy</i> , 2019, 44 , 23
Ni _{0.75} Mo _{0.25} /CC	79	330	<i>ChemElectroChem</i> , 2019, 6 , 1338-1343
Co ₃ S ₄ /EC-MOF/CC	84	226	<i>Adv. Mater.</i> , 2019, 31 , 1806672
NiCoP/CC	82	250	<i>Mater. Today Nano</i> , 2019, 8 , 100053
CoS ₂ /CoP/CC	90	334	<i>Electrocatalysis</i> , 2019, 10 , 253-261
Ru-Co(OH) ₂ /CC	55	203	<i>J. Taiwan Inst. Chem. E.</i> , 2020, 109 , 71-78
NiMoP ₂ -Ni ₂ P/CC	53	258	<i>J. Mater. Sci. Technol.</i> , 2021, 77 , 108-116
Ni ₂ P-MoS ₂ HNSAs/CC	78	258	<i>J. Alloys Compd.</i> , 2021, 856 , 158094
CC-NC-NiFeP	94	145	<i>Nanoscale</i> , 2020, 12 , 8443-8452
Mo-CoP ₃ -2@CC	62	300	<i>Dalton Trans.</i> , 2020, 49 , 5563-5572
Ni-MoC@NCNT/CCs	70	219	<i>Chem. Eng. J.</i> , 2021, 406 , 126815
Ni/MoN@NCNT/CC	207	252	<i>ChemElectroChem</i> , 2020, 7 , 745-752

Table S3. The catalytic performance of metals foam/foil/mesh in recent years (Metals = Fe, Co, Cu, Ti, Au, Mo, etc.)

Catalysts	Conditions	Substrate	Current density (mA cm ⁻²)	HER (mV)	Tafel slope for HER (mV dec ⁻¹)	OER (mV)	Tafel slope for OER (mV dec ⁻¹)	Ref.
Ni ₂ P-FF	1M KOH	Fe Foam	10	N	N	198	77	<i>J. Energy Chem.</i> , 2020, 42 , 71–76
Ni(OH) ₂ -FF	1M KOH	Fe Foam	10	N	N	336	87	<i>J. Energy Chem.</i> , 2020, 42 , 71–76
NiFe(OH) _x /FeS	1M KOH	Fe foam	50	N	N	245	N	<i>Adv. Funct. Mater.</i> , 2019, 29 , 1902180
FeS	1M KOH	Fe foam	100	N	N	273	53	<i>J. Alloys Compd.</i> , 2020, 835 , 155298
P-Co-S	1M KOH	Ti mesh	10	89	61	N	N	<i>ACS Sustain. Chem. Eng.</i> , 2018, 6 , 15618–15623
CoSe ₂	0.5 M H ₂ SO ₄	Ti foil	20	125	48.5	N	N	<i>J. Mater. Chem. A</i> , 2016, 4 , 4553
CoS ₂	1M KOH	Ti mesh	10	91	105.7	N	N	<i>Nanoscale</i> , 2020, 12 , 11573–11581
MoS ₂	0.5 M H ₂ SO ₄	Ti mesh	0	143	57.1	N	N	<i>Colloids Surf. A</i> , 2020, 586 , 124186
MoS ₂ /CoP	1M KOH	Ti foil	10	77	58	N	N	<i>ACS Sustain. Chem. Eng.</i> , 2019, 7 , 10105–10111
1 T/2H-MoS ₂	0.5 M H ₂ SO ₄	Ti plate	20	133	68.4	N	N	<i>Nano Res.</i> 2018, 11 , 4587–4598
MoS ₂ /M _o ₂ C	1M KOH	Ti foil	500	191	43	N	N	<i>Nat. Commun.</i> , 2019 10 , 269
Co-S	1M KOH	Ti mesh	10	N	N	361	64	<i>Electrochem. Commun.</i> , 2015, 60 , 92–96
Cu-CoS ₂	1M KOH	Ti mesh	50	N	N	277	91	<i>J. Alloys Compd.</i> , 2020, 821 , 153219
MnCo ₂ S ₄	1M KOH	Ti mesh	50	N	N	325	51	<i>J. Mater. Chem. A</i> , 2017, 5 , 17211
NiMoS	1M KOH	Ti mesh	50	150	93.1	N	N	<i>Nano Res.</i> , 2017, 11 , 988–996
NiMoS ₄	0.1M KOH	Ti mesh	10	194	97	N	N	<i>J. Mater. Chem. A</i> , 2017, 5 , 16585
NiTe ₂	1M KOH	Ti mesh	10	N	N	315	82	<i>Chemelectrochem</i> , 2018, 5 , 1153–1158
NiSe ₂ /Ti	1KOH	Ti Foil	10/20	96	82	295	82	<i>ACS Appl. Mater. Interfaces</i> , 2016, 8 ,

WS ₂	0.5M H ₂ SO ₄	Au Foil	10	110	100	N	N	<i>Nano Res.</i> , 2015, 8 , 2881–2890
1 T- PeSe ₂	0.5 M H ₂ SO ₄	Au Foil	10	210	33	N	N	<i>ACS Nano</i> , 2019, 13 , 8442–8451
MoS ₂	0.5 M H ₂ SO ₄	Au Foil	10	100	73	N	N	<i>ACS Nano</i> , 2014, 8 , 8617–8624
MoS ₂	1M KOH	Mo Foil	10	184	48	N	N	<i>Electrochim. Acta</i> , 2015, 168 , 133–138
MoS ₂ /rG O	0.5 M H ₂ SO ₄	Mo foil	10	172	52	N	N	<i>J. Mater. Chem. A</i> , 2017, 5 , 18081
CoSe/Co ₉ Se ₈	1M KOH	Co foil	100	N	N	280	40.4	<i>Adv. Energy Mater.</i> , 2018, 8 , 1801926
Co ₃ Se ₄	1M KOH	Co foam	397	N	N	320	44	<i>Adv. Energy Mater.</i> , 2017, 7 , 1602579
Cu ₂ S	1M KOH	Cu foam	10	N	N	290	101	<i>ACS Catal.</i> , 2018, 8 , 3859–3864
CuS _{0.55}	1M KOH	Cu foam	100	N	N	386	33	<i>Chem. Eng. Sci.</i> , 2019, 195 , 665–670
Cu ₂ S- CoOx	1M KOH	Cu foam	25	N	N	255	136	<i>Chem. Commun.</i> , 2020, 56 , 13571
Cu ₂ Se	1M KOH	Cu foam	10	N	N	200	150	<i>Int. J. Hydrog.</i> <i>Energy</i> , 2019, 44 , 22983–22990
Ni-Co- S/CuO	1M KOH	Cu foam	10	N	N	240	62.8	<i>Sustain. Energy</i> <i>Fuels</i> , 2020, 4 , 4039–4045
Cu ₂ S- Co(OH) ₂ NTA/CF	1M KOH	Cu Foam	50	241	92	268	78	<i>Electrochim. Acta</i> , 2019, 316 , 8-18
Cu ₂ S- Cu(OH) ₂ NRA/CF	1M KOH	Cu Foam	50	441	112	444	142	<i>Electrochim. Acta</i> , 2019, 316 , 8-18
Cu ₂ S- Cu ₂ O NTA/CF	1M KOH	Cu Foam	50	416	113	386	119	<i>Electrochim. Acta</i> , 2019, 316 , 8-18
MoN- Cu- NPC/CF	1M KOH	Cu Foam	10	127	152	N	N	<i>J. Mater. Chem. A</i> , 2019, 7 , 13559
Cu- NC/CF	1M KOH	Cu Foam	10	209	179	N	N	<i>J. Mater. Chem. A</i> , 2019, 7 , 13559
Ni-S	1M NaOH	Cu foil	10	130	N	N	N	<i>Mater. Lett.</i> , 2010, 64 , 261–263

Ni ₃ S ₂	0.5 M H ₂ SO ₄	Cu foil	10	91.6	63.5	N	N	<i>Nano Energy</i> , 2017, 36 , 85–94
CuS	0.2 M PBS	Cu foil	10	97	120	N	N	<i>Electrochim. Acta</i> , 2017, 252 , 516–522
MoS _x	0.5 M H ₂ SO ₄	Cu foam	10	200	43.6	N	N	<i>Int. J. Hydrog. Energy</i> , 2018, 43 , 4978–4986
MoS _x	0.5 M H ₂ SO ₄	Cu foil	10	276	60	N	N	<i>Int. J. Hydrog. Energy</i> , 2018, 43 , 4978–4986

Table S4. The HER and OER catalytic performance of a series of metal selenides/tellurides/carbides at the current density of 10 mA cm⁻² under alkaline conditions.

Catalysts	HER (mV)	Tafel slope for HER (mV dec ⁻¹)	OER (mV)	Tafel slope for OER (mV dec ⁻¹)	Reference
CuCo ₂ Se ₄	125	N	N	N	<i>ACS Appl. Energy Mater.</i> , 2020, 3, 3092–3103
NSNF-3	175	130	90	114	<i>Electrochim. Acta</i> , 2020, 354, 136742
Co _{0.9} Fe _{0.1} -Se/NF	125	85.4	246	40	<i>J. Energy Chem.</i> , 2021, 60, 194–201
CNSe-3.0	184	97	244	68	<i>Int. J. Hydrog. Energy</i> , 2021, 46 , 7297–7308
NiSe ₂ /CC	111	118	210	125	<i>Solid State Sci.</i> , 2021, 116 , 106613
Se CoS _{2-x}	280	58.4	90	286.7	<i>Nanoscale</i> , 2021, 13 , 6890–6901
Cu-(a-NiSe _x /c-NiSe ₂)	156.9	51.2	339	54.2	<i>Chem. Energy J.</i> , 2021, 422 , 130048
CoTe-NF	90	143	241	66	<i>Fuel</i> , 2020, 280 , 118666
Fe-Co _{1.11} Te ₂ @NCNTF	107	N	297	N	<i>ChemSusChem</i> , 2020, 13 , 5239-5247
Co _{1.11} Te ₂ @NCNTF	165	N	360	N	<i>ChemSusChem</i> , 2020, 13 , 5239-5247
Co-Co ₂ C/CC	96	82.2	261	58.8	<i>Appl. Catal., B</i> , 2021, 296 , 120334.
Co ₂ C/CC	185	102.2	382	96.8	<i>Appl. Catal., B</i> , 2021, 296 , 120334.
Te/FeNiOOH-NC	167	93	220	52	<i>ACS Appl. Mater. Interfaces</i> , 2021, 13 , 10972–10978
CoSe ₂ @NiSe ₂	162	62.84	N	43.24	<i>Int. J. Hydrog. Energy</i> , 2020, 45 , 30611–30621
NiSe ₂	192	123.1	N	71.44	<i>Int. J. Hydrog. Energy</i> , 2020, 45 , 30611–30621
RuTe ₂ -400	34	28	275	53	<i>Appl. Catal., B</i> , 2020, 278 , 119281.
MoSe ₂ @Ni _{0.85} Se	117	66	N	N	<i>Electrochim. Acta</i> , 2017, 246 , 712-719

NiSe ₂ /Ti	96	82	N	N	<i>ACS Appl. Mater. Interfaces</i> , 2016, 8 , 4718–4723
FeSe ₂ /NF	178	N	245	N	<i>Angew. Chem., Int. Ed.</i> , 2017, 56 , 10506
NiSe ₂ /NF	102	93	N	N	<i>CrystEngComm</i> , 2018, 20 , 3344–3352
Ni ₃ Se ₂ /NF	170	148	N	N	<i>CrystEngComm</i> , 2018, 20 , 3344–3352
NiSe/NF	153	99	329	110	<i>CrystEngComm</i> , 2018, 20 , 3344–3352
Ni _{0.5} Se	290	107	330	51	<i>ACS Appl. Mater. Interfaces</i> , 2018, 10 , 13675–13684
Ni _{0.75} Se	233	86	360	86	<i>ACS Appl. Mater. Interfaces</i> , 2018, 10 , 13675–13684
Ni _{0.85} Se	258	98	370	87	<i>ACS Appl. Mater. Interfaces</i> , 2018, 10 , 13675–13684
coral-like CoSe	N	N	295	40	<i>Electrochim. Acta</i> , 2016, 194 , 59–66
Co ₇ Se ₈ /GC	472	59.1	290	32.6	<i>ACS Appl. Mater. Interfaces</i> , 2016, 8 , 17292–17302
Ni ₃ Te ₂ /GC	N	N	180	64.3	<i>J. Mater. Chem. A</i> , 2018, 6 , 7608–7622
Ni ₃ Te ₂ /Au glass	237	73.1	210	54.2	<i>J. Mater. Chem. A</i> , 2018, 6 , 7608–7622
Ni ₃ Te ₂ /NF	212	126.2	230	N	<i>J. Mater. Chem. A</i> , 2018, 6 , 7608–7622
Ni ₃ Te ₂ /hydrothermal	304	94.2	220	61.5	<i>J. Mater. Chem. A</i> , 2018, 6 , 7608–7622
Co ₄ S ₃ /Mo ₂ C-NSC	63.6	92.1	268	61.2	<i>Appl. Catal., B</i> , 2020, 260 , 118197
MoC-Mo ₂ C-31.4	120	42	N	N	<i>Chem. Sci.</i> , 2016, 7 , 3399–3405
MoCx	151	59	N	N	<i>Nat. Commun.</i> , 2015, 6 , 6512
Co-Mo ₂ C nanowires	118	44	N	N	<i>Adv. Funct. Mater.</i> , 2016, 26 , 5590–5598
Mo/Mo ₂ C-HNS	79	62.86	N	N	<i>ACS Energy Lett.</i> , 2018, 3 , 341–348
N@MoPCx-800	139	69.4	N	N	<i>Adv. Energy Mater.</i> , 2018, 8 , 1701601

Ni-Mo _x C/NC-100	162	104.8	328	74	<i>ACS Appl. Mater. Interfaces</i> , 2018, 10 , 35025–35038
MoC _x octahedra	151	59	N	N	<i>Nat. Comm.</i> , 2015, 6 , 6512
1D Ni/Mo ₂ C@C	179	101	368	N	<i>Chem. Sci.</i> , 2017, 8 , 968-973
Fe ₃ C@NCNT/NPC	N	N	339	62	<i>Catal. Sci. Technol.</i> , 2016, 6 , 6365-6371
Fe ₃ C@NG-800	N	N	361	62	<i>ACS Appl. Mater. Interfaces</i> , 2015, 7 , 21511–21520
