Electronic Supplementary Information

Tailoring the facet of Ni$_3$S$_2$ as bifunctional electrocatalyst for high-performance overall water-splitting

Lingjie Li $^{†a}$, Caiyun Sun $^{†a}$, Bo Shang $^a$, Qing Li $^a$, Jinglei Lei $^*a$, Nianbing Li $^b$, Fusheng Pan $^c$

$^a$School of Chemistry and Chemical Engineering, Chongqing University, Chongqing, 400044 PR China.

$^b$School of Chemistry and Chemical Engineering, Southwest University, Chongqing, 400715 PR China.

$^c$School of Materials Science and Engineering, Chongqing University, Chongqing, 400044 PR China.

*Corresponding author. E-mail: jllei@cqu.edu.cn, Fax: +86 2365678934, Tel: +86 13983064116.

† These authors equally contributed to this work.
# Table of Contents

S1. Calculations and Experiments 3
   1.1 Theoretical models 3
   1.2 Calculation on hydrogen evolution reaction 3
   1.3 Calculation on oxygen evolution reaction 4
   1.4 Mass measurement and calculation 5
   1.5 Evaluation on electrocatalytic performance 6

S2. Analysis of the reactions during different hydrothermal processes 8

S3. Additional Figures and Tables 9

References 25
S1. Calculations and Experiments

1.1 Theoretical models

We chose three relatively stable surface-a, -b, and -c in the (11) surfaces. To obtain the most stable surface, the surface energy (γ) is presented as follows.

\[ \gamma = \frac{E_{\text{slab}} - nE_{\text{bulk}}}{A} - \frac{E_{\text{unrelaxed}}^{\text{slab}} - nE_{\text{bulk}}}{2A} \]

In which \( E_{\text{slab}} \) is the total energy of the slab (fixed on one side), \( E_{\text{unrelaxed}}^{\text{slab}} \) is the total energy of the fixed slab, \( n \) is the number of \( \text{Ni}_3\text{S}_2 \) units in the slab, \( E_{\text{bulk}} \) is the bulk energy per \( \text{Ni}_3\text{S}_2 \) unit, \( A \) is the surface area of one side of the slab, \( 2A \) is the total area of the two sides of the slab.

The computed lattice parameter \( a \) (cube edge length) was about 4.06 Å, and the calculated Ni-Ni and Ni-S bond lengths were 2.52/2.47 and 2.27/2.26 Å, respectively, all of which were in good agreement with their corresponding experimental values [1].

The surface energies of the surface-a, -b, and -c are calculated to be 1.41 J/m\(^2\), 1.57 J/m\(^2\) and 1.68 J/m\(^2\), respectively (Fig. S2). From the above surface energies, we can draw a conclusion that the relative stability trend of the three surfaces is predicted to be \( a > b > c \). Obviously, the surface-a is the most stable surface in the series of (11) surfaces.

1.2 Calculation on hydrogen evolution reaction

\( \Delta G_H \) of the hydrogen atom adsorbed on the surface can represent the HER activity. When the value of \( \Delta G_H \) is close to zero, an optimal HER activity can be achieved. At \( U=0 \), \( \Delta G_H \) can be calculated as follows.

\[ \Delta G_H = \Delta E_H + \Delta ZPE - T\Delta S_H \]

Where \( \Delta E_H \) is the absorption energy of \( \text{H}^* \), \( \Delta ZPE \) is the difference in zero-point energy between the adsorbed and the gas phase and \( \Delta S_H \) is the entropy change of hydrogen absorbed. Additionally, the formula \( \Delta S_H = S(\text{H}^*) - 1/2 S(\text{H}_2) \) is put forward to calculate \( \Delta S_H \), where the vibrational entropy of \( \text{H}^* \) is small enough, and \( S(\text{H}^*) \) can be neglected.
So $\Delta S_H \approx -1/2 \ S (H_2)$, where $S(H_2)$ is the entropy of $H_2$ in the gas phase at standard conditions. The $T S(H_2)$ is 0.4 eV at standard conditions, so $T \Delta S(H_2)$ is calculated to be -0.2 eV. The vibrational frequency of the adsorbed hydrogen atom was calculated by $\Delta ZPE = ZPE(H^\ast) - 1/2 ZPE(H_2)$, where $ZPE(H_2)$ is 0.27 eV.

In this work, we considered nine adsorption sites of $H^\ast$, involving S site (S), three Ni sites (Ni1-Ni3), five bonds (b1-b5) (as shown in Fig. 1b). After relaxation, six configurations were obtained with adsorption of $H^\ast$ at the S, Ni1-Ni2, b1 and b3 sites, as displayed in the Fig. S3.

1.3 Calculation on oxygen evolution reaction

Generally, OER procedure involves four electron transfer paths and can be depicted as follows $^{[2]}$:

$$H_2O \ (l) + ^\ast \rightarrow OH^\ast + (H^\ast + e\ ^\ast) \quad (1)$$
$$OH^\ast \rightarrow O^\ast + (H^\ast + e\ ^\ast) \quad (2)$$
$$O^\ast + H_2O \ (l) \rightarrow OOH^\ast + (H^\ast + e\ ^\ast) \quad (3)$$
$$OOH^\ast \rightarrow ^\ast + O_2 \ (g) + (H^\ast + e\ ^\ast) \quad (4)$$

In which $^\ast$, $O^\ast$, $OH^\ast$ and $OOH^\ast$ stand for an active site and adsorbed intermediates on the (11) surface, respectively. The reaction energies were calculated in each step as follows:

$$\Delta E_{OH^\ast} = E (OH^\ast) - E (^\ast) - (E_{H_2O} - 1/2E_{H_2}) \quad (5)$$
$$\Delta E_{O^\ast} = E (O^\ast) - E (^\ast) - (E_{H_2O} - E_{H_2}) \quad (6)$$
$$\Delta E_{OOH^\ast} = E (OOH^\ast) - E (^\ast) - (2E_{H_2O} - 3/2E_{H_2}) \quad (7)$$
$$\Delta E_{O_2} = E (O_2) - 2(E_{H_2O} - E_{H_2}) \quad (8)$$

Where $E (^\ast)$, $E (OH^\ast)$, $E (O^\ast)$ and $E (OOH^\ast)$ stand for the ground state energies of a clean surface and adsorbed surfaces with $HO^\ast$, $O^\ast$ and $HOO^\ast$, respectively. $E (O_2)$, $E (H_2)$ and $E (H_2O)$ are the ground state energies of $O_2$, $H_2$ and $H_2O$ molecules, respectively.

In order to find the rate determining step of OER from the above four steps, the adsorption free energies of $O^\ast$, $OH^\ast$ and $OOH^\ast$ were calculated by the expressions:

$$\Delta G_1 = \Delta E_{OH^\ast} + (\Delta ZPE - T \Delta S)_1 - eU \quad (9)$$
\[ \Delta G_2 = \Delta E_{O^*} + (\Delta ZPE - T\Delta S)_2 - eU \]  
\[ \Delta G_3 = \Delta E_{OOH^*} + (\Delta ZPE - T\Delta S)_3 - eU \]  
\[ \Delta G_4 = \Delta E_{O_2} + (\Delta ZPE - T\Delta S)_4 - eU \]

Where \( \Delta E \) is the reaction energy of reactants and products adsorbed on the surface, \( \Delta ZPE \) is the difference in zero-point energy between the reactants and products in the gas phase and \( \Delta S \) is the entropy change. The entropy for the adsorbed atoms/molecules at the surface active sites are neglected in the calculations. Moreover, an applied potential \( U \) is considered on each step and e is the charge transferred. Gas water at 0.035 bar can serve as the reference state because gas phase water at this pressure is in equilibrium with liquid water at 300 K. When two molecules of water are dissociated to form one molecule of \( O_2 \), the reaction free energy \( \Delta G \) is 4.92eV. An ideal catalyst should be able to facilitate water oxidation just above the equilibrium potential, and the equilibrium potential is defined as 1.23 eV (4.92/4). Additionally, examining the reaction free-energies of the four charge transfer steps can determine the overpotential of the OER processes, and we should find the minimum overpotential, resulting all charge transfer steps become downhill.

1.4 Mass measurement and calculation

The measurement and calculation details of the \( \text{Ni}_3\text{S}_2 \) loading mass are given as follows: The weight of a sample was measured using a Mettler Toledo XS205DU microbalance (0.01 mg sensitivity). Before weighing, all samples were thoroughly dried in a vacuum oven until the mass displayed no variation. The loading mass of the \( \text{Ni}_3\text{S}_2 \) active materials can be obtained by measuring the weight change of the samples before and after hydrothermal process and calculating according to the following formula: \(^{[3-5]}\)

\[ m = C* \left( m_2 - m_1 \right) \]

where \( m \) is the loading mass of the \( \text{Ni}_3\text{S}_2 \) active materials, \( m_1 \) is the mass of the Ni foam before hydrothermal process and \( m_2 \) is the mass of the sample after hydrothermal process, \( C \) is a constant which represents the molar mass ratio of \( M_{\text{Ni}_3\text{S}_2}/2M_S \) according to the reaction:

\[ 3\text{Ni} + 2\text{S} \rightarrow \text{Ni}_3\text{S}_2 \]
The mass loading of the Ni₃S₂ active materials in the work is ~2.06 mg/cm².

1.5 Evaluation on electrocatalytic performance.

The linear sweep voltammetry (LSV) curves for HER and OER were tested at a scan rate of 5 mV s⁻¹ with 95% iR correction. Electrochemical data were corrected for the uncompensated series resistance R, which was determined through fitting of AC impedance data to a modified Randles circuit. The value of R was 1.06 Ω in 1.0 M KOH. Electrochemical impedance spectra (EIS) were taken out at -0.2 V (vs. RHE) for the HER and 1.53 V (vs. RHE) for the OER, with a frequency range from 100 kHz to 0.1 Hz and a 5 mV AC dither. Cyclic voltammetric (CV) scanning was tested from 0 to -0.5 V vs RHE for HER or 1.2 to 1.8 V vs RHE for OER at a scan rate of 50 mV s⁻¹ for 6,000 cycles to investigate the long-term cycling stability. Besides, chronopotentiometric electrolysis of the working electrode was held at a constant current density of 10 mA cm⁻² for 50 hours for all relevant reactions: HER, OER and water splitting. The preparation method of the working electrodes containing the noble metal catalysts, such as Pt/C for HER and IrO₂ for OER, is stated as follows. Briefly, the electrocatalyst suspensions were prepared by sonication of a mixture of appropriate mass of noble metal electrocatalyst, Nafion solution (5 wt%) and 50/50 mix of deionized water and isopropyl alcohol for at least 1 h under ultrasonic to generate homogeneous ink. Next, the as-prepared catalyst ink was dropped onto the surface of the nickel foam, yielding an approximate catalyst loading of 2.06 mg cm⁻² and left to dry for the electrochemical tests.

The electrochemical active surface areas (ECSA) were estimated by cyclic voltammetry. In short, the double layer capacitance (C_{dl}) was used to indicate the active surface areas. The currents in a narrow potential window without faradaic processes were measured: OCP(Open Circuit Potential)±50 mV. Subsequently, the slope of half-current densities (Δj = j_a - j_c, at OCP) versus scan rates (10, 20, 30, 40, 50, 60, 70 mV s⁻¹) are fitted to estimate the C_{dl}. Then, the geometric double layer capacitance was easily calculated because C_{dl} is one half the slope value of the fitting line. Finally, the ECSA of catalyst is estimated from the double-layer capacitance according to the
equation:[9]

\[ \text{ECSA} = \frac{C_{dl}}{C_s} \times \text{ASA}, \]

where \( C_s \) is the specific capacitance of the sample, and ASA is the actual surface area of the electrode. In this work, the value of \( C_s \) is estimated to be 0.04 mF cm\(^{-2}\).

To estimate the Faradaic efficiency(\( \varepsilon \% \)) of self-supported Ni\(_3\)S\(_2\) electrode, the evolution of H\(_2\) and O\(_2\) gas was measured with a home-made graded cell at a constant current density of 5 mA cm\(^{-2}\). The quantity of produced H\(_2\) and O\(_2\) gas was determined by its volume. The theoretical yields of H\(_2\) and O\(_2\) were simply calculated using the equation as following,[10]

\[ V_{H_2} (\text{mL}) = \frac{Q (\text{C}) \times 22.4 (\text{L mol}^{-1}) \times 1000}{2 \times F (\text{C mol}^{-1})} \]
\[ V_{O_2} (\text{mL}) = \frac{Q (\text{C}) \times 22.4 (\text{L mol}^{-1}) \times 1000}{4 \times F (\text{C mol}^{-1})} \]

The Faradaic efficiency was estimated by comparing the amount of experimentally quantified volume of H\(_2\) and O\(_2\) gas with theoretically calculated gas volume.

S2. Analysis of the reactions during different hydrothermal processes
(1) 0.1 M thiourea solution as the hydrothermal medium:

\[
\text{(NH}_2\text{)}_2\text{CS}+2\text{H}_2\text{O} \rightarrow \text{H}_2\text{S}+\text{CO}_2+2\text{NH}_3 \quad \text{Eq. (S1)}
\]

\[
3\text{Ni}+2\text{H}_2\text{S} \rightarrow \text{Ni}_3\text{S}_2+2\text{H}_2 \quad \text{Eq. (S2)}
\]

(2) 0.1 M thioacetamide solution as the hydrothermal medium:

\[
\text{CH}_3\text{CSNH}_2+\text{H}_2\text{O} \rightarrow \text{H}_2\text{S}+\text{CH}_3\text{CONH}_2 \quad \text{Eq. (S3)}
\]

\[
3\text{Ni}+2\text{H}_2\text{S} \rightarrow \text{Ni}_3\text{S}_2+2\text{H}_2 \quad \text{Eq. (S4)}
\]

(3) 0.1 M Na\textsubscript{2}S solution as the hydrothermal medium:

\[
\text{S}^2-+\text{H}_2\text{O} \rightarrow \text{HS}^-+\text{OH}^- \quad \text{Eq. (S5)}
\]

\[
3\text{Ni}+2\text{HS}^-+\text{O}_2 \rightarrow \text{Ni}_3\text{S}_2+2\text{OH}^- \quad \text{Eq. (S6)}
\]
S3. Additional Figures and Tables

Figure S1. Digital photographs of the samples prepared by hydrothermally treating NF in 0.1 M thiourea solution or 0.1 M thioacetamide (TAA) solution at 150 °C for 3 h.
Figure S2. Side view of the possible surfaces for the (11) surfaces and their surface energies. S atoms are in yellow and Ni atoms are in blue.
Figure S3. (a) The possible adsorption sites of H* on the (11) surfaces and (b) the obtained structures of H* adsorbed on the (11) surfaces after relaxation.
**Figure S4.** Digital photographs of Ni foam before (left) and after (right) the hydrothermal treatment.
Figure S5. Digital photographs of samples (from left to right) were synthesized at different temperatures (150 °C, 160 °C, 180 °C) in 0.1 M Na₂S solution.
Figure S6. FE-SEM images of the blank Ni foam at different resolutions.
Figure S7. The survey spectrum of the Ni$_3$S$_2$/NF.
Figure S8. (a, b) TEM images of the Ni$_3$S$_2$/NF electrode.
Figure S9. Chronopotentiometric curve of Ni$_3$S$_2$/NF in 1 M KOH electrolyte at a current density of -10 mA cm$^{-2}$. 
Figure S10. (a) Home-made setup directly testing the amount of gas produced during electrolysis. (b) H₂ and O₂ gas produced.
Figure S11. The SEM images of Ni$_3$S$_2$/NF after 50 h stability test of (a, b) HER and (c, d) OER.
Figure S12. The XRD results of Ni$_3$S$_2$/NF after 50 h stability test of (a) HER and (b) OER.
Table S1. The values of ΔZPE, ZPE, ΔE and ΔG (H⁺) of H⁺ at the six adsorptions on the (11) surface.

<table>
<thead>
<tr>
<th>Surface</th>
<th>Adsorption site</th>
<th>ΔE (H⁺) /eV</th>
<th>ZPE (H⁺) /eV</th>
<th>ΔZPE (H⁺) /eV</th>
<th>ΔG (H⁺) /eV</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td></td>
<td>1.037</td>
<td>0.178</td>
<td>0.043</td>
<td>1.280</td>
</tr>
<tr>
<td>Ni1</td>
<td></td>
<td>-0.086</td>
<td>0.149</td>
<td>0.014</td>
<td>0.128</td>
</tr>
<tr>
<td>(11)</td>
<td>Ni2</td>
<td>0.390</td>
<td>0.170</td>
<td>0.035</td>
<td>0.625</td>
</tr>
<tr>
<td></td>
<td>b1</td>
<td>0.117</td>
<td>0.171</td>
<td>0.036</td>
<td>0.353</td>
</tr>
<tr>
<td></td>
<td>b3</td>
<td>0.903</td>
<td>0.156</td>
<td>0.021</td>
<td>1.124</td>
</tr>
</tbody>
</table>
Table S2. Comparison of the HER electrocatalytic performance of the as-prepared Ni$_3$S$_2$ material in this work with those of some previous reported materials.

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Catalysts</th>
<th>Mass loading (mg cm$^{-2}$)</th>
<th>$\eta_{10}$ (mV vs. RHE)</th>
<th>Tafel slope (mV dec$^{-1}$)</th>
<th>Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Our work</strong></td>
<td>Ni$_3$S$_2$</td>
<td>2.06</td>
<td>189</td>
<td>89.3</td>
<td>6000 cycles /50 h</td>
</tr>
<tr>
<td>[12]</td>
<td>Ni$_3$S$_2$</td>
<td>--</td>
<td>271</td>
<td>156.5</td>
<td>5000 cycles</td>
</tr>
<tr>
<td>[13]</td>
<td>Ni$_3$S$_2$</td>
<td>--</td>
<td>198</td>
<td>121</td>
<td>500 cycles /20 h</td>
</tr>
<tr>
<td>[14]</td>
<td>Ni$_3$S$_2$</td>
<td>--</td>
<td>300</td>
<td>100</td>
<td>3000 cycles</td>
</tr>
<tr>
<td>[15]</td>
<td>Ni$_3$S$_2$</td>
<td>0.6</td>
<td>240</td>
<td>152</td>
<td>10000 cycles</td>
</tr>
<tr>
<td>[16]</td>
<td>Ni$_3$S$_2$</td>
<td>--</td>
<td>260</td>
<td>95</td>
<td>--</td>
</tr>
<tr>
<td>[17]</td>
<td>Ni$_3$S$_2$</td>
<td>--</td>
<td>272</td>
<td>329</td>
<td>--</td>
</tr>
<tr>
<td>[18]</td>
<td>Ni$_3$S$_2$</td>
<td>0.52</td>
<td>189</td>
<td>125.7</td>
<td>--</td>
</tr>
<tr>
<td>[19]</td>
<td>Ni$_3$S$_2$</td>
<td>3.7</td>
<td>318(20)</td>
<td>151</td>
<td>--</td>
</tr>
<tr>
<td>[20]</td>
<td>Ni$_3$S$_2$</td>
<td>1.73</td>
<td>339</td>
<td>128</td>
<td>--</td>
</tr>
<tr>
<td>[21]</td>
<td>Ni$_3$S$_2$-GQDs</td>
<td>8.0</td>
<td>274</td>
<td>138.3</td>
<td>--</td>
</tr>
<tr>
<td>[22]</td>
<td>Ni$_3$S$_2$</td>
<td>--</td>
<td>242</td>
<td>87</td>
<td>--</td>
</tr>
<tr>
<td>[23]</td>
<td>Ni$_3$S$_2$</td>
<td>0.28</td>
<td>335</td>
<td>97</td>
<td>20 h</td>
</tr>
<tr>
<td>[24]</td>
<td>Ni$_9$S$_8$</td>
<td>11.04</td>
<td>230</td>
<td>123.3</td>
<td>24 h</td>
</tr>
<tr>
<td>[25]</td>
<td>Ni$_3$S$_2$</td>
<td>1.6</td>
<td>223</td>
<td>--</td>
<td>20 h</td>
</tr>
</tbody>
</table>
Table S3. Comparison of the OER electrocatalytic performance of the as-prepared Ni$_3$S$_2$ material in this work with those of some previous reported materials.

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Catalysts</th>
<th>Mass loading (mg cm$^{-2}$)</th>
<th>$\eta_{10}$ (mV vs. RHE)</th>
<th>Tafel slope (mV dec$^{-1}$)</th>
<th>Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Our work</td>
<td>Ni$_3$S$_2$</td>
<td>2.06</td>
<td>296</td>
<td>65.1</td>
<td>50 h</td>
</tr>
<tr>
<td>[26]</td>
<td>Ni$_3$S$_2$</td>
<td>4.6</td>
<td>287</td>
<td>82</td>
<td>5000 cycles</td>
</tr>
<tr>
<td>[14]</td>
<td>Ni$_3$S$_2$</td>
<td>--</td>
<td>400</td>
<td>51</td>
<td>500 cycles /20 h</td>
</tr>
<tr>
<td>[27]</td>
<td>Ni$_3$S$_2$@G</td>
<td>--</td>
<td>300</td>
<td>80</td>
<td>--</td>
</tr>
<tr>
<td>[28]</td>
<td>Ni$_3$S$_2$</td>
<td>--</td>
<td>380(20)</td>
<td>188.4</td>
<td>--</td>
</tr>
<tr>
<td>[20]</td>
<td>Ni$_3$S$_2$</td>
<td>1.73</td>
<td>290</td>
<td>134</td>
<td>10000 cycles</td>
</tr>
<tr>
<td>[21]</td>
<td>Ni$_3$S$_2$-GQDs</td>
<td>8.0</td>
<td>300</td>
<td>115.2</td>
<td>12 h</td>
</tr>
<tr>
<td>[29]</td>
<td>Ni$_3$S$_2$</td>
<td>--</td>
<td>420(100)</td>
<td>162</td>
<td>--</td>
</tr>
<tr>
<td>[17]</td>
<td>MoS$_2$@Ni$_3$S$_2$</td>
<td>0.52</td>
<td>310</td>
<td>114</td>
<td>----</td>
</tr>
<tr>
<td>[24]</td>
<td>Ni$_3$S$_8$</td>
<td>11.04</td>
<td>340</td>
<td>150</td>
<td>24 h</td>
</tr>
<tr>
<td>[30]</td>
<td>Ni$_3$P$_5$</td>
<td>3</td>
<td>295</td>
<td>--</td>
<td>1000 cycles</td>
</tr>
<tr>
<td>[31]</td>
<td>Ni$_3$S$_2$</td>
<td>--</td>
<td>340</td>
<td>150</td>
<td>20 h</td>
</tr>
<tr>
<td>[32]</td>
<td>ALD NiS$x$</td>
<td>--</td>
<td>372</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>[33]</td>
<td>NiS</td>
<td>43</td>
<td>335(20)</td>
<td>89</td>
<td>1000 cycles/20 h</td>
</tr>
</tbody>
</table>


Table S4. Comparison of electrocatalytic performance of Ni$_3$S$_2$/NF with recently reported bifunctional electrocatalysts for overall water splitting in basic electrolyte (1 M KOH).

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Catalysts</th>
<th>Current density (mA cm$^{-2}$)</th>
<th>Applied voltage (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Our work</strong></td>
<td>Ni$_3$S$_2$</td>
<td>10</td>
<td><strong>1.55</strong></td>
</tr>
<tr>
<td>[34]</td>
<td>NiCo$_2$S$_4$</td>
<td>10</td>
<td>1.61</td>
</tr>
<tr>
<td>[17]</td>
<td>Mo-W-S-2@Ni$_3$S$_2$</td>
<td>10</td>
<td>1.62</td>
</tr>
<tr>
<td>[35]</td>
<td>N-Ni$_3$S$_2$/VS$_2$</td>
<td>10</td>
<td>1.65</td>
</tr>
<tr>
<td>[36]</td>
<td>MoS$_2$/Ni$_3$S$_2$</td>
<td>10</td>
<td>1.56</td>
</tr>
<tr>
<td>[37]</td>
<td>Ni$_3$Se$_2$</td>
<td>10</td>
<td>1.61</td>
</tr>
<tr>
<td>[24]</td>
<td>Ni/Ni$_9$S$_8$</td>
<td>10</td>
<td>1.61</td>
</tr>
<tr>
<td>[38]</td>
<td>NiCo$_2$S$_4$</td>
<td>10</td>
<td>1.63</td>
</tr>
<tr>
<td>[33]</td>
<td>NiS</td>
<td>10</td>
<td>1.64</td>
</tr>
<tr>
<td>[39]</td>
<td>NiCo$_2$S$_4$</td>
<td>10</td>
<td>1.65</td>
</tr>
<tr>
<td>[25]</td>
<td>Ni$_3$S$_2$</td>
<td>10</td>
<td>1.6</td>
</tr>
<tr>
<td>[40]</td>
<td>NiSe</td>
<td>10</td>
<td>1.63</td>
</tr>
<tr>
<td>[41]</td>
<td>NiFe LDH</td>
<td>10</td>
<td>1.7</td>
</tr>
</tbody>
</table>
References


[27] Q. C. Dong, Y. Z. Zhang, Z. Y. Dai, P. Wang, M. Zhao, J. J. Shao, W. Huang, X. C. Dong, Graphene as an intermediary for enhancing the electron transfer rate: A free-standing Ni$_3$S$_2$@graphene@Co$_9$S$_8$ electrocatalytic electrode for oxygen evolution reaction, Nano Res. 11 (2018) 1389-1398.


