Electronic Supplementary Material

NiFeRuO$_x$ nanosheets on Ni foam as an electrocatalyst for efficient overall alkaline seawater splitting

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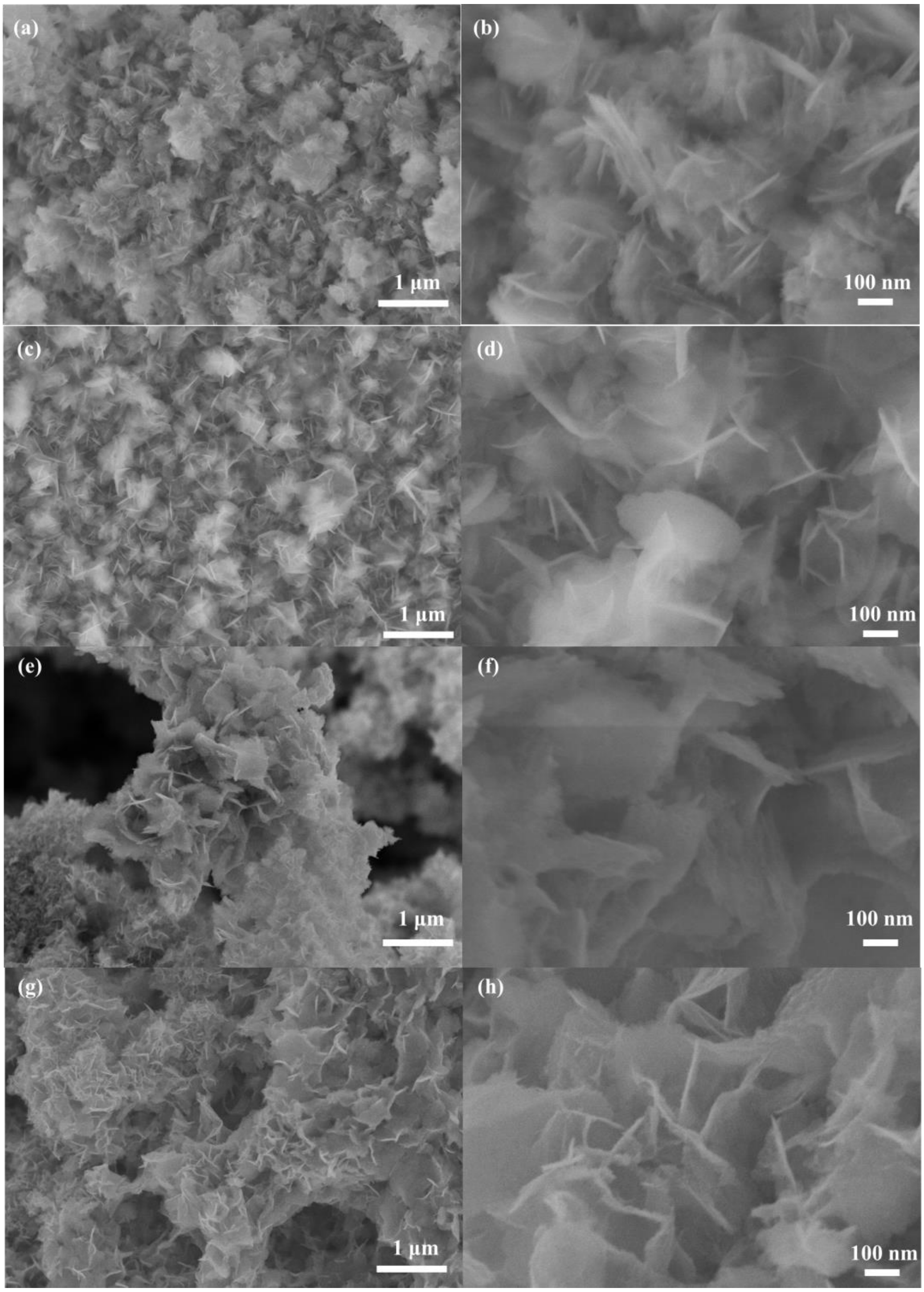

Fig. S1 Morphologies of NiFeRuO$_x$/NF (a, b) without calcination, calcined at (c, d) 250 °C, (e, f) 300 °C and (g, h) 350 °C with different magnifications.

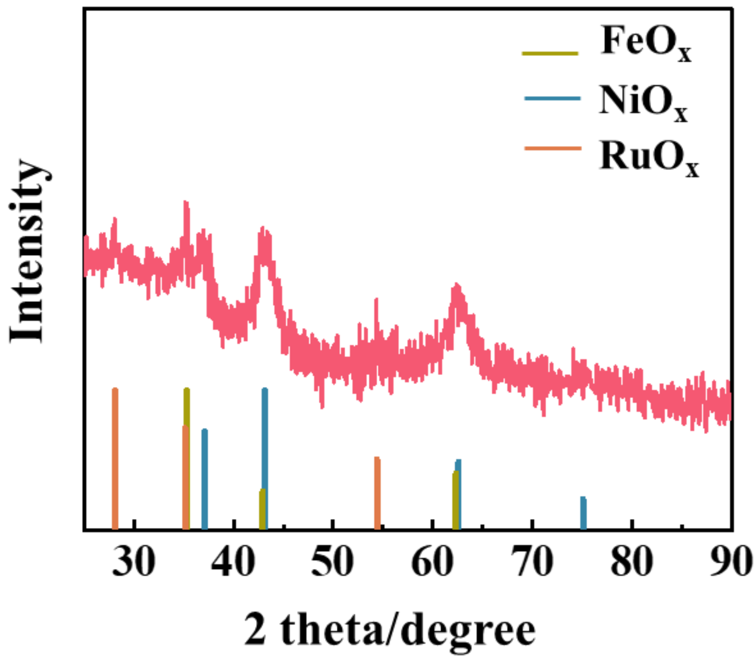

Fig. S2 The XRD pattern of as-synthesized NiFeRuO$_x$ without NF.

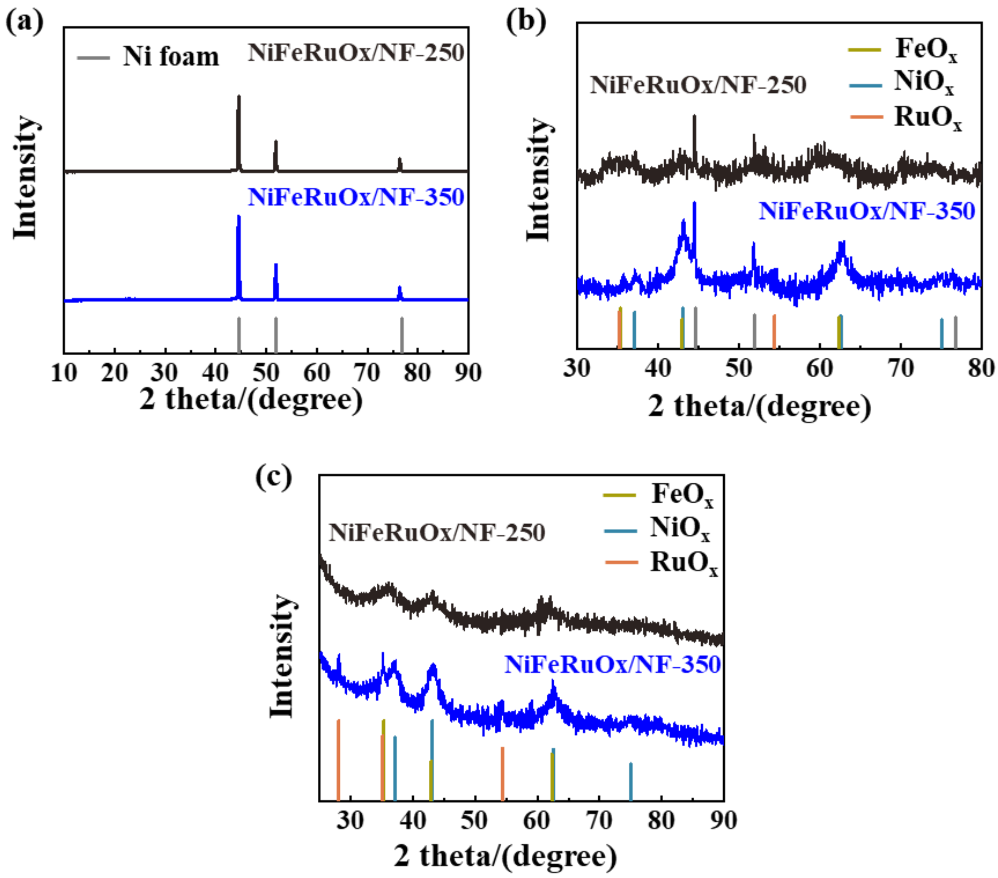

Fig. S3 The XRD patterns of samples calcined at 250 °C and 350 °C. (a) NiFeRuO$_x$/NF (b) materials scraped from the foam (c) without NF.

Table S1 The metal contents in NiFeRuO$_x$/NF detected by ICP-AES.

Ru content/mg L^{-1}	Fe content/mg L^{-1}	Ni content/mg L^{-1}	Ru/(Ru+Fe+Ni) atomic ratio
29.5	29.0	861.3	1.9%

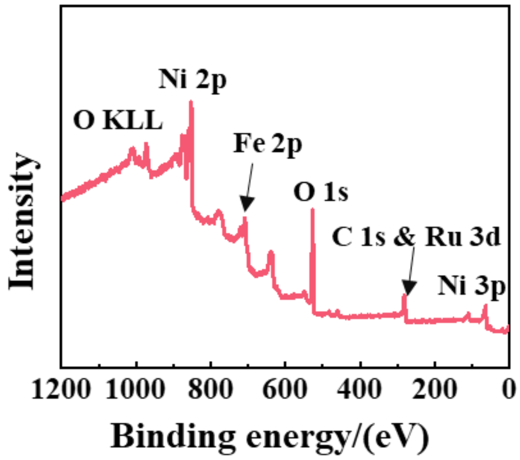

Fig. S4 Wide-scanning XPS spectrum of NiFeRuO$_x$/NF.

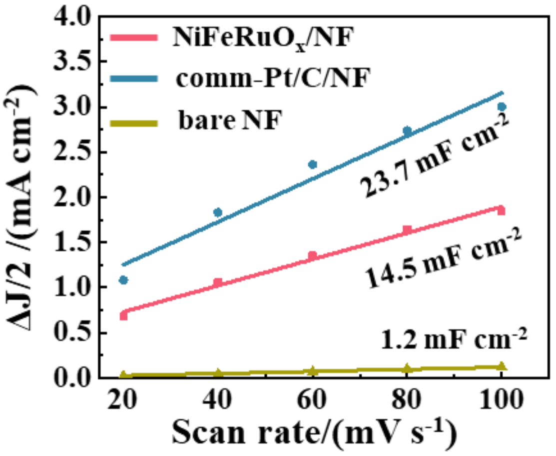

Fig. S5 The C_{dl} of NiFeRuO$_x$/NF, commercial Pt/C/NF and bare NF for HER.

The C_{dl} were obtained from the linear relationship between the capacitive current (ΔJ) and scan rates.

For the calculation of ECSA, the value of specific capacitance for a flat surface (1 cm^2) is assumed as 40 μF cm^{-2}. Note that NF was used as the support and its specific capacitance is much larger than that of a flat surface. Therefore, here the NF was considered as the standard [1]. The ECSA is calculated according to the following equation [2, 3]:

$$A_{ECSA} = \frac{C_{dl} - electrocatalyst\ (mF\ cm^{-2})}{C_{dl} - bare\ Ni\ foam\ (mF\ cm^{-2})\ per\ ECSA\ (cm^{-2})}$$

Taking $NiFeRuO_x$/NF as an example, upon the HER, it can be calculated as:

$$A_{ECSA} = \frac{14.5\ mF\ cm^{-2}}{1.2\ mF\ cm^{-2}\ per\ ECSA} = 12.1\ cm^2_{ECSA}$$

Tab.S2 The ECSA values of electrocatalysts normalized by C_{dl}.

ECSA for HER/(cm^2_{ECSA})	NiFeRuOx/NF	commercial PtC/NF	bare NF
	12.1	19.7	1
ECSA for OER/(cm^2_{ECSA})	**NiFeRuOx/NF**	**commercial RuO_2/NF**	**bare NF**
	3.4	1.5	1

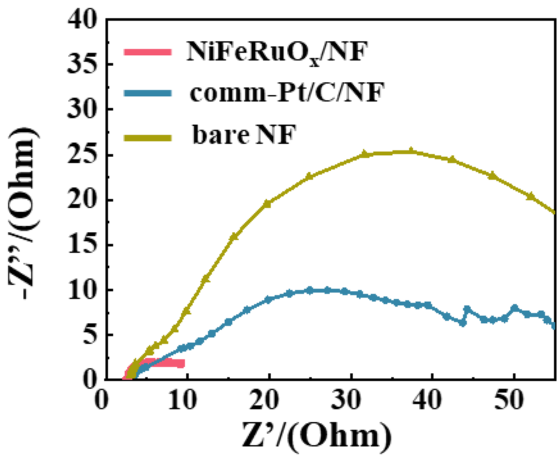

Fig.S6 Nyquist plots of $NiFeRuO_x$/NF, commercial Pt/C/NF and bare NF for HER.

Tab.S3 The mass content of Ru in $NiFeRuO_x$/NF and Pt commercial Pt/C/NF.

	NiFeRuOx/NF	commercial PtC/NF
Mass content of Ru or Pt	0.472 mg	0.2 mg

According to ICP, the mass of Ru in $NiFeRuO_x$/NF (1 * 1 cm^2) is calculated to 0.472 mg.

According to the preparation of commercial Pt/C/NF (in 2.4 Electrochemical measurements), the mass of Pt loaded on the NF was 0.2 mg (5 mg/mL * 200 μL * 20 wt.%). Considering the price of Ru is about 1/3 of Pt [4], we can estimate the price of Pt in commercial Pt/C/NF is 1.27 times as much as that of Ru in $NiFeRuO_x$/NF. Moreover, $NiFeRuO_x$/NF could perform as a bifunctional electrocatalyst in alkaline simulated seawater.

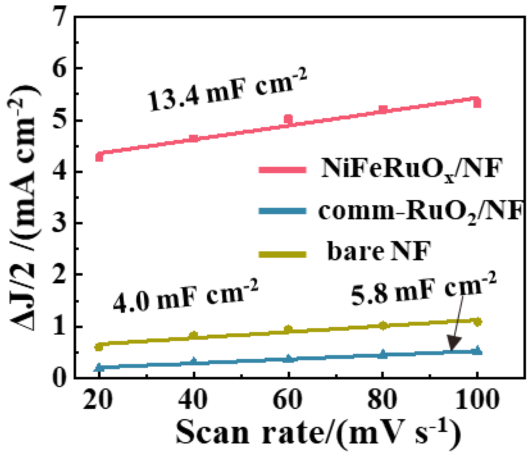

Fig.S7 The C_{dl} of $NiFeRuO_x$/NF, commercial RuO_2/NF and bare NF for OER.

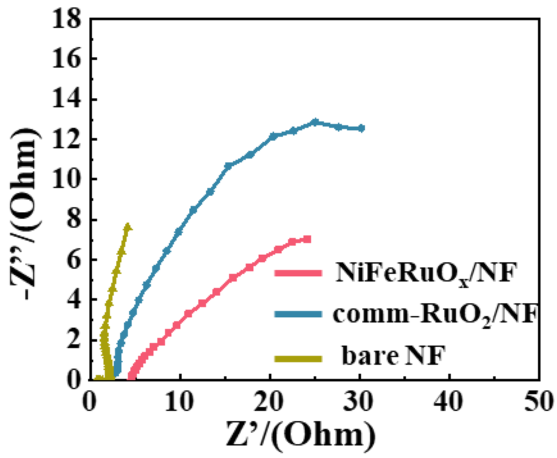

Fig.S8 Nyquist plots of $NiFeRuO_x$/NF, commercial RuO_2/NF and bare NF for OER.

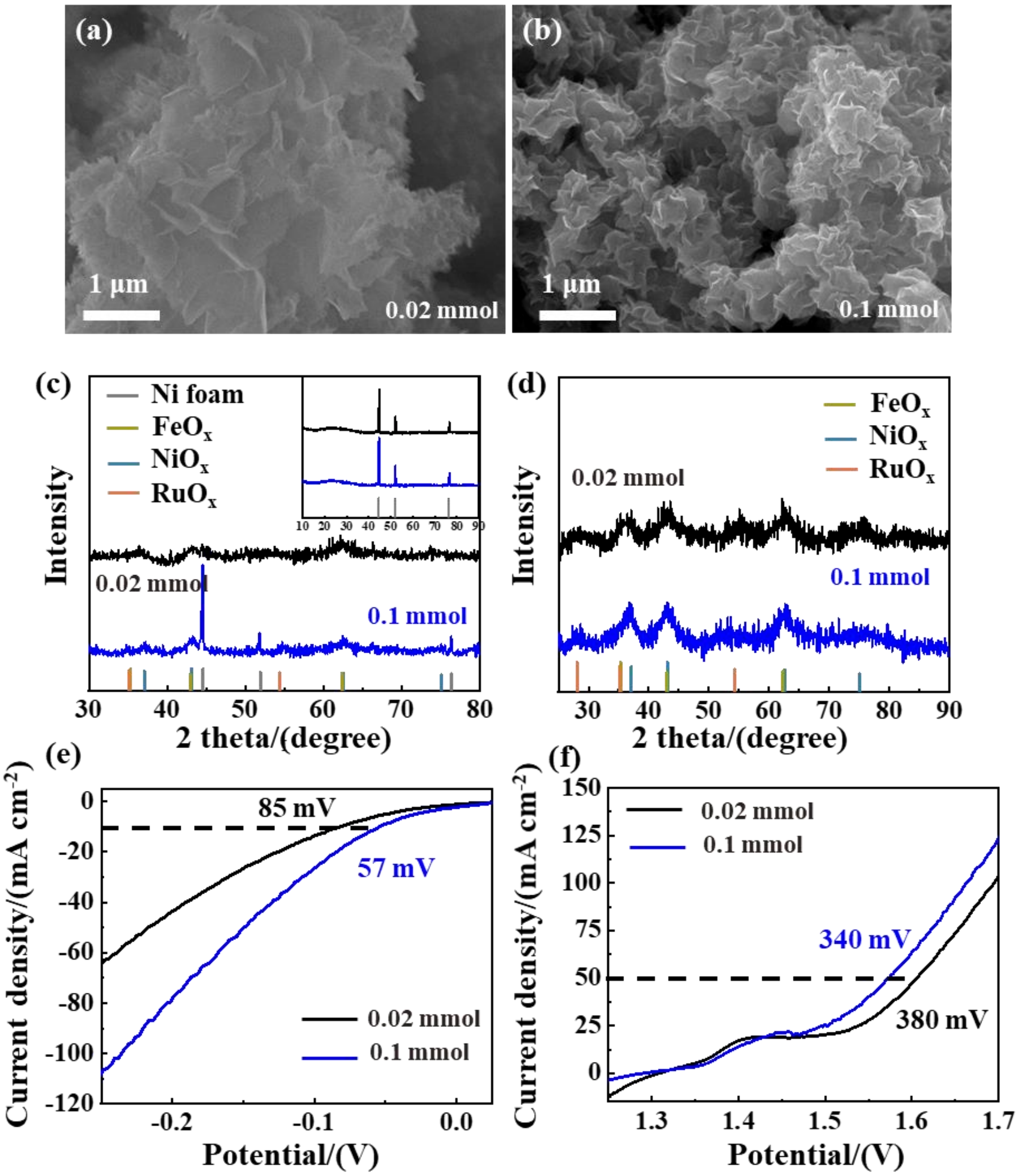

Fig.S9 (a, b) SEM images of 0.02 mmol and 0.1 mmol samples. (c) The XRD patterns of materials scraped from 0.02 mmol and 0.1 mmol samples. Inserted is the samples on NF. (d) The XRD patterns of 0.02 mmol and 0.1 mmol samples without NF. (e) HER and (f) OER polarization curves of 0.02 mmol and 0.1 mmol samples.

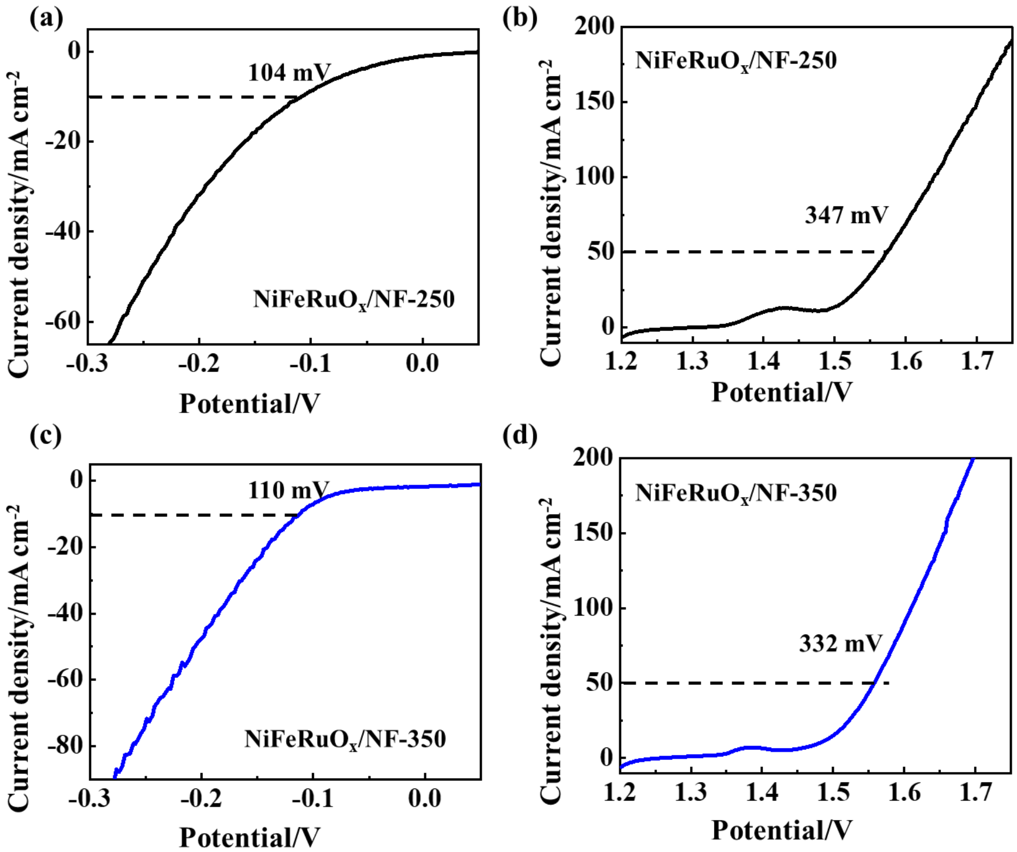

Fig.S10 (a) HER and (b) OER polarization curves of NiFeRuO$_x$/NF calcined at 250 °C. (c) HER and (b) OER polarization curves of NiFeRuO$_x$/NF calcined at 350 °C.

Tab.S4 Comparison of the electrocatalytic overall water splitting activity of the NiFeRuO$_x$/NF with the reported electrocatalysts in alkaline media.

Catalysts	Electrolytes	Cell voltage/V at 10 mA cm^{-2}	References
NiFeRuO$_x$/NF	**1 M KOH+3.5 wt.%NaCl**	**1.53**	**This work**
Ru_2Ni_2 SNs/C	1 M KOH	1.58	Nano Energy, 2018, 47, 1-7
Ru_1Ni_1 -NCNFs	1 M KOH	1.564	Adv. Sci., 2020, 7, 1901833
RuCo NSs	1 M KOH	1.524	Adv. Energy Mater., 2020, 2002860
Ru/NiFe LDH-F	1 M KOH	1.53	Nanoscale, 2020, 12, 9669-9679
Ru-CoMo/CFP	1 M KOH	1.54	Appl. Surf. Sci., 2021, 541, 148518
RuCoOx	1 M KOH	1.54	Nano Lett., 2021, 21, 9633−9641
NiMoRuO	1 M KOH	1.56	Chem. Eng. J., 2021, 420, 127686
Ru–$NiSe_2$/NF	1 M KOH	1.537	Small, 2022, 18, 2105305
RuO_2-C-300	1 M KOH	1.52	Small, 2022, 18, 2203778
1D-Cu@Co-CoO/Rh	1 M KOH	1.60	Small, 2021, 17, 2103826

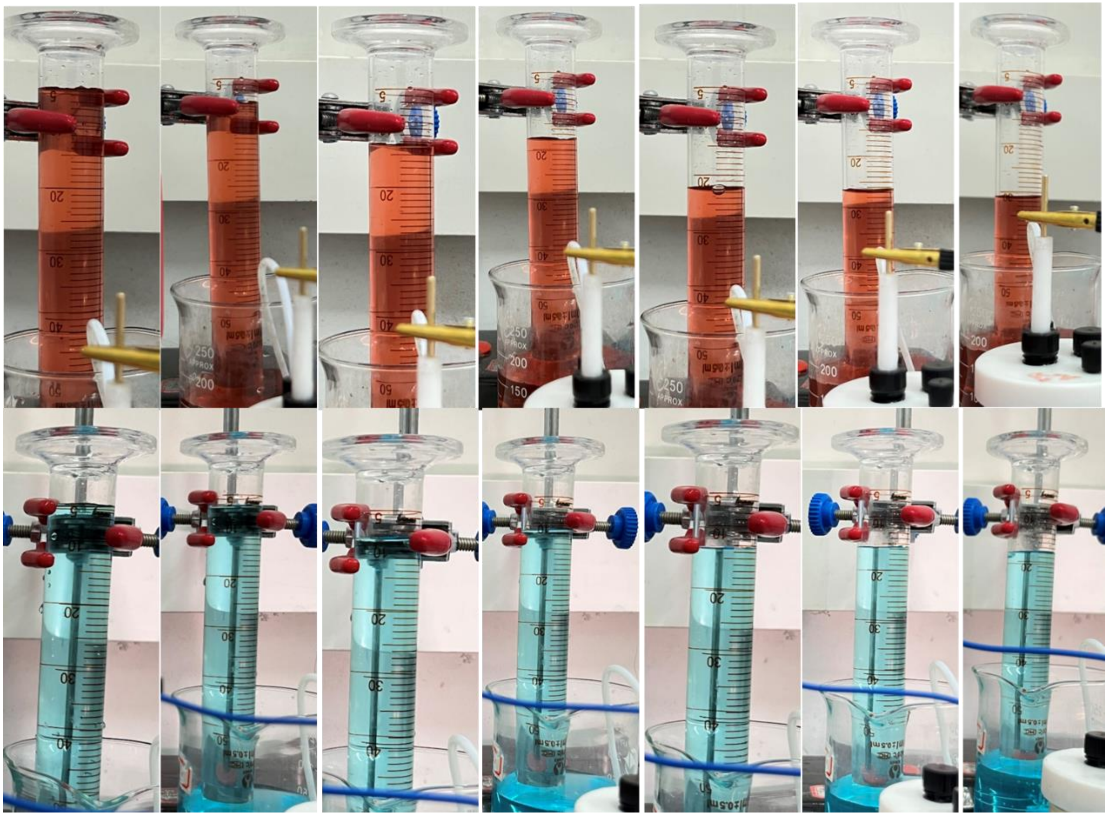

Fig.S11 Experimentally collected H_2 (top) and O_2 (bottom) at different times of 0, 10, 20, 30, 40, 50, 60 min.

Tab.S5 The metal contents in $NiFeRuO_x$/NF after OER stability test detected by ICP-AES.

Ru content/mg L^{-1}	Fe content/mg L^{-1}	Ni content/mg L^{-1}	Ru/(Ru+Fe+Ni) atomic ratio
22.8	21.9	834.0	1.5%

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2. Sun X, Shao Q, Pi Y, Guo J, Huang X. A general approach to synthesise ultrathin NiM (M = Fe, Co, Mn) hydroxide nanosheets as high-performance low-cost electrocatalysts for overall water splitting. Journal of Materials Chemistry A, 2017, 5(17): 7769-7775
3. Yang Y Q, Zhang K, Ling H L, Li X, Chan H C, Yang L C, Gao Q S. MoS_2-Ni_3S_2 heteronanorods as efficient and stable bifunctional electrocatalysts for overall water splitting. ACS Catalysis, 2017, 7(4): 2357-2366
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