Electronic Supplementary Information (ESI)

Low-content CeO_x dually promoted Ni_3Fe@CNTs electrocatalyst for overall water splitting

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Fig. S1

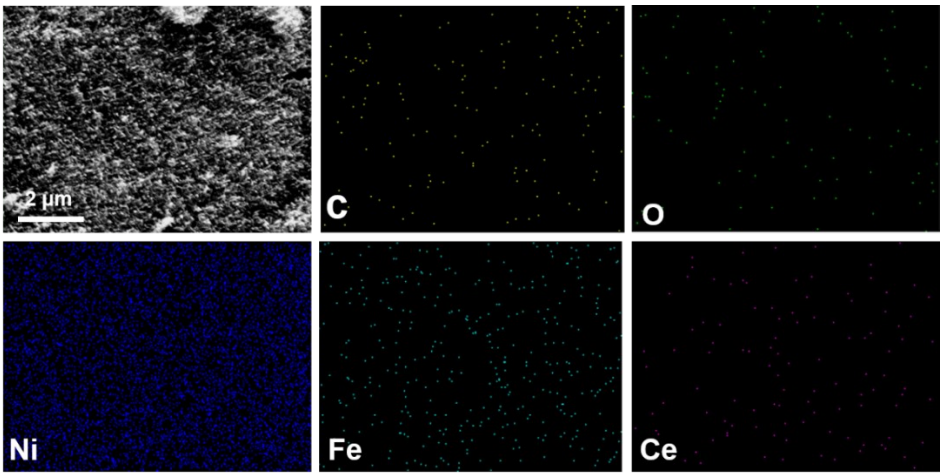

Fig. S1 SEM image of the Ni_3Fe@CNTs/CeO_x/NF composites and the corresponding EDS elements mappings of C, O, Ni, Fe and Ce elements.

Fig. S2

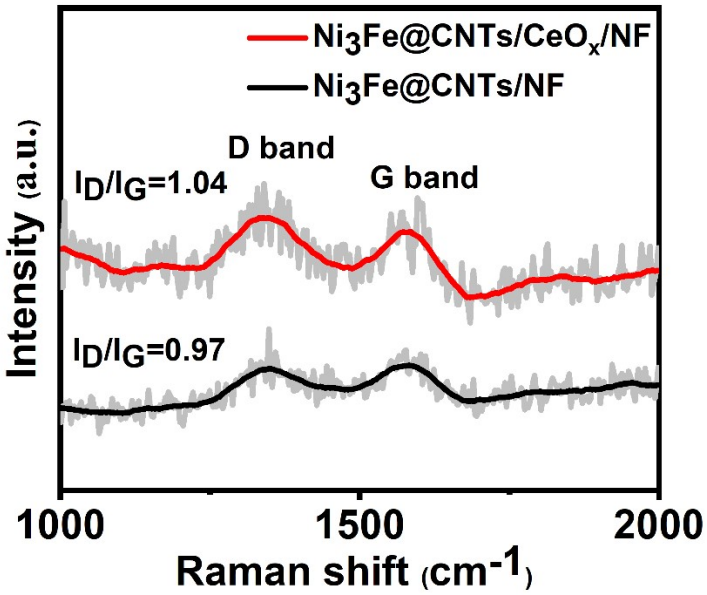

Fig. S2 Raman spectra of Ni_3Fe@CNTs/CeO_x/NF and Ni_3Fe@CNTs/NF.

Fig. S3

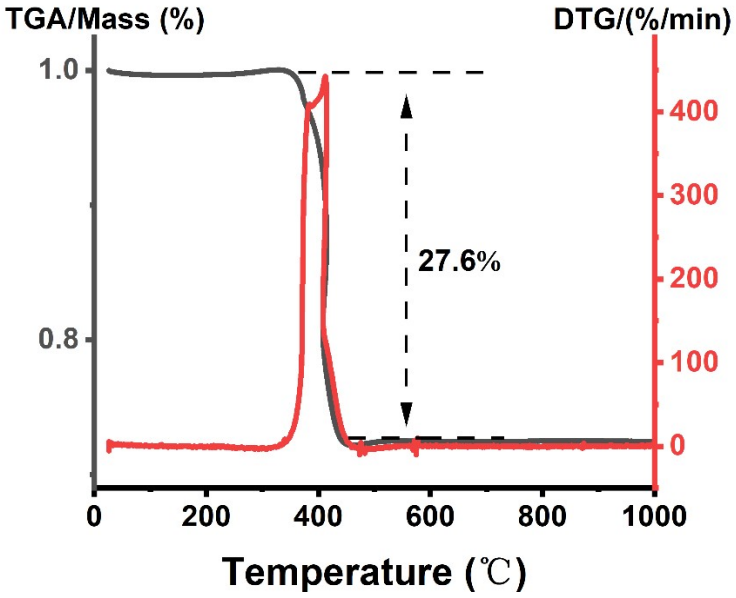

Fig. S3 Thermogravimetric analysis and derivative thermogravimetry (TGA/DTG) of the Ni_3Fe@CNTs/CeO_x/NF composite.

Fig. S4

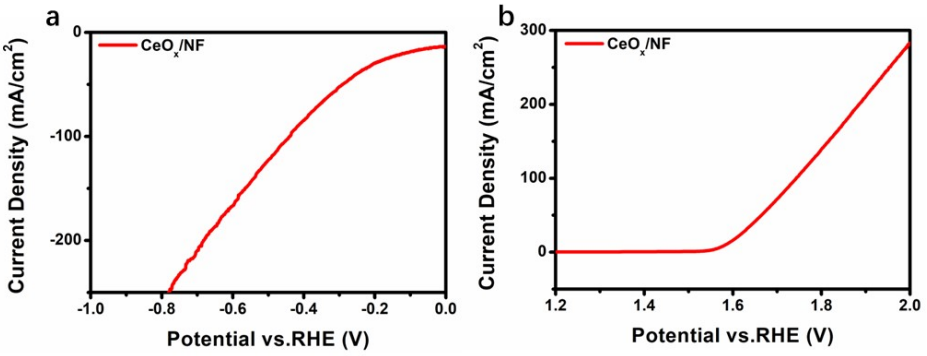

Fig. S4 LSV curve for CeO_x/NF: (a) The HER performance (b) The OER performance

Fig. S5

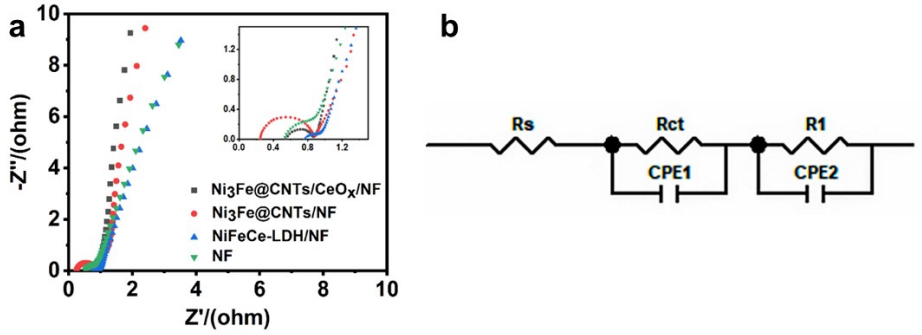

Fig. S5 (a) Electrochemical impedance spectra for the OER between Ni_3Fe@CNTs/CeO_x/NF, Ni_3Fe@CNTs/NF, together with NiFeCe-LDH/NF and NF for comparison; (b) the equivalent circuit diagram of Ni_3Fe@CNTs/CeO_x/NF.

Fig. S6

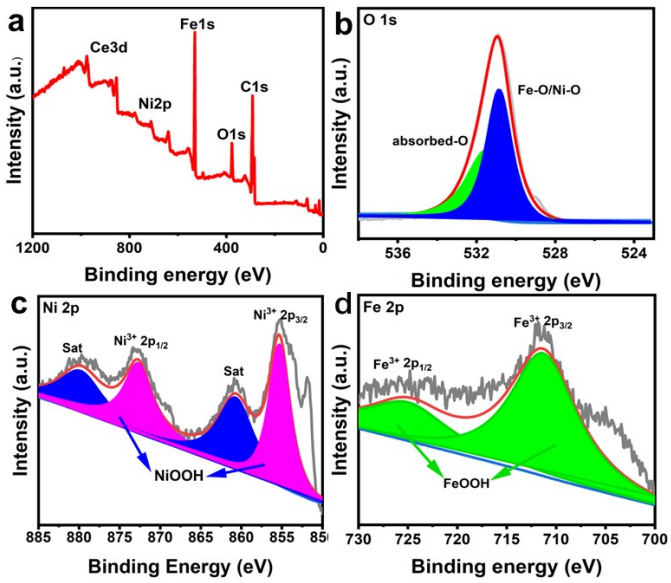

Fig. S6 XPS spectra of the Ni_3Fe@CNTs/CeO_x/NF composite after the OER testing: (a) a full spectrum, (b) O 1s, (c) Ni 2p, and (d) Fe 2p.

Fig. S7

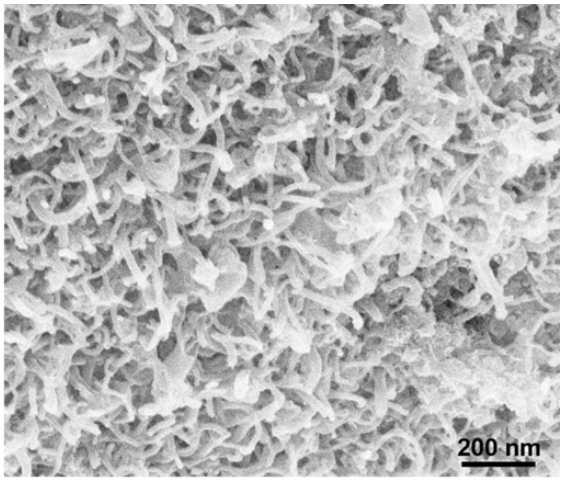

Fig. S7 SEM of Ni_3Fe@CNTs/CeO_x/NF after OER test.

Fig. S8

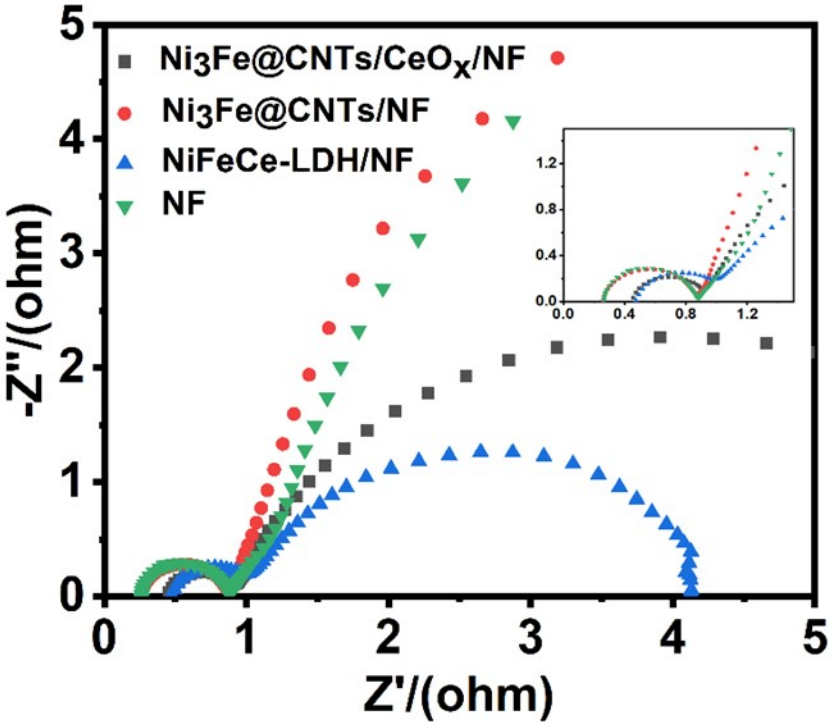

Fig. S8 Electrochemical impedance spectra of Ni_3Fe@CNTs/CeOx/NF and Ni_3Fe@CNTs/NF for the HER, together with NiFeCe-LDH/NF and NF for comparison.

Fig. S9

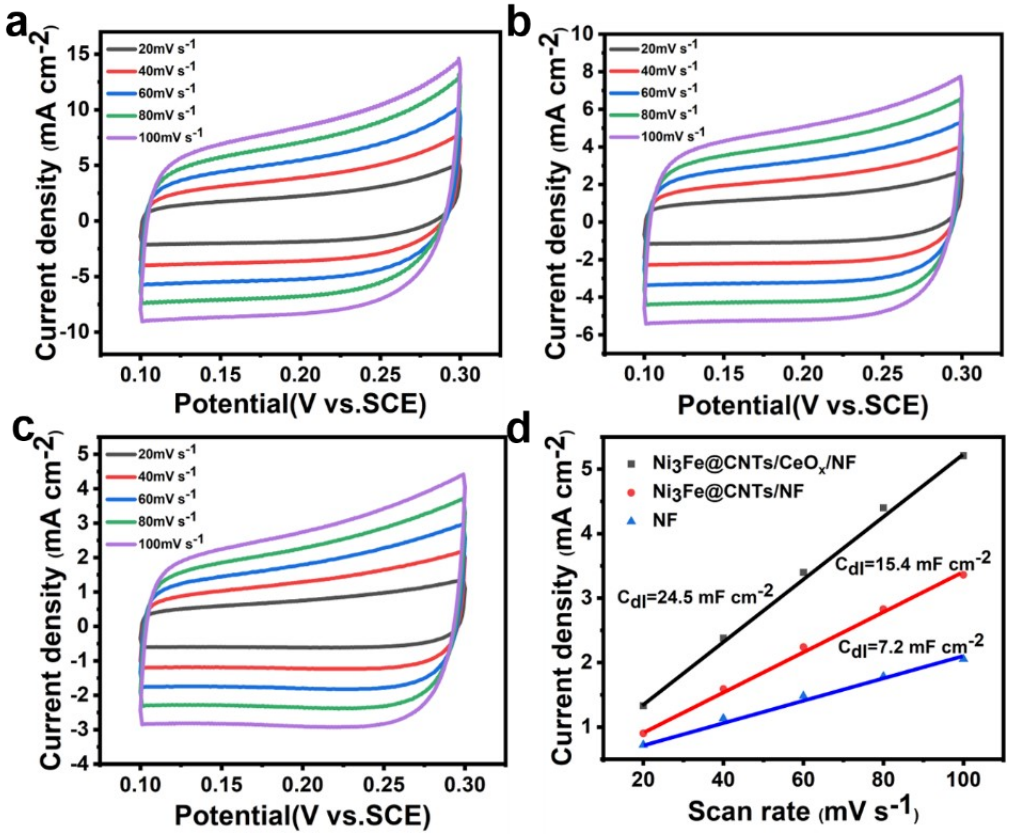

Fig.S9 Cyclic voltammograms (CVs) for (a) Ni_3Fe@CNTs/CeO_x/NF, (b) Ni_3Fe@CNTs/NF, (c) NF measured at sweep speeds from 20 to 100 mV s^{-1} and (d) the current densities at 0.15 V vs. SCE plotted as a function of scan rates.

Fig. S10

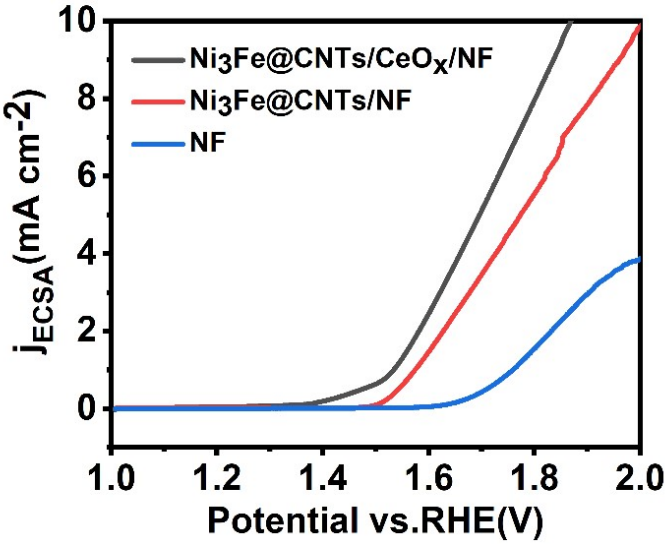

Fig. S10 The OER LSV curves normalized by ECSA for Ni_3Fe@CNTs/CeO_x/NF, Ni_3Fe-CNTs/NF, and NF.

Table S1

The ICP-OES result of Ni, Fe and Ce in the Ni_3Fe/CeO_x-CNTs.

Element	Mass fraction（wt.%）	Mole fraction
Ni	19.29	3.28
Fe	5.33	0.95
Ce	1.34	0.09

Table S2

Comparison Rct between Ni_3Fe@CNTs/CeO_x/NF, Ni_3Fe@CNTs/NF, and NF for the OER.

Catalyst	Ni_3Fe@CNTs/CeO_x/NF	Ni_3Fe@CNTs/NF	NF
Rct /Ω	0.27	0.60	1.73

Table S3

Comparison of OER performance at 10 mA cm^{-2} between the Ni_3Fe@CNTs/CeO_x composite and those Ni_3Fe-based electrocatalysts reported previously (in 1.0 M KOH solution).

Catalysts	Overpotential (mV)	Long-term stability (h)	References
Ni_3Fe-NC/NF	203	110	*J. Mater. Chem. A, 2023, 11, 6452*
Fe_4Ni-Se/NF	207	70	*J. Electroanal. Chem., 2022, 906, 116014*
Hollow $FeNi_3N$	210	30	*J. Mater. Chem. A, 2021, 9, 7750*
$Fe_{0.2}Ni_{0.8}$/NC	270	12	*Chem. Eng. J., 2020, 394, 124977*
Fe-enriched-$FeNi_3$/NC	300	3000 cycles	*J. Colloid Interface Sci., 2021, 582, 977*
Ni_3Fe@B-doped carbon	280	20	*J. Alloys Compd., 2020, 835, 155267*
Ni_3FeN/Ni_3Fe	250	2000 cycles	*J. Mater. Chem. A, 2021, 9, 4036*
Ni_3Fe/N-C	330	10	*Carbon, 2021, 174, 475*
$FeNi_3$@NC	277	20	*Appl. Catal. B, 2020, 268, 118729*
Ni_3Fe-CW	237	50	*Chem. Eng. J., 2022, 439, 135722*
Ni_3Fe@CNTs/CeO_x	195	100	**This work**

Table S4

Comparison of HER performance at 10 mA cm^{-2} between the Ni_3Fe@CNTs/CeO_x composite and those Ni_3Fe-based electrocatalysts reported previously (in 1.0 M KOH solution).

Catalysts	Overpotential (mV)	Long-term stability (h)	References
Fe_4Ni-Se/NF	93	70	*J. Electroanal. Chem., 2022, 906, 116014*
(Ni, Fe)S_2@MoS2	130	44	*Appl. Catal. B Environ., 2019, 247, 107*
Hollow $FeNi_3N$	185	30	*J. Mater. Chem. A, 2021, 9, 7750*
$Ni_3Fe/NiFe_2O_4$ NPs@CNT	128	40	*ACS Appl. Mater. Interfaces 2020, 12, 50, 55782*
Fe-Ni@NC-CNTs	202	11	*Angew. Chem. Int. Ed., 2018, 57, 8921*
Ni_3Fe@BC	330	20	*J. Alloys Compd., 2020, 835, 155267*
Ni_3FeN/Ni_3Fe	125	2000 cycles	*J. Mater. Chem. A, 2021, 9, 4036*
$Ni_3Fe(OH)_9/Ni_3Fe$	217	12	*ACS Appl. Energy Mater. 2018, 1, 3, 986-992*
Ni_3Fe-CW	76	50	*Chem. Eng. J., 2022, 439, 135722*
Ni_3Fe-NC/NF	98	110	*J. Mater. Chem. A, 2023, 11, 6452*
Ni_3Fe@CNTs/CeO_x	125	100	**This work**

Table S5

Comparison of electrocatalytic performance as the electrolyzer at 10 mA cm^{-2} between the Ni_3Fe@CNTs/CeO_x composite and those Ni_3Fe-based electrocatalysts reported previously (in 1.0 M KOH solution).

Catalysts	Overall voltage (V)	References
Ni_3Fe-NC/NF	1.49	*J. Mater. Chem. A, 2023, 11, 6452*
S–Fe–Ni/NF	1.49	*J. Mater. Chem. A, 2023, 11, 4661–4671*
Fe_4Ni-Se/NF	1.55	*J. Electroanal. Chem., 2022, 906, 116014*
Hollow $FeNi_3N$	1.63	*J. Mater. Chem. A, 2021, 9, 7750*
$Ni_3Fe/NiFe_2O_4$ NPs@CNT	1.62	*ACS Appl. Mater. Interfaces 2020, 12, 50, 55782*
Ni_3FeN/Ni_3Fe	1.61	*J. Mater. Chem. A, 2021, 9, 4036*
Fe-enriched-$FeNi_3$/NC	1.59	*J. Colloid Interface Sci., 2021, 582, 977*
Ni_3Fe-CW	1.54	*Chem. Eng. J., 2022, 439, 135722*
Ni_3Fe–FeV_2O_4@C/NF	1.51	*ACS Sustainable Chem. Eng. 2021, 9, 24, 8249*
Ni_3Fe/Co-N-C	1.54	*Chem. Eng. J., 2020, 395, 125151*
Ni_3Fe@CNTs/CeO_x	1.641	**This work**

Table S6

Comparison of exchange current densities for the OER between Ni_3Fe@CNTs/CeO_x/NF, Ni_3Fe@CNTs/NF, NF and IrO_2.

Catalyst	Ni_3Fe@CNTs/CeO_x/NF	Ni_3Fe@CNTs/NF	NF	IrO_2
Exchange current densities (mA/cm^2)	5.16×10^{-3}	1.83×10^{-3}	2.85×10^{-4}	1.38×10^{-4}

Table S7

Comparison of exchange current densities for the HER between Ni_3Fe@CNTs/CeO_x/NF, Ni_3Fe@CNTs/NF, NF, and Pt.

Catalyst	Ni_3Fe@CNTs/CeO_x/NF	Ni_3Fe@CNTs/NF	NF	Pt
Exchange current densities (mA/cm^2)	3.65×10^{-7}	1.79×10^{-7}	6.7×10^{-7}	1.95×10^{-3}