

Supplementary Information

Ce–Metal–Organic Framework-Derived CeO₂–GO: An Efficient Electrocatalyst for Oxygen Evolution Reaction

Materials and methods

Chemicals

Analytical reagents (cerium nitrate hexahydrate, trimesic acid, ruthenium oxide) were purchased from Sigma-Aldrich and used directly. Ethanol was purchased from Duksan, South Korea. Graphene oxide (GO) was purchased from Standard Graphene (South Korea) and used directly without further purification.

Characterization

Powder XRD (PANalytical X'Pert PRO, USA) with a Cu K radiation source (1.5405) was used to determine the phase purity and crystallinity of the synthesized samples. The functional groups of the electrocatalysts were identified using Fourier transform infrared (Perkin Elmer Spectrum Two spectrophotometer) in attenuated total reflectance mode. The morphologies of the catalysts were investigated using scanning electron microscopy (Hitachi S-4800, equipped with a field emission gun, Japan), and high-resolution transmission electron microscopy (FEI Tecnai G2 F20 S-TWIN, equipped with a 200-kV Schottky field-emission gun, USA). The elemental compositions of the catalysts were determined by X-ray photoelectron spectroscopy (Thermo Fisher Scientific K-alpha, USA) using Al K α radiation (1486.6 eV). The BET-specific surface area of the electrocatalysts was measured using a Belsorp II-mini (BEL, Japan Inc.).

Electrode preparation and electrocatalytic performance

The electrode ink was prepared using an 8:1:1 ratio of electrocatalyst, carbon black, and polyvinylidene fluoride binder, respectively, in n-methyl-2-pyrrolidone solvent and sonicated for 45 min to obtain a uniform dispersion. The ink was then dispersed on Ni foam (2 cm \times 1 cm) and dried overnight at 60 °C in a vacuum oven. Pt mesh and Hg/HgO were used as the counter and reference electrodes, respectively. KOH (1.0 M) was used as the electrolyte. Oxygen evolution reaction polarization curves were obtained using linear sweep voltammetry at a scan rate of 5 mV s⁻¹. The stability tests were performed using chronoamperometry.

The electrochemically active surface area (ECSA) of the synthesized electrocatalysts, which was proportional to the electrochemical double-layer capacitance (C_{dl}), was determined from the CV curves in the non-Faradaic region. The ECSA was calculated using the equation:

$$ECSA = C_{dl}/C_s, \quad (S1)$$

where C_s is the general specific capacitance (0.04 mF cm^{-2}) obtained from a previous report on metal electrodes in aqueous KOH solutions [1]. The CV curves of the electrocatalysts were recorded in the non-Faradaic region at 0.15–0.20 V against Hg/HgO. The plot of the charging current density (i_c) as a function of the scan rate for each sample is a straight line, and the slope of the line is equal to the C_{dl} value of the catalyst.

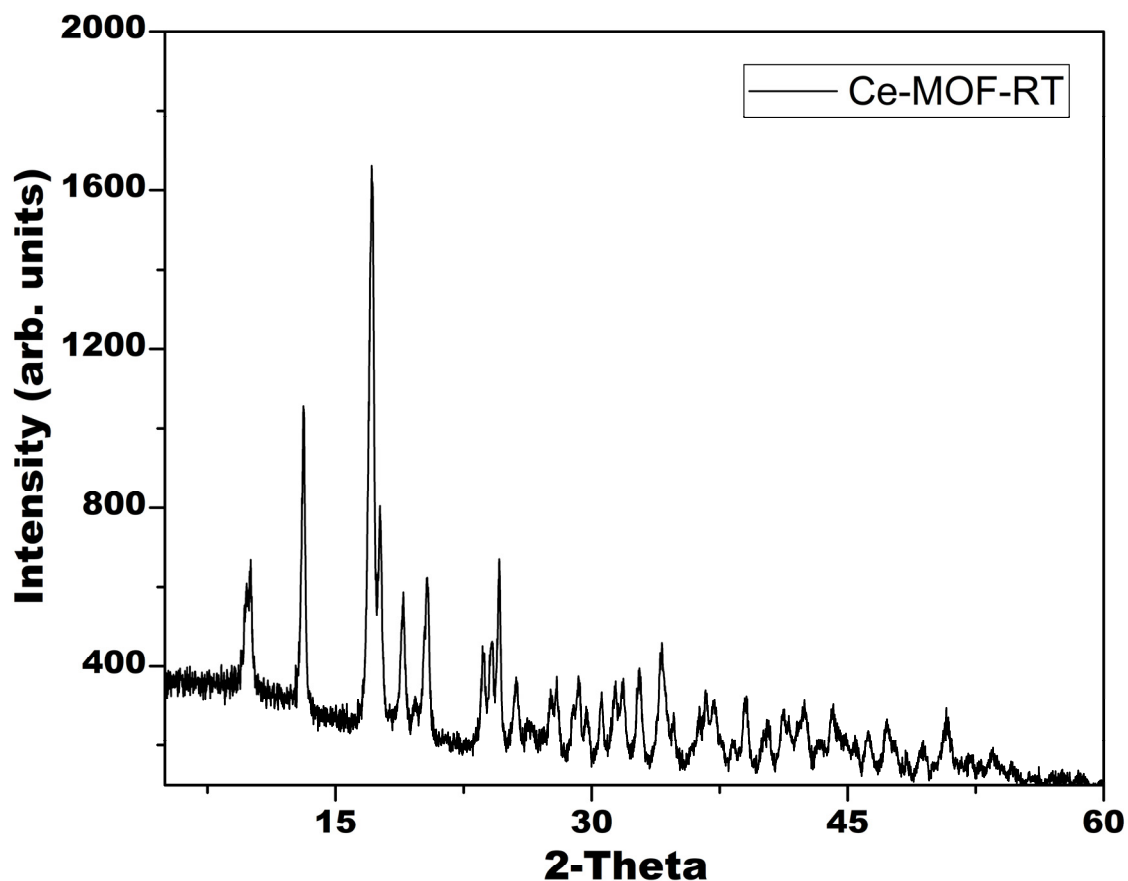


Figure S1. XRD pattern of the pristine Ce-MOF.

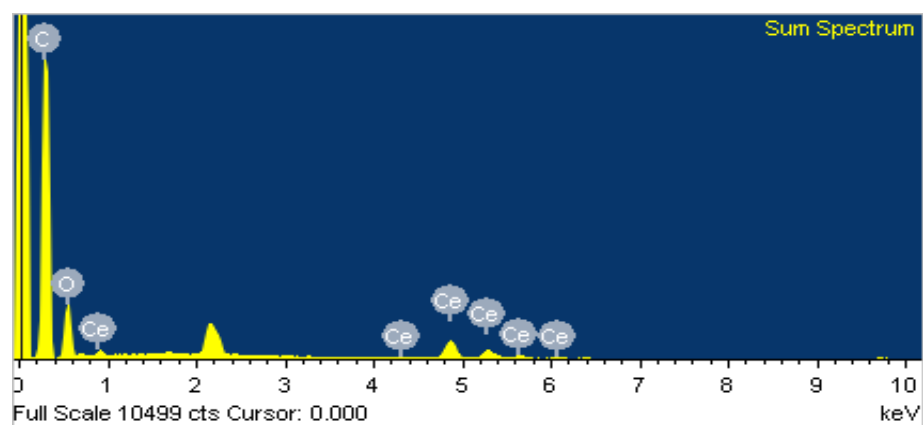


Figure S2. EDS analysis of CeO₂-GO-3 electrocatalyst.

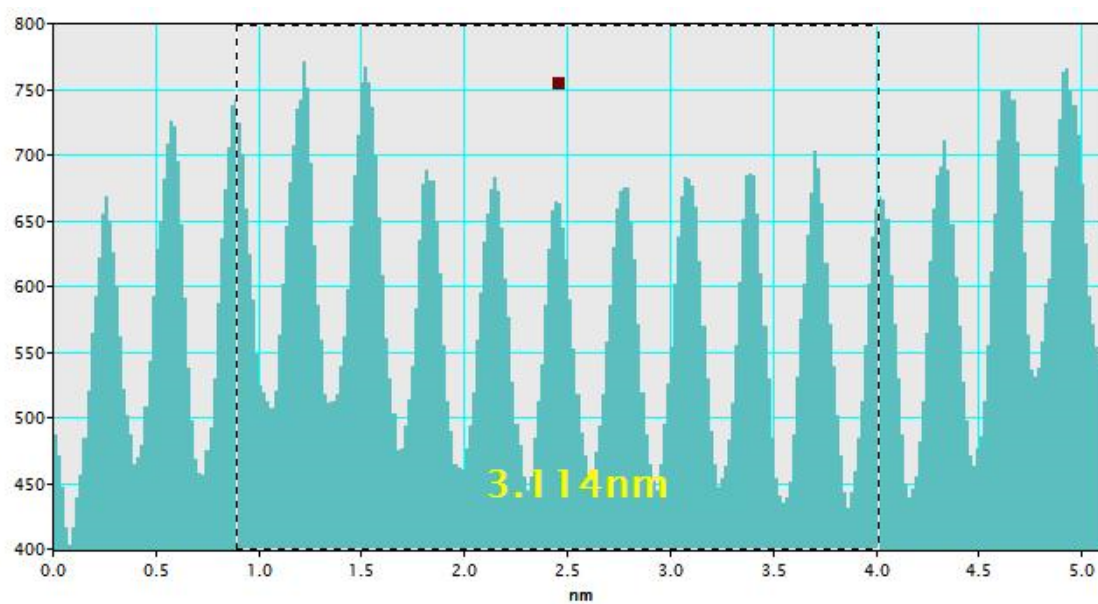


Figure S3. d-spacing line profiles corresponding to the 0.311 (111) plane.

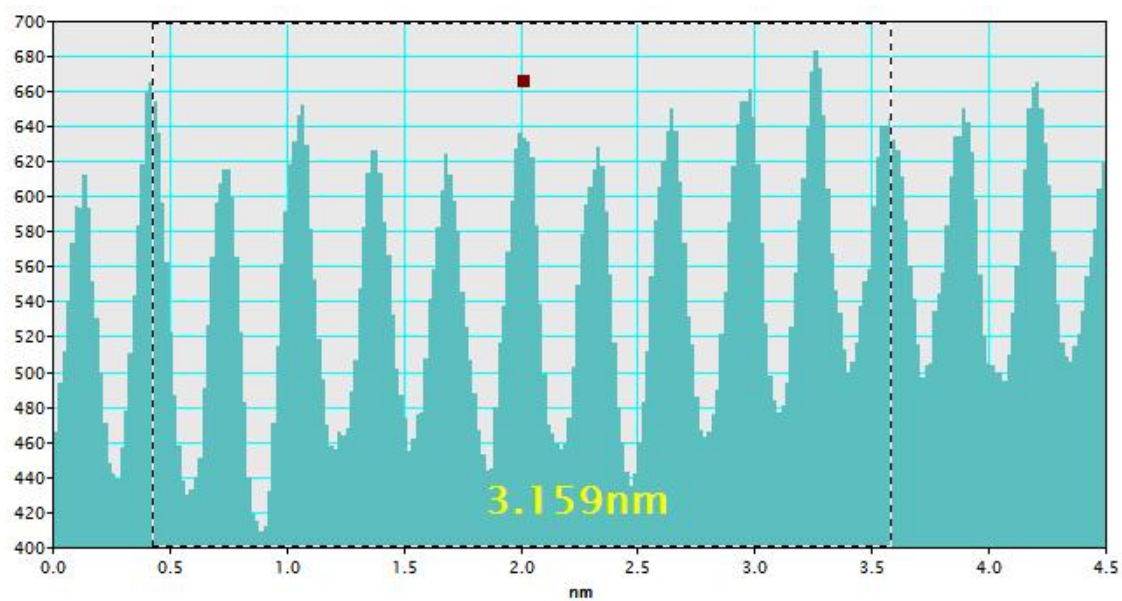


Figure S4. d-spacing line profiles corresponding to the 0.315 (111) plane.

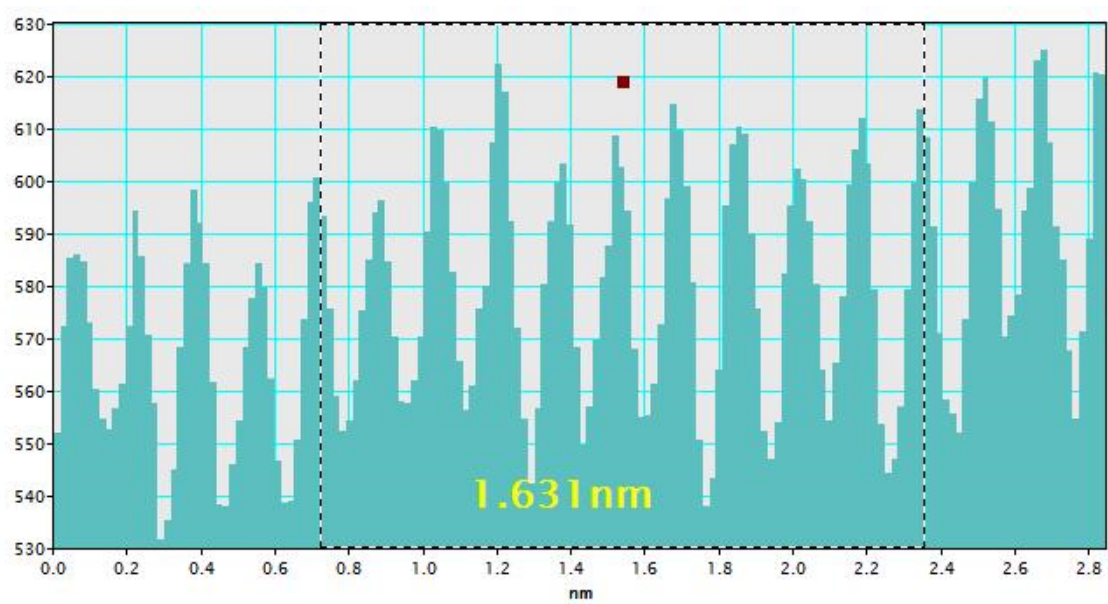


Figure S5. d-spacing line profiles corresponding to the 0.163 (311) plane.

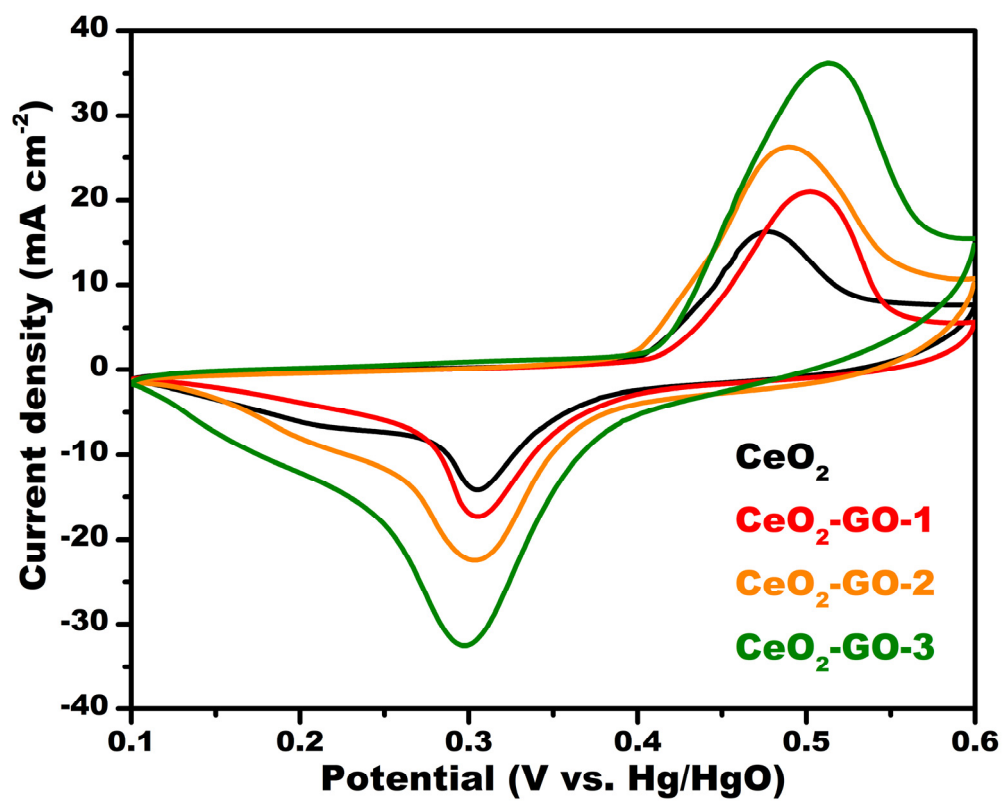


Figure S6. Comparative CV curves at standard scan rate in aqueous 1.0 M KOH electrolyte.

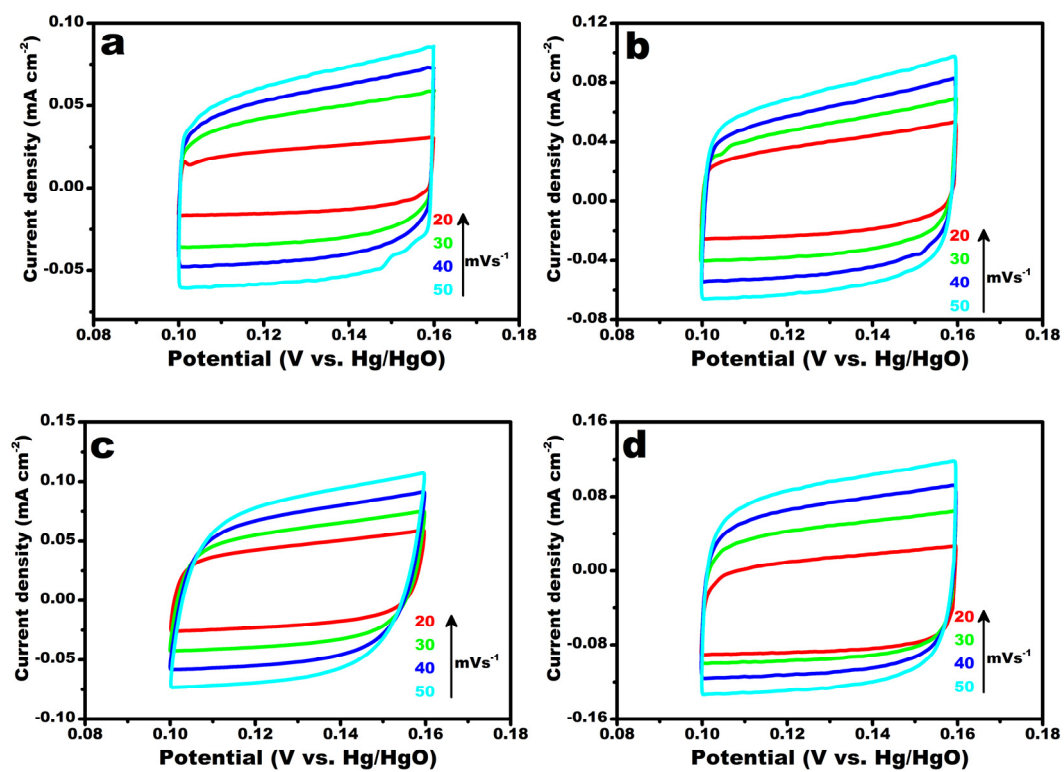


Figure S7. CV curves of the electrocatalysts in (a) 1.0 M KOH; CeO₂, (b) CeO₂-GO-1, (c) CeO₂-GO-2, and (d) CeO₂-GO-3.

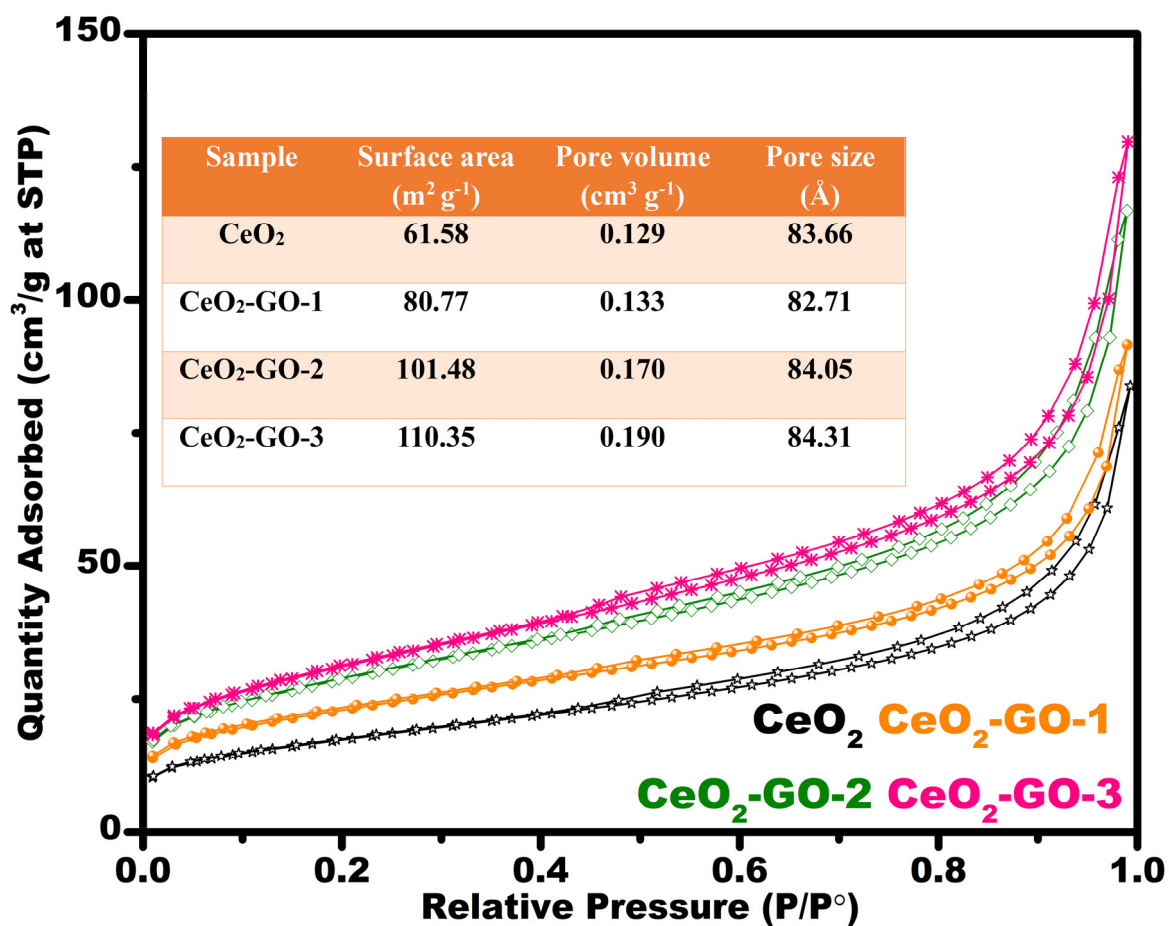


Figure S8. N₂ adsorption–desorption profiles of CeO₂, CeO₂–GO-1, CeO₂–GO-2, and CeO₂–GO-3. The inset shows the determined BET parameters.

Table S1. EIS fitted values and the equivalent circuit.

Electrocatalyst	Series resistance (R _s) (Ω)	Charge transfer resistance (R _{ct}) (Ω)
CeO ₂	0.89	10.05
CeO ₂ -GO-1	0.88	6.23
CeO ₂ -GO-2	0.88	4.69
CeO ₂ -GO-3	0.87	3.51

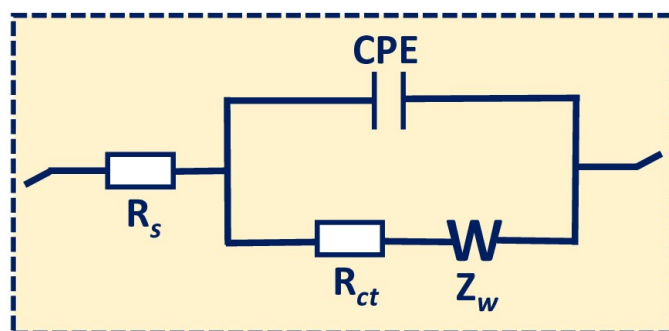


Table S2. Comparison of OER performance of different electrocatalysts.

Electrocatalyst	Electrolyte	Over potential (10 mA/cm ²) vs RHE	Tafel slope (mV dce ⁻¹)	Ref
CeO ₂ -Ru	0.5 M KOH	420	122	2
CeO ₂ /Co(OH) ₂ hybrid catalysts (HCs)	1.0 M KOH	410	66	3
Ce-NiO-E	1.0 M KOH	382	118.7	4
Co ₃ O ₄ /CeO ₂ nanohybrids (NHs)	1.0 M KOH	270	60	5
Ce-MOF	1.0 M KOH	316	96	6
GO@Ce-MOF	1.0 M KOH	311	68	
Calcinated Ce-MOF	1.0 M KOH	309	58	
Calcinated GO@Ce-MOF	1.0 M KOH	287	39	
CeO _x /CoO _x	1.0 M NaOH	331	66	7
H-Co ₃ O ₄ /CeO ₂ @N-doped carbon nanofibers (N-CNFs)	0.1 M KOH	310	85	8
CeO ₂ @ N-doped carbon (NC)-900	0.1 M KOH	413	167	9
CeO ₂ -supported Co/nitrogen-doped carbon nanorods (N-CNR)	0.1 M KOH	410	90	10
CuO _x -CeO ₂ /C	0.1 M KOH	580	177	11
CeO ₂	1.0 M KOH	420	261	Present study
CeO ₂ -GO-1	1.0 M KOH	360	293	
CeO ₂ -GO-2	1.0 M KOH	300	185	
CeO ₂ -GO-3	1.0 M KOH	240	176	

References

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