Supporting Information

Revealing the highly effective electrocatalyst carbon nanotube-coupled Cu-Mn mixed oxide toward the robust bifunctional electrochemical water splitting in alkaline medium

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2.2.2 Synthesis of CuO

Cu_2O nanoparticles were synthesized via a controlled chemical reduction method. In a typical procedure, an 2M of $Cu(NO_3)_2{\cdot}3H_2O$ was dissolved in deionized water under constant stirring to obtain a clear solution. An aqueous 1M NaOH solution was then added dropwise to create an alkaline environment, resulting in the formation of a $Cu(OH)_2$ intermediate. Subsequently, a mild reducing agent such as glucose or ascorbic acid was introduced slowly into the reaction mixture under continuous stirring at elevated temperature. This reduction led to the formation of Cu^{2+}/Cu^{+} a characteristic brick-red CuO precipitate. After completion of the reaction, the product was collected by centrifugation, washed several times with deionized water and ethanol to remove residual impurities. The washed product is dried at 60–80 °C overnight. For enhanced crystallinity and purity, the dried powder may be calcined at 300 °C for 2 hours in air.

2.2.3 Synthesis of Mn_2O_3

Mn_2O_3 nanoparticles were prepared using a thermal decomposition approach. Initially, a manganese precursor such as $Mn(NO_3)_2{\cdot}4H_2O$ was dissolved in deionized water to form a homogeneous solution. The solution was heated under continuous stirring until complete solvent evaporation, yielding a solid precursor. This precursor was then calcined in air at elevated temperature (typically 500 °C) for several hours to induce thermal decomposition and oxidation, resulting in the formation of Mn_2O_3. After calcination, the product was allowed to cool naturally to room temperature, followed by gentle grinding to obtain fine Mn_2O_3 powder suitable for further studies.

2.4 Materials characterizations

An investigation was conducted on the crystalline structure of the powder. In order to collect data, a BRUKER USA D8 Advance, a Da Vinci diffractometer, and powder X-ray diffraction (XRD) were utilized. Fourier Transform Infrared (FTIR) spectrophotometer named SHIMADZU IRTracer-100 is used to identify functional groups, determine the presence of specific molecules, and even quantify their amounts in a sample. It features a high signal-to-noise (S/N) ratio of 60,000:1, a resolution of 0.25 cm^{-1}, and rapid scanning capabilities of 20 spectra per second. The Cu-K radiations used in the experiment ranged from 10 to 90 degrees. For the purpose of determining the composition and elemental state of CNT-CMO, X-ray photoelectron spectroscopy (XPS) was utilized, with magnesium serving as the radiation input. The apparatus used for this experiment was a PerkinElmer Phi 1600 ESCA. For the purpose of examining the morphology of CNT-CMO at 20 kV, an increased capacity scanning electron microscope (Thermo Scientific Apreo S) was utilized. Additionally, an enhanced level transmission electron microscope (JEOL Japan, JEM-2100 Plus) was utilized for the purpose of analyzing the internal morphological features. Using energy dispersive X-ray spectroscopy (EDAX) ISIS300, the profile of elements on the surface of CNT-CMO was determined. These elements included Copper (Cu), Manganese (Mn), carbon (C), nitrogen (N), and oxygen (O).

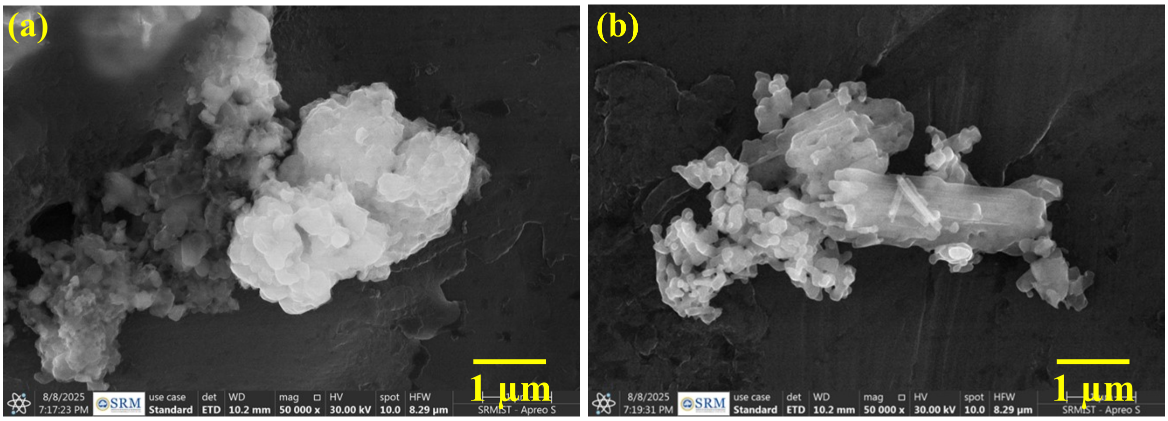

Fig. S1 SEM image of the synthesized (a) CuO and (b) Mn_2O_3.

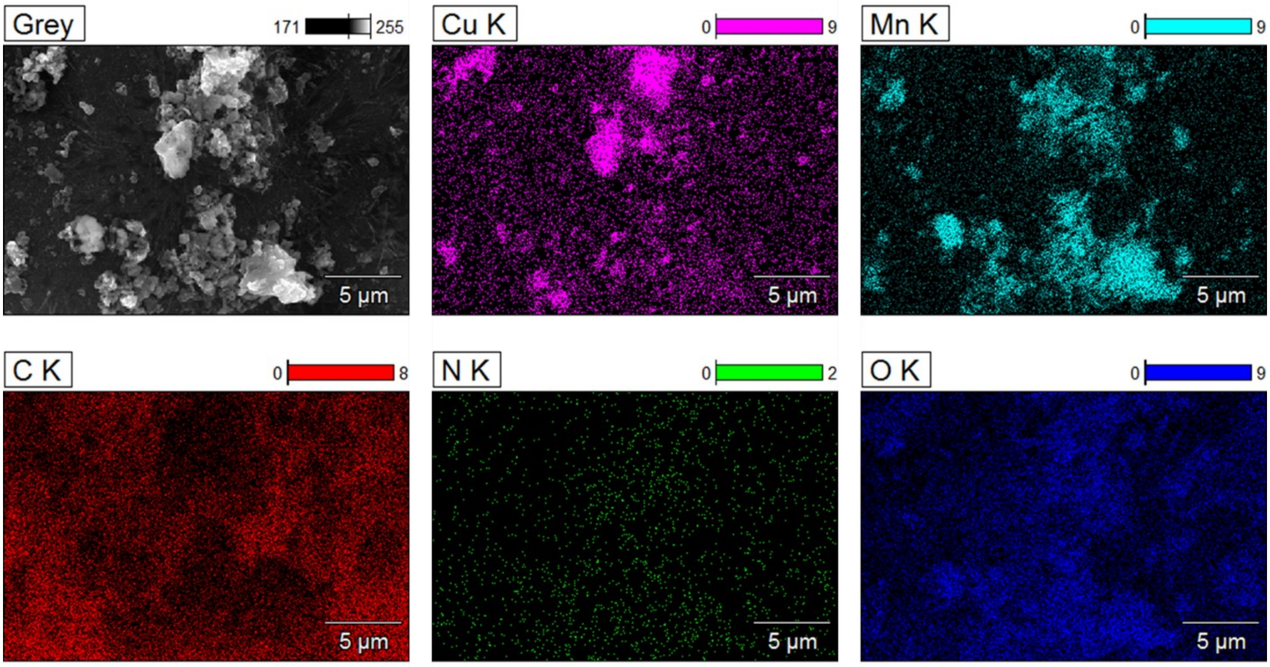

Fig. S2 Element mapping of CNT-CMO.

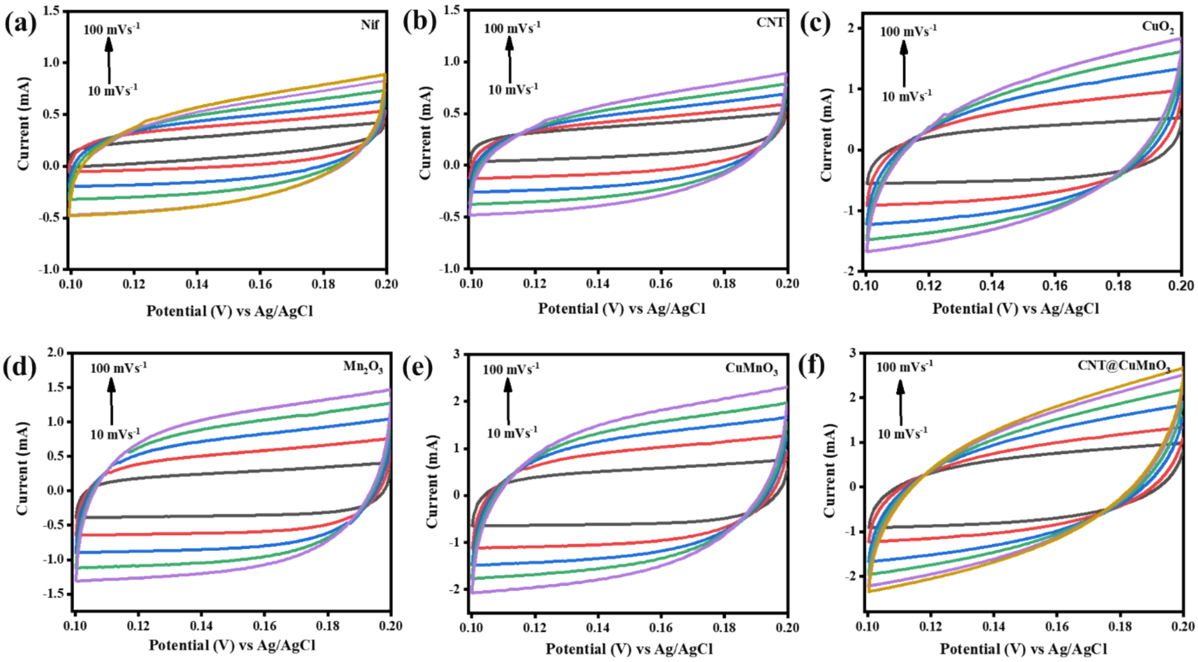

Fig. S3 ECSA linear plot from CV of (a) bare NF, (b) CNT/NF, (c) CuO/NF, (d) Mn_2O_3/NF, (e) CMO/NF, and (f) CNT-CMO/NF in 1M KOH at scan rate of (20-100 mVs^{-1}),

Calculations

Calculating the potential of a reversible hydrogen electrode (RHE):

The potential towards reversible hydrogen electrode (RHE) has been determined using the Nernst equation,

$$E_{RHE} = E_{\mathrm{Ag/AgCl}} + 0.059 \times pH + E^{0}_{\mathrm{Ag/AgCl}} \text{ ……... (S1)}$$

Where, E_{RHE} is the converted potential versus an RHE, $E^{0}_{\mathrm{Ag/AgCl}} = 0.197$ V at room temperature (27 ˚C) and $E_{\mathrm{Ag/AgCl}}$ is the experimental measured potential versus Ag/AgCl reference electrode.

Calculation of Overpotential

The recorded overpotential for OER and HER were calculated from the following equation:

$$|\eta\mathrm{OER}| = 1.23 - E_{\mathrm{RHE}} - iR \text{ ……. (S2)}$$

$$|\eta\mathrm{HER}| = 0 - E_{\mathrm{RHE}} - iR \text{ ……. (S3)}$$

Tafel Slope

The Tafel slope values were obtained from the Tafel plot by using the following mathematical equation:

$$\eta = a + b\log j \text{ ………(S4)}$$

Where, η, b, and j are the overpotential, Tafel slope and current density of the respective Tafel equation.

Electrochemical active surface area (ECSA)

The double-layer capacitance (C_{dl}) of the samples was determined from the cyclic voltammograms, which was expected to be linearly proportional to the effective surface area. CV measurements performed in the region of 0.1-0.2 V could be mostly considered as the double-layer capacitive behaviour. The double-layer capacitance was estimated by plotting the at 0.15 V against the scan rate (20-100 $\mathrm{mVs^{-1}}$).

The ECSA was calculated using:

$$\mathrm{ECSA} = C_{dl}/C_{s} \text{ ……. (S5)}$$