



# Three-dimensional mesoporous Ir–Ru binary oxides with improved activity and stability for water electrolysis



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## ABSTRACT

Water electrolysis (WE) involves both the oxygen evolution reaction (OER) and the hydrogen evolution reaction (HER). Because the kinetics of the OER are much slower than those of the HER, the overall efficiency of electrolysis is decreased. Furthermore, since the OER occurs in extremely harsh environments, stability of materials needs to be considered for WE application. To overcome this challenge, researchers have conducted many studies to investigate OER catalysts. In the current study, to achieve a balance between activity and stability, three-dimensional mesoporous IrO<sub>2</sub>/RuO<sub>2</sub> (MS-IrO<sub>2</sub>/RuO<sub>2</sub>) was prepared via nano-replication and the Adams method sequentially, and for comparison, Ir–Ru binary oxides (IrO<sub>2</sub>/RuO<sub>2</sub>) with a high specific surface area were synthesized using commercial RuO<sub>2</sub> via the Adams method. Thereafter, the effects of the structural and electrochemical characteristics of the catalysts on the OER activity were analyzed. MS-IrO<sub>2</sub>/RuO<sub>2</sub> with an Ir/Ru molar ratio of 1:10 was shown to have a lower overpotential (300 mV at 10 mA cm<sup>-2</sup>) than conventional IrO<sub>2</sub>/RuO<sub>2</sub> (340 mV). After the accelerated stability test for over 2 h using the chronopotentiometry technique, the increase in overpotential was as low as 22 mV for MS-IrO<sub>2</sub>/RuO<sub>2</sub>, lower than that of IrO<sub>2</sub>/RuO<sub>2</sub> (44 mV). The results of this work are anticipated to prove useful to aid researchers in better understanding viable approaches for improving OER performance.

## 1. Introduction

As renewable energy technologies have matured, their power generation capability has increased commensurately. However, as their performance is highly dependent on the surrounding environment, they often experience intermittent power generation problems. A possible solution for the problem of fluctuating power is to use water electrolysis (WE) technology to convert electric power into hydrogen energy. One option to accomplish this is polymer electrolyte membrane water electrolysis (PEMWE). This technique is attractive because it produces high purity H<sub>2</sub>, has a rapid response rate, and supports high current density operation, among other features [1–7]. However, before PEMWE can be properly commercialized, challenges of efficiency and stability must be addressed. WE involves both the oxygen evolution

reaction (OER) and the hydrogen evolution reaction (HER). However, the kinetics of the OER are much more sluggish than those of the HER, which degrades the overall WE efficiency. Furthermore, as the OER takes place in harsh environments (e.g., high voltage and low pH), the stability of the materials used in WE is of concern. In an effort to overcome these problems, researchers have focused on the development of OER catalysts [8–16].

At present, OER catalyst research is focused on mixed metal oxides, metal/metal oxide supports, selective leaching of Ir transition metal alloys, and shape control [17–20]. As the activity order for the OER is Os > Ru > Ir > Pt > Au whereas the stability order is Au > Pt > Ir > Ru > Os, mixed metal oxides have been suggested to strike a suitable balance between catalytic activity and stability [21–34]. For example, mixing a more active metal (e.g., Ru) and a relatively stable

**Abbreviations:** WE, water electrolysis; OER, oxygen evolution reaction; HER, hydrogen evolution reaction; PEMWE, polymer electrolyte membrane water electrolysis; OMS, ordered mesoporous silica; HMDS, hexamethyldisilazane; DIW, deionized water; AST, accelerated stability test; GC-RDE, glassy carbon rotating disk electrode; RHE, reversible hydrogen electrode; EIS, electrochemical impedance spectroscopy; XRD, X-ray diffractometer; BET, Brunauer–Emmett–Teller; PSD, pore size distribution; TEM, transmission electron microscopy; FE-SEM, field-emission scanning electron microscope; EDS, energy-dispersive X-ray spectroscopy; XPS, X-ray photoelectron spectroscopy; ECSA, electrochemical surface area; CV, cyclic voltammetry; TOF, turnover frequency

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