NJC

ROYAL SOCIETY OF CHEMISTRY

PAPER

View Article Online
View Journal





Cite this: DOI: 10.1039/d2nj04389k

# Multifunctional Na-enriched Ni–Fe/Ni–P plates for highly efficient photo- and electrocatalytic water splitting reactions

A. Anantha Krishnan,[a] Aneesh Kumar M. A,[a] Revathy B. Nair,[b] Sivaraj R,[a] Lamiya A,[a] P. K. Jishnu,[a] Sajith Kurian,[b] Thomas Mathew,[a] M. Ameen Sha[c] and P. S. Arun *[a]

Received 2nd September 2022,
Accepted 25th October 2022

DOI: 10.1039/d2nj04389k

rsc.li/njc

In this work, we first report a novel sodium-enriched Ni–Fe mixed-oxide catalyst incorporated into a Ni–P electrode for photo and electrocatalytic water splitting. A one-pot special sol–gel method was adopted for the synthesis of sodium-enriched Ni–Fe mixed-oxide catalysts, and the parameters were optimized based on the electrode and characterized by suitable analytical techniques. The reported catalyst system has high solar water splitting activity with a high quantum efficiency of 53.89%. The functional electrode exhibited a very low overpotential of 198.3 mV at a current density of 10 mA $cm^{-2}$ during oxygen evolution reactions. Even though the oxygen evolution reaction is sluggish as it demands a high overpotential, the developed electrode system exhibited excellent OER characteristics by acting as a reversible electrode. Moreover, the LSV plots of electrodes before and after 1000 cycle CV revealed that the electrode possesses a high long-term electrochemical stability during the reversible OER. A high double-layer capacitance and a low charge transfer resistance value of the catalytic electrode are due to the high distribution of electroactive sites such as $Na^{+}$, $Ni^{2+}$, and $Fe^{3+}$ on the surface and the combined effect of various functional components in the catalytic system. $NaNiO_2$ and $Fe_2O_3$ were preserved in the Z-scheme photo-catalyst, and it also enhanced the electron flow and conductivity which favours simultaneous oxidation and reduction. The developed electrode system exhibited excellent water splitting characteristics due to faster electron transfer reactions in sodium-incorporated catalysts. Furthermore, the coexistence of $Ni^{2+}$ and $Fe^{3+}$ would increase the electrical conductivity due to the synergic effect between $Ni^{2+}$ and $Fe^{3+}$. The photo- and electrocatalytic activity and stability of the catalytic electrode system is competent with the recently reported and comparable catalyst. The present work proposes an electrode system capable of large-scale water splitting with excellent activity and stability.

## 1. Introduction

Sustainable energy and sustainable natural environment are the most challenging topics in this developing world.[1,2] As the non-renewable sources of fuels are depleting, renewable fuels ensure an alternative energy source to overcome the future scarcity of fossil fuels.[3–7] Water splitting to produce hydrogen is a topic of great interest. Metal oxides and sulfides such as $TiO_2$, $SnO_2$, FeO, $Fe_2O_3$, $Fe_3O_4$, $Cu_2O$, ZnO, $WO_3$, ZnS, and SnS[8–16] have been developed for water splitting. Nonetheless, the practical applicability of these catalysts is limited due to high recombination rate, stability, and large band gap (*e.g.*, $TiO_2$ ~ 3.2 eV, $SnO_2$ ~ 3.8 eV)[17–19] and reproducibility affects the photocatalytic activity. High overpotential, surface area, and electrochemical stability also affect the electrocatalytic water splitting. In this context, a suitable catalyst with constructive crystallographic, optical, electronic, and orbital properties for sustainable energy production should be developed to address these issues. Among the metal oxides, nickel oxide has been widely used in photocatalytic water splitting due to the good electron capturing affinity of nickel atoms.[20–22] It has also been reported that metallic Ni, in combination with a NiO semiconductor, forms an ohmic contact, facilitating the transfer of electrons.[23] This enables good charge separation and movement of electrons to the active sites, enabling a high water splitting activity.

[a] Department of Chemistry, St. John's College (Affiliated to University of Kerala), Anchal, Kollam, Kerala, 691308, India. E-mail: arunps@stjohns.ac.in
[b] Department of Chemistry, Mar Ivanios College (Affiliated to University of Kerala), Nalanchira, Thiruvanathapuram, Kerala, 695015, India. E-mail: sajith.kurian@mic.ac.in
[c] Department of Chemistry, University of Kerala, Kariavattom Campus, Thruvananthapuram, Kerala, 691308, India. E-mail: shaalameen@gmail.com