ABSTRACT

The global transition toward sustainable and low-carbon energy systems has intensified the demand for efficient, clean, and decentralized energy technologies. Conventional fossil fuel based energy generation remains a major contributor to greenhouse gas emissions, necessitating the development of alternative solutions. In this context, renewable energy sources, particularly solar photovoltaics along with electrochemical energy conversion technologies such as fuel cells and hydrogen generation, have attracted significant interest due to their potential to enable clean and reliable energy generation.

Electrochemical systems, especially fuel cells and water electrolysers, play a key role in future energy conversion and storage. Their performance largely hinges on the efficiency of electrode reactions, particularly the oxygen evolution reaction (OER) and methanol oxidation reaction (MOR). Advancing hydrogen production and fuel cell technology depends on developing efficient, low-cost electrocatalysts for these reactions. Hydrogen production through water splitting and power generation via direct methanol fuel cells (DMFCs) are widely regarded as promising sustainable energy technologies.

Currently, RuO_2 and IrO_2 are the benchmark electrocatalysts for the oxygen evolution reaction (OER) in water splitting applications. However, their high cost and limited availability present significant challenges to widespread industrial deployment. As a result, transition metal-based oxides and hydroxides have gained attention as cost-effective alternatives due to their abundance and favourable electrochemical properties. Nickel-based oxides and hydroxides offer a cost-effective alternative, showing strong activity for both OER and methanol oxidation. Performance enhancements are achieved through strategies such as doping, defect engineering, surface reconstruction, and interface design.

In this study, a novel Ni- based amorphous electrical steel ribbon alloy with $(Ni_{87}Fe_{4}Cr_{9})_{78}Si_{8}B_{14}$ composition, is developed through melt-spinning technique and employed as a self-supported electrocatalyst. Controlled surface modification through potentiostatic cathodic corrosion at varied durations (30, 45, 60, 90, and 120 minutes) enables the in-situ formation of different proportions of α-$Ni(OH)_2$ on the ribbon surface. These electrodes are evaluated for their electrocatalytic performance in 1 M KOH and 1 M KOH + 1 M MeOH electrolytes for the oxygen evolution reaction (OER) and methanol oxidation reaction (MOR), respectively. This work demonstrates the dual functionality of amorphous alloy ribbons for both OER and, for the first time, MOR applications. The results highlight their scalability, structural stability, and potential as efficient electrocatalysts, introducing a new class of materials for Hydrogen generation and Direct methanol fuel cells (DMFCs).

In addition, while various strategies like heteroatom doping, nanostructuring, surface de-alloying, and self-supported catalyst designs have individually shown promise in enhancing Ni-based electrocatalysts for OER and MOR, their combined potential remains largely unexplored. To address this gap, the present study utilizes the same electrode composition developed through melt spinning subjected to controlled chemical de-alloying in 0.5 M HNO_3 for varying durations (0 to120 min) to induce surface nanostructuring and compositional tuning. This integrated approach aims to synergistically enhance electrocatalytic activity and stability, demonstrating the potential of multicomponent amorphous alloys as efficient bi-functional catalysts for OER and MOR.

In the pursuit of sustainable and secure energy solutions, solar power has emerged as a key driver of green growth. Among various renewable technologies, on-grid rooftop solar (OGRTS) systems offer a reliable and eco-friendly option for meeting industrial and infrastructure energy demands. In this present work, the design and implementation of an OGRTS pilot level solar photo-voltaic plant of 500kWp, as a model for decentralized solar energy adoption. The work highlights essential methodologies in system design, site-specific feasibility analysis, and power distribution planning. It also outlines key engineering, material management, and installation practices that contribute to optimizing project efficiency and cost-effectiveness. By integrating technical and commercial and environmental life cycle assessment evaluations, the study underscores the role of solar PV plant in promoting clean energy transitions, reducing carbon emissions, and supporting long-term energy policy development.

Thus, this research work ensured a holistic approach covering both material-level catalyst innovations and system-level PV plant design, enabling the validation of catalyst material performance in laboratory conditions and relevance in broader renewable energy integration of PV plant, a step towards future hybrid energy systems.