Materials Advances

EDITORIAL

View Article Online
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Cite this: *Mater. Adv.*, 2024, 5, 4023

DOI: 10.1039/d4ma90053g

rsc.li/materials-advances

Introduction to surface engineering of transition metal-based 2D layered materials for anti-corrosion and energy applications

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The discovery of two-dimensional (2D) layered materials has attracted immense interest across numerous scientific and industrial applications due to their extraordinary properties. These properties includes high surface area, excellent mechanical strength, and tunable electronic properties, making them promising candidates for various applications.[1]

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With high surface-to-volume ratios, these 2D materials, including layered double hydroxides (LDHs), transition metal dichalcogenides (*e.g.*, MoS_2), hexagonal boron nitride (h-BN), and so on, possess unique catalytic or adsorption features. Improved catalytic activity and fascinating adsorption features in the pores of the materials make them superior for water splitting, electrochemical CO_2 reduction (eCO2RR), anti-corrosion activity, supercapacitors, and other energy-storage applications. In recent years, surface engineering of 2D materials has appeared as a promising approach to modify their properties for enhanced performance in the above applications.

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Dr Subrata Kundu received his PhD degree from the Indian Institute of Technology (IIT), Kharagpur, India, in early 2005. Then he moved to the University of Nebraska, Lincoln, USA, and later to Texas A&M University, College Station, Texas, USA, as a post doctoral fellow (from 2005 to 2010). He visited Texas A&M University again in 2016–2017 with a 'Bhaskara Advanced Solar Energy (BASE)' fellowship for ten months. He is currently working as a Principal Scientist at CSIR-CECRI, Karaikudi, India. Dr Kundu recently received prestigious FRSC (Fellow of Royal Society of Chemistry) from London in 2023. Dr Kundu has served as an Associate Editor of the prestigious 'Journal of Materials Chemistry A' and 'Materials Advances' of the RSC since November 2022 and 'Scientific Reports' of the Nature Group since 2015. Dr Kundu and his co-workers are working in the forefront area of Materials Sciences with emphasis on energy, environment, catalysis and electrocatalysis fields.

Strategies including chemical functionalization, defect or vacancy creation, heterostructure formation, nanostructuring, cation or anion doping, and so on have proven to be fascinating for the above-mentioned applications.[2] Chemical functionalization comprises the covalent or non-covalent attachment of functional groups to the surface of 2D materials. This technique permits the modification of surface chemistry, which can influence properties such as wettability and corrosion resistance, and allow modification of reaction pathways to lower the activation energy barrier. For example, hydrophobic chemical modification of the surface can enhance the electrocatalytic activity of an electrocatalyst involving non-polar active species, such as in the oxygen reduction reaction (ORR) and eCO2RR, and can enhance its anti-corrosion properties by repelling water and corrosive agents.[3] Meanwhile, hydrophilic modification leads to enhanced electrocatalytic activity involving polar species, like in water splitting. Defect engineering allows modification of the electronic and chemical properties of 2D materials.[4] This results in enhanced catalytic activity and improved charge transfer, and mitigates corrosion susceptibility. Creating heterostructures by stacking two or more different 2D materials offers an extraordinary opportunity for tuning material properties.[5] Heterostructures display exceptional electronic band structures and interface effects that can be beneficial for diverse applications. Doping of foreign cations and anions in the host 2D layer could regulate the electronic structure of the active metal ions and thereby reflect improved adsorption ability of electroactive ions.[6]

Corrosion is a universal problem that affects the durability and performance of metallic structures in various industries and in many types of construction. The special surface properties of modified 2D materials make them attractive candidates for anti-corrosion and corrosion-inhibition properties. Surface modification of 2D materials can form a robust protective layer on the metal surface that prevents corrosive agents (*e.g.*, Cl^- ions in marine corrosion) from reaching the substrate. When it comes to energy-related applications, the surface engineering of 2D layered materials holds intense potential in energy storage, catalysis, and energy conversion. For example, the surface functionalization of layered materials allows them to be used as electrodes in Li-ion batteries and other energy-storage applications. Also, surface engineering would lead to modifying the electrocatalytic behavior towards improved water splitting and other energy-conversion techniques.

In the context of the current energy scenario and the societal need for increased utilization of 2D materials, this special themed collection comprises a diverse set of research work, highlighting various opportunities in the field of energy and anti-corrosion applications. Shchukin *et al.* provided a review article focused on 2D layered nanomaterials for energy generation and storage applications (**https://doi.org/10.1039/D3MA00924F**). Various other transition metal-based 2D materials were also reported for hydrogen generation, supercapacitor and battery-related applications (**https://doi.org/10.1039/D3MA00523B**, **https://doi.org/10.1039/D3MA01008B**, **https://doi.org/10.1039/D3MA01100C** and **https://doi.org/10.1039/D3MA01079A**). Sheng *et al.* reported the anti-corrosion application of 2D transition metal-based layered materials (**https://doi.org/10.1039/D3MA00919J**). Overall, the research given in the collection showcases the importance of advances in surface-engineering techniques, in terms of their diverse applications in various energy-related applications.

Lastly, we would like to express our gratitude to the entire *Materials Advances* editorial team for helping and working together to bring this themed collection out in great shape. We hope that reading these interesting papers from various research domains will help readers become aware of the scope of research being carried out on transition metal-based 2D layered materials and inspire them to think of new uses for these commonplace materials.

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