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Introduction to Superwetting nanoelectrodes for renewable energy

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In this editorial, Xiaoming Sun introduces the collection 'Superwetting nanoelectrodes for renewable energy', guest edited by Zuankai Wang, Alex Bell, Alberto Vomiero and Xiaoming Sun. This themed issue in *Nanoscale* aims to publish papers focusing on the fundamental understanding and practical applications of superwetting nanoelectrodes.

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Electrochemical reactions that take place at the interface between electrode and electrolyte involve charge transfer, mass transport, and phase transformation. With the development of nanoelectrodes, it has been widely recognized that the dynamics of H₂ or O₂ bubbles' formation, which is tailored by the wetting or superwetting properties of electrolyte/electrode interfaces, critically influence the operational efficiency of electrochemical energy conversion and storage systems, industrial manufacturing processes, and environmental remediation technologies. Despite that wettability is a centuries-old concept, from 1805, the concept of superwetting electrodes is new and has sparked tremendous attention in recent decades, thanks to the rapid development of hydrogen energy and well-established nanostructure synthesis techniques.

In 2014, the "superaerophobic electrode" was proposed for explaining the extraordinary rapid hydrogen evolution reaction (HER) current increase rates, which were observed on a MoS₂ nanoarray electrode. Such nanoelectrodes reduced bubble adhesion force, and consequent bubble detachment size, lowered the diffusion resistance and enhanced current density increase rates, even surpassing

commercial Pt/C film electrodes at high current densities. In the latest decade, the influence of bubble evolution behaviors has been intensively investigated, and the tailoring of electrode structure for regulating the three-phase interfaces has become equally important apart from promotion of intrinsic activity of catalysts. By combining optimized materials with higher intrinsic activities and optimized nanostructures with superwetting properties, unprecedented capabilities of electrodes have been fully unlocked by interfacial regulation.

Typically, superwettability has been derived as superaerophobic electrodes for gas evolution reactions (GERs), and superaerophilic electrodes for gas consumption reactions (GCRs). For example, the severe bubble adhesion in HzOR on the electrode surface can be minimized by constructing "superaerophobic" nanostructured Cu films, and the "superaerophobic" nanostructured RuO₂@TiO₂ electrode exhibits an excellent CIER performance with a Faradaic efficiency over ≈90%. Similarly, the bubbles can merge into the superaerophilic electrode as a bursting state within 100 ms, overcoming the inherent solubility of most target reactive gas species. Recently, ultralight flexible 3D nickel (nanocone-shaped nickel structures) micro-mesh decorated with NiCoP has been developed for high stability alkaline zinc batteries, which demonstrated outstanding cycling stability, retaining 91% of its initial capacity after 11 000 cycles. In this context, gas-diffusion electrodes (GDEs) with super-

hydrophobic three-phase boundaries have been widely applied in gas consumption reactions including fuel cells, metal-air batteries and CO₂-reduction reactions, exhibiting much enhanced catalytic activity and high efficiency. In addition, superwetting nanoelectrodes have also been applied in the design of GCR based electrochemical sensors. By synergizing the convergence of nanoscience, interfacial physics, and electrochemistry, superwetting nanoelectrodes provide an effective strategy for promoting the mass transfer (particularly the gas species) in renewable energy technologies through innovative interface design, and advance the industrialization of electrochemical energy conversion and storage.

The rapid proliferation of research activities in the intrinsically interdisciplinary superwetting electrodes field has inspired us to organize this themed issue, aiming to consolidate the latest advancements and conceptual breakthroughs for renewable energy systems. As guest editors of this themed issue, we would like to thank all the authors for the high quality of the contributions, and the editorial staff from *Nanoscale* for their guidance and support throughout the creation process. We hope that this themed issue can provide new insights and innovative strategies for researchers in chemistry, materials, energy, physics and beyond, and further promote the development of electrochemical energy technologies on the industrialized scale.

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Alex Bell

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Xiaoming Sun

Professor Xiaoming Sun was born in Shandong Province in February 1976 and was granted his B.S. degree and PhD from the Department of Chemistry, Tsinghua University in 2000 and 2005, respectively. After his postdoctoral work at Stanford University, he joined the State Key Laboratory of Chemical Resource Engineering, Beijing University of Chemical Technology in 2008 as a full professor and PhD candidate supervisor. He was awarded the National Excellent Doctoral Dissertation in 2007 and the Outstanding Youth Fund of the National Natural Science Foundation in 2011. His main research interests include the controllable synthesis of inorganic nanomaterials and their applications in energy chemistry, especially water electrolysis, fuel cells, and batteries.