

Efficient Alkaline Water Oxidation Electrocatalysis Enabled via the Modulation of Sn-Containing Anions towards NiFe Oxyhydroxide

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Despite being considered as efficient non-noble metal-based electrocatalysts for alkaline oxygen evolution reaction (OER), NiFe (oxy)hydroxides (NiFeO_xH_y) typically fall short of meeting practical requirements. To address this challenge, herein, we introduce a facile *in situ* electrochemical incorporation technique to form Sn-doped NiFe-layered double hydroxide (NiFeSn-LDH) precatalysts. Subsequently, under the alkaline OER process, the precatalyst evolves into stannate ion-adsorbed NiFe oxyhydroxides (NiFeOOH). The presence of these stable stannate oxyanions plays a key role in mitigating Fe leaching, optimizing the electronic structure of NiFeOOH, and improving its reaction kinetics, thereby significantly enhancing alkaline

OER performance. Notably, the nickel foam-supported NiFeSn-LDH demonstrates impressive results delivering a large current density of 100 mA cm⁻² at an overpotential as low as ~260 mV and maintaining the industrial-relevant ~500 mA cm⁻² current density over 5 days with negligible activity decay, surpassing the performances of most of the transition metal-based electrocatalysts. Comprehensive advanced characterizations of the precatalysts, before and after the OER reactions, have been performed to uncover stable residual stannate ions at the surface of NiFeO_xH_y and to determine their pivotal role in promoting alkaline OER.

Introduction

Hydrogen energy is regarded as one of the most promising alternatives to conventional fossil fuels owing to its high energy density and notable environmental friendliness.^[1–4] In contrast to traditional methods reliant on fossil fuels, water electrolysis offers a more efficient and eco-friendly means of generating H₂, and has garnered significant global research attention.^[5–8] However, the development of water electrolysis is severely confined by its anodic half-reaction, *i.e.*, oxygen evolution reaction (OER), which suffers from sluggish reaction kinetics.^[9,10]

Recently, there has been a significant surge in the development of electrocatalysts aimed at boosting the performance of the OER.^[11–14] Especially, current industrial alkaline OER catalysts predominantly comprise non-noble metals such as Ni and its alloys (e.g., Raney nickel), albeit exhibiting moderate catalytic performance.^[15,16] Interestingly, over the past years, the nickel-iron systems, particularly NiFe(oxy)hydroxides (NiFeO_xH_y), emerged as the research focus in the field of OER, due to their inherent superior OER activity, as highlighted by notable contributions from the Bell and Boettcher groups.^[17–19] Nevertheless, a key challenge with NiFeO_xH_y, lies in the dissolution of Fe atoms from its lattice into the electrolyte during alkaline OER especially under strengthened conditions (such as higher operating temperatures, pH levels, and extended operation periods), leading to significantly decreased performance and limiting their practical application potentials.^[18,20,21] Therefore, there is a critical need to devise an effective, feasible, and straightforward method for stabilizing the Fe atoms within NiFeO_xH_y, thereby augmenting its intrinsic OER activity.

On the other hand, currently, it is widely accepted that for most NiFe-based compounds including oxides, hydroxides, alloys, phosphides, borides, and chalcogenides,^[22–27] it is inevitable that they undergo reconstruction into higher-valent NiFeO_xH_y structures, that usually serves as the real active structures for alkaline OER. At the same time, other anions present in these precatalysts typically oxidize into water-soluble oxyanions, subsequently dissolving into the surrounding alkaline aqueous media (KOH or NaOH solutions).^[28,29] The leaching of nonmetal species (such as S, Se, and P) is believed to significantly promote the formation of more porous surface structures, increasing the specific surface area, and accelerating

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the OER capability of the in-situ reconstructed real active (oxy)hydroxides.^[30,31] Furthermore, a couple of pioneering investigations have uncovered a fascinating phenomenon concerning transition metal (TM)-based precatalysts in alkaline OER. It has been observed that non-metal species, corroded into oxyanions, can undergo partial re-adsorption onto the surface of reconstructed TM-based (oxy)hydroxides (TMO_xH_y). This re-adsorption process further enhances the OER performance by optimizing the electronic structure of the associated TMO_xH_y , as well as its reaction kinetics and thermodynamics towards alkaline OER intermediates.^[32–35] Similarly, gathering insights from Pourbaix diagrams of individual elements, it is theoretically conceivable that analogous oxygenation-dissolution-re-adsorption phenomena may occur with numerous metal species (such as Sn, Ge, Ti, and W) in TM-based precatalysts.^[36] The reconstructed structures, i.e., the adsorption of metal-formed oxyanions onto the surface of TMO_xH_y , likely exhibit enhanced catalytic performance. However, investigations addressing this aspect are notably sparse, resulting in a significant gap in understanding the potential role of oxyanions in enhancing alkaline OER.

Taking the aforementioned concerns into consideration, stabilizing the metal-formed oxyanions adsorbed by NiFeO_xH_y could offer a solution to addressing the challenge of unsatisfactory alkaline OER performance of NiFeO_xH_y , especially under industrial-relevant environments. Therefore, this study focuses on the deliberate development of a well-defined precatalyst for alkaline OER, Sn-doped NiFe-layered double hydroxide (NiFeSn-LDH), by a facile one-step electrodeposition process. This approach aims to achieve in-situ formation of the targeted NiFe oxyhydroxides (NiFeOOH) adsorbing stannate ions. This is because: firstly, NiFe-LDH materials are widely used as an effective OER precatalyst, which is known to readily transform into the higher-valent NiFeO_xH_y during the alkaline water oxidation process.^[37,38] Secondly, the Pourbaix diagram of Sn indicates that within the anodic OER potential window in 1 M KOH aqueous solution, Sn tends to exist as $\text{Sn}(\text{OH})_6^{2-}$, which is theoretically water-soluble.^[36] As a result, a series of advanced characterizations supported this notion, revealing that after subjecting NiFeSn-LDH precatalyst to OER chronoamperometry (CP) for 24 h in 1 M KOH aqueous solution, the real active structure, i.e., $\text{Sn}(\text{OH})_6^{2-}$ adsorbed NiFeOOH , is emerged. Notably, as expected, compared with the reference sample without the presence of Sn, the optimum NiFeSn-LDH supported on the fluorine-doped tin oxide (NiFeSn-LDH/FTO) glass substrate and nickel foam (NiFeSn-LDH/NF) exhibited significantly enhanced OER performances in 1 M KOH aqueous electrolyte. Specifically, NiFeSn-LDH/NF achieved a remarkable current density of as large as 100 mA cm^{-2} at an overpotential of only $\sim 260 \text{ mV}$ and maintained an industrial-relevant current density of 500 mA cm^{-2} over 5 days with minimal activity degradation, positioning it among the top-performing TM-based alkaline OER catalysts reported to date. This substantial performance enhancement can be attributed to the presence of adsorbed $\text{Sn}(\text{OH})_6^{2-}$, which effectively shields the Fe atoms from leaching into the electrolyte, and modulates the electronic structure of NiFeOOH , thereby promoting its reaction kinetics.

We believe the current work can inspire the community to stimulate further research efforts towards developing more efficient metal-formed oxyanions-incorporated non-noble metal-based OER electrocatalysts, and potentially extending such catalyst systems to other electrooxidation catalysis applications.

Results and Discussion

Synthesis of FTO-Supported NiFeSn-LDH and NiFe-LDH

To prepare the binder-free FTO-supported NiFeSn-LDH and NiFe-LDH, a typical three-electrode system was employed, where the FTO glass substrate, Pt foil, and saturated calomel electrode (SCE) served as the working, counter, and reference electrode, respectively. The aqueous electrolyte contained Ni^{2+} , Fe^{3+} , and Sn^{4+} with a targeted molar ratio. After exerting one-pot electrodeposition under a constant applied voltage of -1.2 V for 4 min, the NiFeSn-LDH and NiFe-LDH nanosheets were grown directly onto the surface of the FTO. Note that compared to the pristine NiFe-LDH with its characteristic hydrotalcite structure, the NiFeSn-LDH incorporates Sn into the double layers consisting of $[\text{Ni}_{1-x}\text{Fe}_x\text{O}_6]$ motifs (as illustrated in Figure 1 and Experimental Section).

Characterizations of NiFeSn-LDH and NiFe-LDH

The powder X-ray diffraction (PXRD) was first carried out on the as-prepared NiFeSn-LDH/FTO and NiFe-LDH/FTO, as well as the bare FTO substrate. In Figure 2a, apart from the peaks originating from the FTO, a low-crystallinity LDH phase can be observed, which is characteristically found for those LDH samples prepared using electrodeposition (PDF #40-0215).^[39,40] In order to further explore the chemical state, phase composition, and morphology of NiFeSn-LDH and NiFe-LDH, X-ray photoelectron spectroscopy (XPS), Raman spectroscopy, field emission scanning electron microscopy (FESEM), as well as transmission electron microscopy (TEM) and the corresponding selected area electron diffraction (SAED), high-angle annular dark field-scanning transmission electron microscopy (HAADF-STEM) and the associated energy dispersive X-ray (EDX) characterizations were performed. In Figure S1a, the high-resolution Ni $2p_{3/2}$ XPS spectrum of NiFe-LDH can be fitted into a prominent peak at $\sim 855.5 \text{ eV}$ together with a minor peak at $\sim 857.2 \text{ eV}$, indicative of Ni^{2+} and Ni^{3+} , respectively, characteristic of a typical NiFe-LDH structure.^[41] Additionally, the Fe $2p_{3/2}$ XPS peak of NiFe-LDH was located at 712 eV , corresponding to the presence of Fe^{3+} (Figure S1b).^[15,42] Notably, in the case of NiFeSn-LDH, both Ni $2p_{3/2}$ and Fe $2p_{3/2}$ displayed positive and negative shifts, respectively, indicating the successful incorporation of Sn atoms into the pristine NiFe-LDH lattice, which induced the electron interaction among host Ni and Fe atoms and their neighboring Sn dopants (Figure S1a, b).^[15,43] Interestingly, an evident Sn $3d_{5/2}$ XPS signal representing Sn^{4+} was detected for NiFeSn-LDH at $\sim 486.3 \text{ eV}$, further confirming the incorporation of Sn atoms^[44] (Figure S1c). The Raman spectrum

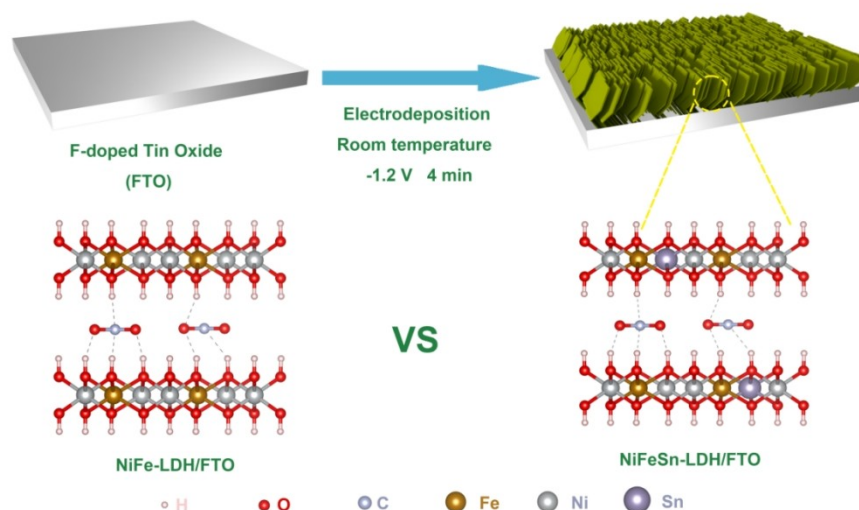


Figure 1. The schematic illustration for the synthesis of FTO-supported NiFeSn-LDH and NiFe-LDH.

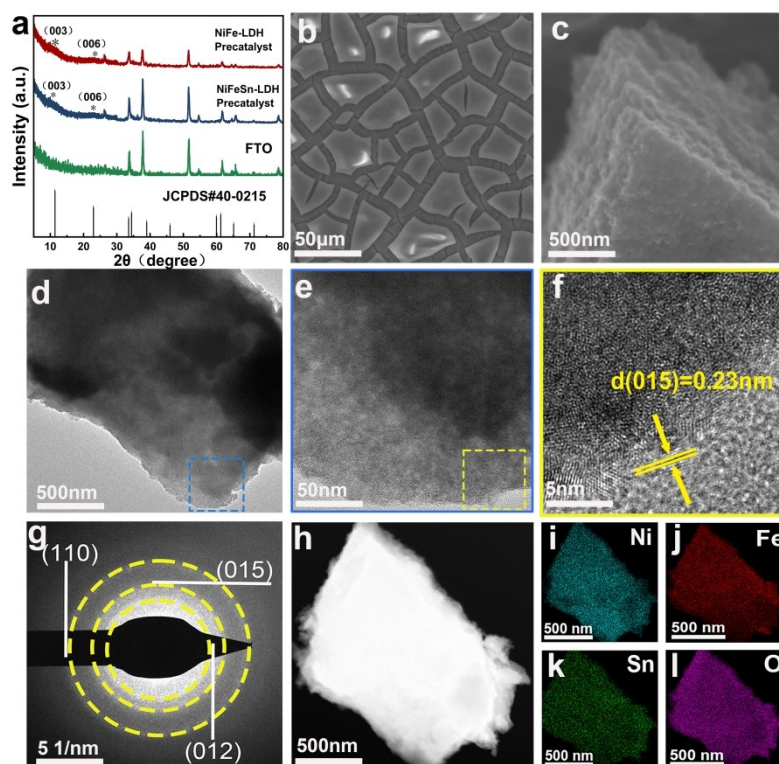


Figure 2. (a) The PXRD patterns of FTO, NiFe-LDH/FTO and NiFeSn-LDH/FTO, (b, c) The FESEM images of NiFeSn-LDH/FTO, (d, e) TEM image, (f) HRTEM image and (g) SAED pattern of NiFeSn-LDH/FTO, together with (h) corresponding HAADF pattern and elemental mappings of Ni (i), Fe (j), Sn (k), and O (l).

of NiFeSn-LDH depicted in Figure S2 exhibited two characteristic bands at ~ 457 and ~ 528 cm^{-1} , arising from the $\text{M}^{3+}\text{--O--M}^{2+}$ and $\text{M}^{3+}\text{--O--M}^{3+}$ in the LDH structure, implying successful preparation of our targeted catalyst.^[45] The FESEM image of the as-prepared NiFeSn-LDH showed sheet-like nanostructures (Figure 2b, c), which can be affirmed by its TEM images (Figure 2d, e). The high-resolution TEM (HRTEM) image

of NiFeSn-LDH presented discernible lattice fringes with a distance of 0.23 nm, indexed to the (015) plane of the LDH structure (Figure 2f). Moreover, the corresponding SAED pattern also signified the presence of (012), (015), and (110) facets of the LDH phase, further confirming the successful synthesis of the targeted material (Figure 2g). Besides, the HAADF-STEM pattern of such a sample with the associated EDX elemental

mapping images was also recorded (Figure 2h–l). The homogeneous distribution of Ni, Fe, Sn, and O within the selected sample region demonstrated the expected doping of Sn into NiFe-LDH, which was also substantiated by the atomic ratio based on such EDX measurements (Ni:Fe:Sn = 1:0.26:0.02, Table S1). On the other hand, similar FESEM, TEM, HRTEM, and SAED results can be observed for the Sn-free NiFe-LDH sample (Figure S3a–g), also illustrating the successful formation of the LDH structure. Of note, the findings of the HAADF-STEM with the corresponding EDX revealed an even distribution of Ni, Fe, and O within the NiFe-LDH region, with an atomic ratio of Ni and Fe closely matching that of NiFeSn-LDH (Figure S3h–k and Table S2). This suggested that, in addition to the absence of Sn, NiFe-LDH possessed a morphology, phase structure, crystallinity, lattice parameters, and Ni/Fe content similar to those of NiFeSn-LDH. Despite these similarities, distinct differences in electrochemical OER performances between the two samples were observed under identical testing conditions, suggesting that the presence of Sn species could be the most prominent factor influencing the observed differences, which will be elaborated in the subsequent sections.

Electrocatalytic OER Performances

The OER performance of all samples was assessed in a typical three-electrode system under ambient conditions, employing a 1 M KOH aqueous solution as the electrolyte. The working electrode comprised FTO-supported samples, while a Hg/HgO electrode and Pt foil served as the reference and counter electrodes, respectively. To begin, we systematically screened the NiFeSn-LDH samples with varying Sn incorporation levels by electrodeposition in solutions containing progressively increased Sn proportions (relative to the total Ni^{2+} , Fe^{3+} , and Sn^{4+} concentrations in equimolar solutions), ranging from 0.05 to 0.15. In Figure S4, the SEM-EDS proved that the above proportion of the sample after deposition is strictly in accordance with the designed ratio. As shown in Figure S5, the fresh samples appear uniform color of yellow, and they turn to black after activation. The linear sweep voltammetry (LSV) results in Figure S6 unveiled that the NiFeSn-LDH with a Sn proportion of 0.1 exhibited the most favorable OER activity. Therefore, this sample was then selected for comprehensive characterization in the subsequent analyses. Next, we compared the OER electrochemistry of such an optimum NiFeSn-LDH deposited on FTO with the pristine NiFe-LDH/FTO. As illustrated in Figure 3a and Figure S7, NiFeSn-LDH/FTO demonstrated superior OER activity, i.e., affording 10 mA cm^{-2} current density at only $\sim 252 \text{ mV}$ overpotential, outperforming NiFe-LDH/FTO. Note that the bare FTO substrate showed inert OER activity and Figure S8 clearly ruled out the possible influence of Pt foil (counter electrode) for OER catalysis.^[22] Figure S9 verifies the good reproducibility of the experiment by testing the LSV curves of three distinct electrodes. Subsequently, the Tafel analysis was measured by the steady-state method on both NiFeSn-LDH/FTO and NiFe-LDH/FTO.^[46] As shown in Figure 3b, the former exhibited a significantly lower Tafel value, meaning

more favorable reaction kinetics than the latter.^[15,47] In addition, the cyclic voltammetry (CV) curves of NiFeSn-LDH/FTO and NiFe-LDH/FTO at different scanning rates were conducted to obtain their electrochemical double-layer capacitance (C_{dl}) values (Figures S10 and 3c). NiFeSn-LDH/FTO demonstrated a C_{dl} value of $0.1923 \text{ mF cm}^{-2}$, approximately double that of NiFe-LDH/FTO ($0.1099 \text{ mF cm}^{-2}$). Given the fact that C_{dl} is proportional to the electrochemically active surface area (ECSA), this indicated that the incorporation of Sn species into NiFe LDH leads to an increase in surface active sites.

As there are no precise methods proposed for calculating accurate C_{dl} so far, we adopted the common determination of C_{dl} through CV cycling for calculation in the current work.^[16,48] Furthermore, we normalized the LSV curves of NiFeSn-LDH/FTO and NiFe-LDH/FTO against their respective C_{dl} to understand their intrinsic activity.^[32,49,50] Notably, Sn-doped NiFe-LDH displayed superior inherent activity compared to its Sn-free counterpart (Figure S11). Besides, the electrochemical impedance spectra (EIS) results manifested that Sn-doping can also boost the charge transfer ability during the OER process, which further contributed to the elevation of OER activity of NiFeSn-LDH (Figure 3d and Table S3). The stability tests for NiFeSn-LDH/FTO and NiFe-LDH/FTO were operated by chronopotentiometry (CP) measurement at a current density of 10 mA cm^{-2} for 24 h. In Figure 3e, only a slight activity decay was observed for NiFeSn-LDH/FTO, while the continuously increased overpotential for NiFe-LDH/FTO, indicating that the introduction of Sn dopants indeed improved the presented OER stability. Encouraged by the superior OER performances of NiFeSn-LDH/FTO, we also electrodeposited NiFeSn-LDH on nickel foam (NiFeSn-LDH/NF) substrate with excellent electrical conductivity and three-dimensional macroporous architecture. The FESEM images first confirmed the homogenous growth of NiFeSn-LDH on NF (Figure S12a–c). Meantime, the TEM, HRTEM, SAED, and HAADF-STEM with EDX characterizations on the NiFeSn-LDH peeled from NF demonstrated that NF-supported NiFeSn-LDH had a similar morphology, phase structure, crystallinity, and lattice parameters to those deposited on FTO (Figure S12d–l). Based on these points, we conducted the OER electrochemistry towards NiFeSn-LDH/NF with the reference sample, NiFe-LDH deposited on NF (NiFe-LDH/NF) using the same method and conditions. As expected, the LSV (Figure 3f), Tafel slope (Figure S13), C_{dl} (Figure S14a–c) and the associated C_{dl} -normalized LSV (Figure S14d), as well as EIS (Figure 3g and Table S4) results uncovered the similar trend between NiFeSn-LDH/NF and NiFe-LDH/NF to the cases when deposited on FTO. Notably, NiFeSn-LDH/NF only required an overpotential of as low as $\sim 260 \text{ mV}$ to deliver 100 mA cm^{-2} current density, and its Tafel slope was merely $\sim 38.78 \text{ mV dec}^{-1}$ (Figure 3f). It is worth noting that such an alkaline OER activity of NiFeSn-LDH/NF surpassed previously documented TM-based catalysts supported on NF (Figure 3h and Table S5). Subsequently, to measure how much oxygen is experimentally observed relative to the amount that is theoretically predicted, the faraday efficiency (FE) was measured. In Figure S15, the highest OER FE of NiFeSn-LDH/FTO was determined as 97%, which shows that NiFeSn-LDH/NF has a good efficiency in the electrolytic process.^[51] Eventually, the

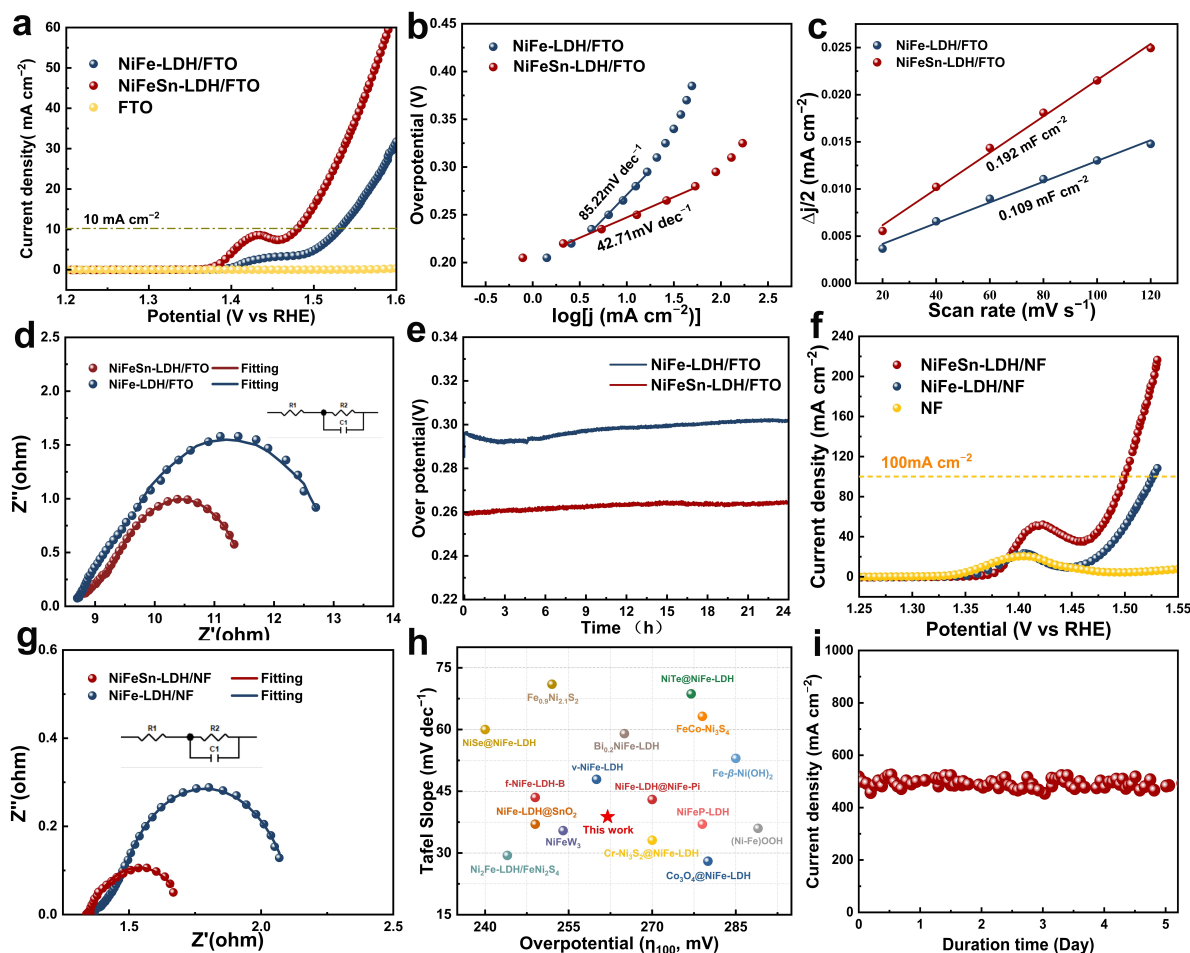


Figure 3. (a) Comparison of linear sweep voltammetry curves of NiFe-LDH/FTO and NiFeSn-LDH/FTO at the scanning rate of 5 mV s^{-1} . (b) The Tafel curves of NiFe-LDH/FTO and NiFeSn-LDH/FTO under steady-state conditions. (c) The C_{dl} value of NiFe-LDH/FTO and NiFeSn-LDH/FTO achieved by acquiring CV curves at scanning rates of 20, 40, 60, 80, 100, and 120 mV s^{-1} , followed by calculations. (d) Nyquist plot of NiFe-LDH/FTO and NiFeSn-LDH/FTO obtained from EIS fitting to an equivalent circuit at an anodic potential of 1.53 V (vs RHE). (e) The stability test curve acquired by conducting CP tests on NiFe-LDH/FTO and NiFeSn-LDH/FTO at a current density of 10 mA cm^{-2} . (f) Linear sweep voltammetry curves of NiFe-LDH/NF, NiFeSn-LDH/NF, and NF at the scanning rate of 5 mV s^{-1} . (g) Nyquist plot of NiFe-LDH/NF and NiFeSn-LDH/NF attained from EIS fitting to an equivalent circuit at an anodic potential of 1.5 V (vs RHE). (h) The performance comparison using overpotentials and Tafel slopes of the current NiFe-based catalysts in alkaline environments. (i) The observed stability curve by conducting a CA test lasting over 5 days at a current density of 500 mA cm^{-2} .

practical application potential of our NiFeSn-LDH/NF was assessed (Figure 3i). Under a chronoamperometry (CA) at an industrial-relevant current density of $\sim 500 \text{ mA cm}^{-2}$, the NiFeSn-LDH/NF maintains a remarkable stability curve over 5 days, affirming its promising prospects for further larger-scale application.

Determination of the Active Structures and Role of the Doped Sn

As aforementioned, it is widely accepted that the surface reconstruction of NiFe-LDH would inevitably occur during the OER process in alkaline media. Therefore, to understand the real active structures of the investigated catalysts in the present work, as well as the role of the doped Sn in promoting the basic OER performances, herein, a series of post-OER (after 24 h OER CP at 10 mA cm^{-2}) characterizations were carried out based on

the samples supported on FTO (to exclude possible interferences from the NF substrate).

To begin, comparing their initial states, the PXRD pattern of post-OER NiFeSn-LDH/FTO and NiFe-LDH/FTO showed that in addition to the peaks originating from the FTO substrate, very similar weak and broad (003) and (006) peaks assigned to LDH phase were hardly be identifiable (Figure 4a). This observation suggests the structural transformation of NiFeSn-LDH to NiFe-based oxyhydroxides. To gain more insights into this point, surface-sensitive techniques including Raman and XPS spectroscopies were adopted on the samples peeled from the FTO substrate. As displayed in Figure 4b, two characteristic bands, *i.e.*, E_g bending and A_{1g} stretching vibration of Ni–O in NiOOH were easily discernible in the Raman spectra of the post-OER NiFeSn-LDH (at ~ 480 and $\sim 565 \text{ cm}^{-1}$) and NiFe-LDH (at ~ 473 and $\sim 560 \text{ cm}^{-1}$).^[15,52,53] These findings manifested that these two LDH precatalysts successfully transformed into the NiFe oxyhydroxides (NiFeOOH).^[15] Notably, two points are worth

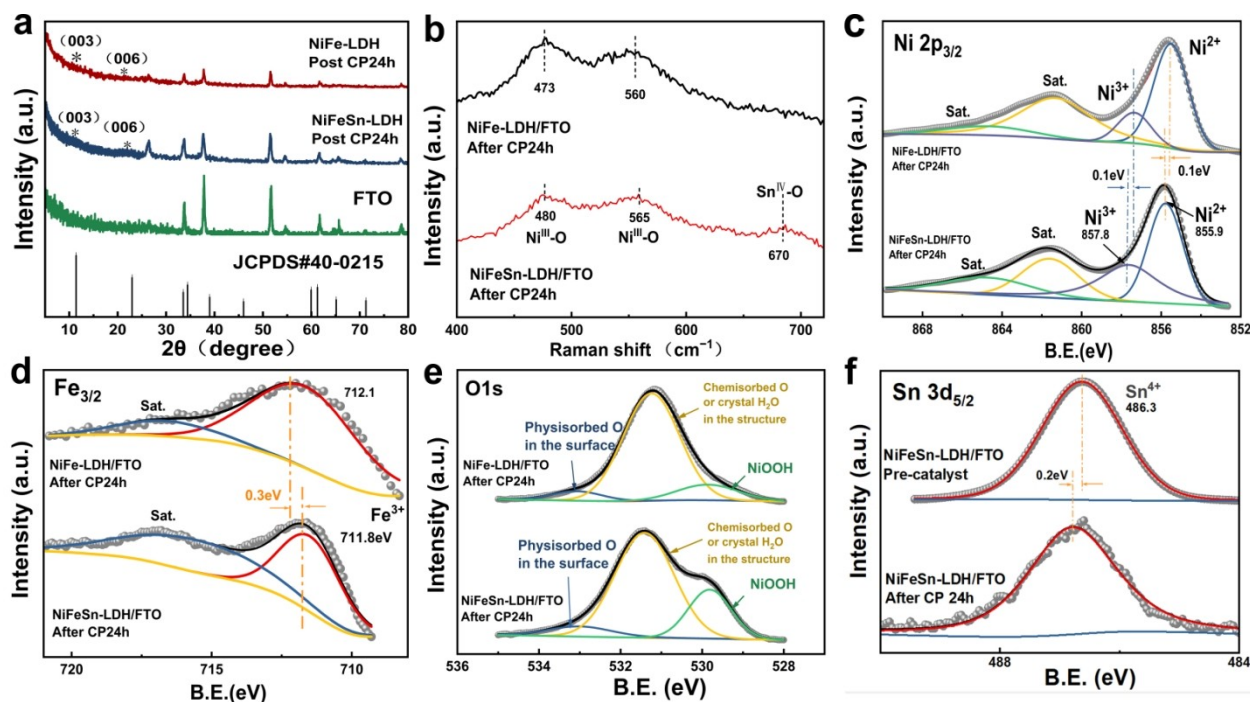


Figure 4. (a) XRD patterns of NiFe-LDH/FTO and NiFeSn-LDH/FTO after CP test. (b) Raman spectra of NiFe-LDH/FTO and NiFeSn-LDH/FTO after CP test. The high resolution (c) Ni 2p_{3/2}, (d) Fe 2p_{3/2} and (e) O 1s XPS spectra of NiFe-LDH/FTO and NiFeSn-LDH/FTO after CP test. (f) High resolution Sn 3d_{5/2} XPS spectra of NiFeSn-LDH/FTO before OER and after CP test.

mentioning: i) In the case of post-OER NiFeSn-LDH, an additional band was clearly identified at ~670 cm⁻¹, originating from the presence of the Sn⁴⁺-O bond.^[54] Intriguingly, such a band was absent in the spectrum of the same NiFeSn-LDH sample before electrochemistry. This can be probably interpreted that the Sn dopants within the NiFe-LDH lattice were evolved as water-soluble Sn(OH)₆²⁻ during the OER process in 1 M KOH aqueous solution (as predicted by the Pourbaix diagram of Sn).^[36] As demonstrated by considerable previous works, the anions of many TM-based compounds would transform into oxyanions during alkaline OER, which were dissolved into the aqueous electrolytes and subsequently re-adsorbed by the concurrently *in-situ* reconstructed TM-based (oxy)hydroxides. Accordingly, in the case of NiFeSn-LDH, the dissolved Sn(OH)₆²⁻ was then re-adsorbed by the surface of *in-situ* evolved NiFeOOH; ii) In the system of NiFeOOH, the Raman intensity ratio of E_g bending and A_{1g} stretching vibration of Ni-O (I_{Eg}/I_{A1g}) can serve as a direct indicator of amounts of Fe dopants within NiOOH. Typically, the lower this intensity ratio, the more Fe is present.^[15,55] The I_{Eg}/I_{A1g} value of the post-OER NiFeSn-LDH (0.175) was apparently lower than that of the post-OER NiFe-LDH (2.812), indicating more stabilized Fe. This could be attributed to the presence of surface-adsorbed Sn(OH)₆²⁻ may inhibit the leaching of Fe from the reconstructed NiFeOOH during the OER process.

Additionally, the XPS results of Ni 2p_{3/2} XPS for both post-OER NiFeSn-LDH and post-OER NiFe-LDH revealed an evident increase in the proportion of Ni³⁺ compared to Ni²⁺, signifying the surface reconstruction of LDH into higher-valence oxyhydroxide (Figure 4c). In the Fe 2p_{3/2} XPS spectra for both

samples, the Fe³⁺ peaks positively shifted compared with those in their respective spectra before electrochemistry, also substantiating the occurrence of surface oxidative reconstruction (Figure 4d). Moreover, the surface evolution of oxyhydroxides can be further verified by the O 1s XPS spectra of these two samples (Figure 4e), from which NiOOH could be identified.^[56,57]

Furthermore, the Sn 3d_{5/2} XPS peak indicative of Sn⁴⁺ slightly shifted to higher binding energy for the post-OER NiFeSn-LDH compared with that for the sample before OER. This demonstrated that the doped Sn⁴⁺ within the NiFe-LDH was evolved as a stannate ion and then adsorbed on the surface of reconstructed NiFeOOH during OER in 1 M KOH aqueous solution, in agreement with the Raman data and analysis (Figure 4f). Another noteworthy point here is that the XPS peaks representing Ni³⁺ and Ni²⁺, as well as Fe³⁺ for the post-OER NiFeSn-LDH emerged at higher and lower binding energy positions, respectively, compared with those for the post-OER NiFe-LDH, unveiling the electronic modification of the reconstructed NiFeOOH induced by its surface-adsorbed stannate ions (Figure 4c, d). On the other hand, various microscopic characterizations were also employed to determine the real active structures of NiFeSn-LDH and NiFe-LDH under alkaline water oxidation. The FESEM images of post-OER NiFeSn-LDH and post-OER NiFe-LDH both displayed sheet-like morphology, which are the typical structures for (oxy)hydroxides^[58,59] (Figures 5a, b and S16a, b). Such a morphology can be further proven through TEM images of these two samples (Figures 5c and S16c). In addition, from the HRTEM images in Figure 5d, the distance of the lattice fringes at the edge region of the post-OER NiFeSn-LDH can be identified as 0.206 nm, which can be

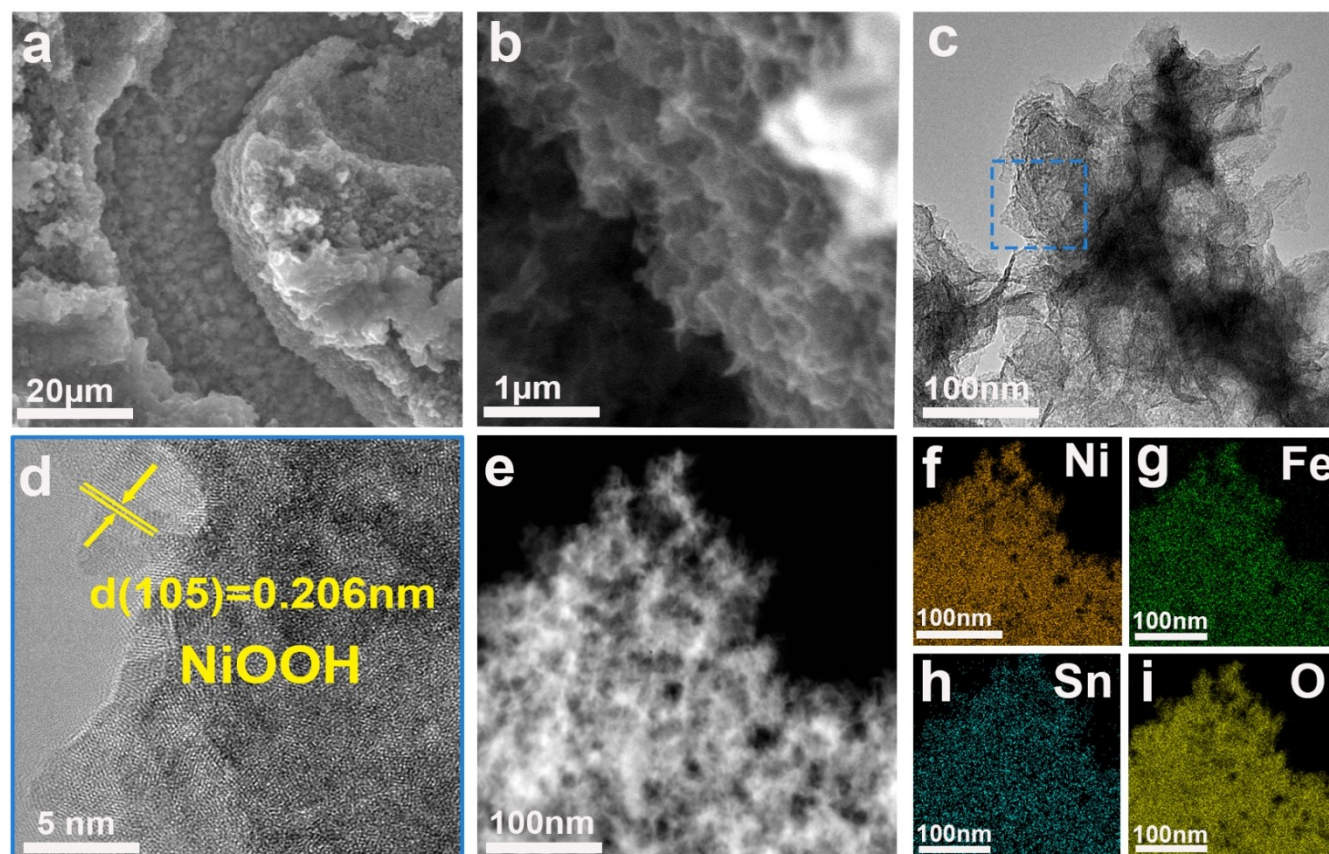


Figure 5. (a, b) FESEM images of NiFeSn-LDH/FTO after the CP test, (c) TEM image and (d) HRTEM image of NiOOH scratched off from NiFeSn-LDH/FTO after the CP test, together with (e) corresponding HAADF pattern and elemental mappings of Ni (f), Fe (g), Sn (h), and O (i).

ascribed to the (105) plane of NiOOH (PDF #6-75). Similarly, the (105) plane and (101) plane of NiOOH (PDF #6-75) can also be found from the HRTEM image against the edge of the post-OER NiFe-LDH (Figures S16d). Besides, from the HADDF-STEM pattern and the associated EDX elemental mapping, Ni, Fe, Sn, and O were distributed evenly within the selected post-OER NiFeSn-LDH area, implying the stable existence of $\text{Sn}(\text{OH})_6^{2-}$ (as oxyanion) adsorbed on the surface of in-situ evolved NiFeOOH (Figure 5e–i). Analogically, homogenous Ni, Fe, and O can be also found in the region of post-OER NiFe-LDH (Figure S16e–h). Importantly, the corresponding EDX atomic ratio results showed that sufficient Sn was still retained for the post-OER NiFeSn-LDH, arising from the remained LDH precatalyst and the re-adsorbed $\text{Sn}(\text{OH})_6^{2-}$.

In contrast, compared to the post-OER NiFe-LDH, substantially more Fe was found in the NiFeSn-LDH after OER CP (Tables S1, S2), consistent with the Raman analysis, *i.e.*, the presence of $\text{Sn}(\text{OH})_6^{2-}$ could effectively protect the Fe within NiFeOOH from leaching into the KOH electrolyte during OER process. According to the Pourbaix diagram, it can be seen that Sn and Fe will form $\text{Sn}(\text{OH})_6^{2-}$ and ferrate ions, respectively, which then dissolve into the electrolyte in a strong alkali environment.^[36] Due to the high electronegativity of oxygen anion ($\text{Sn}(\text{OH})_6^{2-}$), there is a strong interaction between Fe

element and oxygen anions, which weakens the occupation between the 3d orbital of Fe^{3+} and the 1 s orbital of OH^- in the electrolyte, thus effectively avoiding the oxidation of Fe element to a higher valance state in a strong alkali environment.^[60–63]

Based on the above post-OER characterizations, we can conclude that the surface of NiFeSn-LDH and NiFe-LDH reconstructed into the NiFeOOH with and without $\text{Sn}(\text{OH})_6^{2-}$ adsorption, respectively. At the same time, the improved activity and stability of NiFe-LDH induced by Sn doping mainly stemmed from the re-adsorption of the $\text{Sn}(\text{OH})_6^{2-}$ on the surface of the in-situ reconstructed NiFeOOH during the OER process, and the involved alkaline OER reaction steps are summarized in Figure S17.^[11] The stable presence of the surface $\text{Sn}(\text{OH})_6^{2-}$ can greatly suppress the dissolution of Fe from NiFeOOH during basic OER, as well as tune the electronic structure of NiFeOOH and enhance its reaction kinetics.^[64,65]

Conclusions

In this study, we synthesized a Sn-doped NiFe-layered double hydroxide (NiFeSn-LDH) using a facile electrodeposition technique for alkaline OER. Based on the comprehensive pre- and

post-OER characterizations, coupled with the related background knowledge, we reasonably conclude that during water oxidation in 1 M KOH aqueous media, the Sn dopants from NiFeSn-LDH were evolved as the soluble $\text{Sn}(\text{OH})_6^{2-}$, dissolved into the electrolyte, and are subsequently re-adsorbed onto the concurrently reconstructed NiFeOOH surface. This stable existence of surface-adsorbing oxyanions effectively prevented the leaching of Fe atoms from the NiFeOOH lattice. Furthermore, it induced beneficial alterations in the electronic structure of NiFeOOH, resulting in enhanced OER kinetics. Notably, when NiFeSn-LDH is deposited on the conductive NF, it can afford a current density of 100 mA cm^{-2} at an overpotential of only $\sim 260 \text{ mV}$, as well as maintain an industrial-relevant current density of as high as $\sim 500 \text{ mA cm}^{-2}$ over 5 days without visible activity degradation. This performance surpasses that of most reported TM-based electrocatalysts for alkaline OER. Our work sheds light on the key role of residual surface oxyanions during water oxidation and provides insight into the design strategy to develop a new generation of low-cost, high-performance NiFe-based catalysts for water electrolysis. It is also intriguing to discover that the adsorption of residual surface Sn-containing oxyanions can positively influence the OER performance of d-block TM-based precatalysts as well as potentially improve the kinetics by stabilizing OER reaction intermediates.^[31,33] This finding is likely to inspire further development of novel *p*-block metals (such as Ge, Bi, Al, and In)-mediated TM-based precatalysts for electrocatalysis.

Experimental Section

Chemicals and Materials

Deionized water was used to carry out all the experiments. The potassium hydroxide KOH (95%), nickel nitrate $\text{Ni}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (98%), ferrous nitrate $\text{Fe}(\text{NO}_3)_2 \cdot 9\text{H}_2\text{O}$ (98.5%) were acquired from Sinopharm Group Co. Ltd. and $\text{SnCl}_4 \cdot 4\text{H}_2\text{O}$ was obtained from Macklin Biochemical Technology Co., Ltd. The electrode substrates NF and FTO were purchased from Merck & Co., Inc.

Synthesis of NiFeSn-LDH and NiFe-LDH

The electrodeposition was conducted in a standard three-electrode system, where bare FTO or NF served as the working electrode, Pt foil worked as the counter electrode, and SCE was used as the reference electrode. $\text{Ni}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, $\text{Fe}(\text{NO}_3)_2 \cdot 9\text{H}_2\text{O}$, and $\text{SnCl}_4 \cdot 4\text{H}_2\text{O}$ (totally 50 mM) were dissolved into 50 mL deionized water with a molar ratio of $\text{Ni}^{2+}:\text{Fe}^{3+}:\text{Sn}^{4+} = 4:1:0.56$ (the Sn^{4+} proportion relative to the total molar sum of Ni^{2+} , Fe^{3+} , and Sn^{4+} was ~ 0.1). For optimizing the Sn dopants, the electrodeposition was also performed in the aqueous solution where the proportion of Sn^{4+} against the total molar of Ni^{2+} , Fe^{3+} , and Sn^{4+} was ~ 0.05 and ~ 0.15 (note that the volume of the deposition solution and molar ratio of $\text{Ni}^{2+}:\text{Fe}^{3+}$ was fixed as 50 mL and 4:1, respectively). The constant applied potential was set as -1.2 V for 240 s with a CHI760e electrochemical workstation. The resulting loading mass was around $\sim 1.03 \text{ mg cm}^{-2}$ on the FTO, and that on NF was comparable. For the preparation of FTO or NF-supported NiFe-LDH preparation, the same procedure as mentioned above was followed, except no Sn^{4+} source was included. The loading mass was controlled to match that of the NiFeSn-LDH case.

Characterization

The phase information of the studied samples was obtained using PXRD on a Bruker D8 ADVANCE X-ray diffractometer with $\text{Cu K}\alpha$ radiation ($\lambda = 1.5406 \text{ \AA}$). The morphology and structure of the targeted samples were investigated by FESEM (electron microscopy SU800, Hitachi, Tokyo, Japan) at a 20 kV acceleration. The TEM (FEI Talos F200X) was further employed to gain more insights into their microstructures, phase, as well as composition presence and distribution. The XPS measurements were carried out on an ESCALAB 250Xi spectrometer (Thermo Scientific, USA) equipped with a pass energy of 30 eV with a power of 100 W (10 kV and 10 mA) and a mono-chromatized α X-ray ($h\nu = 1486.65 \text{ eV}$) source. All samples were analyzed under a pressure of less than $1.0 \times 10^{-9} \text{ Pa}$. Spectra were acquired through the advantage software (Version 5.979) with a step of 0.05 eV. The Raman spectroscopy was recorded using a Horiba LabRam HR Evolution confocal Raman microscope with a laser excitation wavelength of 473 nm, laser power of 1.25 mW, and $100\times$ objective lens ($\text{NA} = 0.95$).

Electrochemical Measurements

The electrochemistry was conducted using a CHI760e and EC-Lab electrochemical workstations in a standard three-electrode system. The catalysts electrodeposited on different substrates directly served as the working electrodes, while a Pt foil ($1 \times 1 \text{ cm}$) and Hg/HgO electrode acted as the counter electrode and reference electrode, respectively. The LSV, CV, CP, and CA experiments were carried out with an iR compensation of 95% on the CHI760e instrument. Moreover, the CV and LSV tests were conducted at a scan rate of 5 mVs^{-1} . All measured potentials were calibrated with respect to RHE based on the following equation: $E(\text{RHE}) = E(\text{Hg/HgO}) + 0.098 \text{ V} + (0.0591 \times \text{pH}) \text{ V}$, where the pH value of 1 M KOH was adopted from our previous report.^[66] The method for calculating overpotential involves measuring the potential at a current density of 10 mA cm^{-2} and then subtracting the theoretical potential for water splitting ($\eta_{10} = E_{\text{RHE}} - 1.23 \text{ V}$). The choice of 10 mA cm^{-2} as a reference point is because this current density is close to the practical operating conditions for solar fuel synthesis, thus holding significant practical value.^[67] The Tafel slope, C_{dl} , and EIS were conducted on the EC-Lab electrochemical workstation. The Tafel slope was determined through a steady-state measurement, i.e., the CA was performed at a fixed potential for 3 minutes, and the applied potential gradually increased with an interval of 15 mV .^[50] The average current density obtained at each potential was used for the calculation of Tafel plots. The Tafel slope was determined according to the Tafel equation: $\eta = \text{blog } j + a$, where η , b , and j represent overpotential (V), Tafel slope (mV dec^{-1}), and current density (mA cm^{-2}), respectively. To assess the C_{dl} , CV was performed at a non-Faradaic voltage region. The half of the difference for the current density at the middle point of the CV potential window was plotted as a function of the scan rate, yielding the corresponding slope, which is the specific value of C_{dl} . The EIS was recorded at 1.53 V (vs. RHE) for catalysts deposited on FTO, as well as 1.50 V (vs. RHE) for the ones on NF. The amplitude of the sinusoidal wave was determined in a frequency range of 100 kHz to 1 mHz. The charge transfer resistance (R_{ct}) was reflected by the diameter of the semicircle in the Nyquist plots after fitting in the EC-Lab. The FE was measured through the water drainage method. During this process, a consistent potential was maintained at the electrode, while the volume of gases (oxygen) generated was continuously tracked. Subsequently, the quantity of hydrogen moles was determined by utilizing gas laws. Lastly, the theoretically anticipated amount of O_2 was calculated by invoking the Faraday law, which asserts that the passage of 96,500 coulombs produces one equivalent of a chemical reaction.^[51]

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Conflict of Interests

The authors declare no conflict of interest.

Data Availability Statement

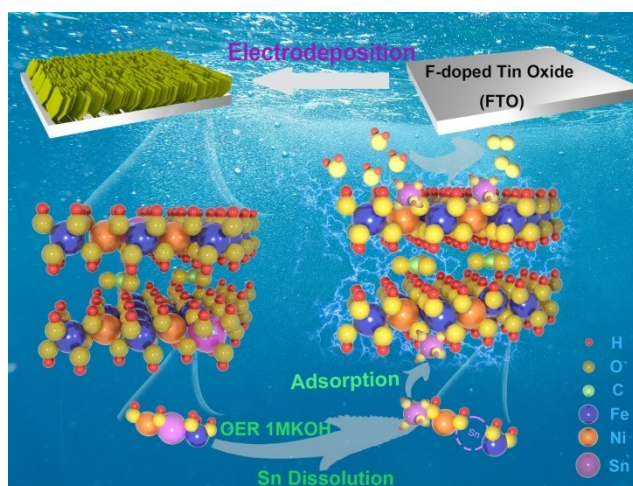
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Keywords: electrochemical reconstruction · leaching-adsorption · oxyanions · NiFe (oxy)hydroxides · alkaline OER

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A critical role of Tin: During the alkaline OER process, Sn-doped NiFe-LDH precatalysts undergo in-situ evolution into NiFeOOH, which subsequently surface adsorbs $\text{Sn}(\text{OH})_6^{2-}$. These Sn oxyanions endow the

NiFeOOH to display remarkable activity and stability through inhibiting Fe leaching, modifying the electronic structure, and enhancing OER reaction kinetics.

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**Efficient Alkaline Water Oxidation
Electrocatalysis Enabled via the Mod-
ulation of Sn-Containing Anions
towards NiFe Oxyhydroxide**



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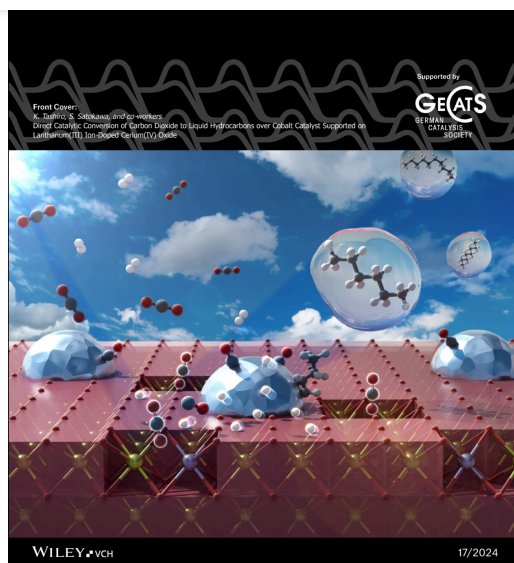
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Direct Catalytic Conversion of Carbon Dioxide to Liquid Hydrocarbons over Cobalt Catalyst Supported on Lanthanum(III) Ion-Doped Cerium(IV) Oxide

Keigo Tashiro, Hikaru Konno, Akihide Yanagita, Shunta Mikami, Shuhei Shimoda, Erika Taira, David S. Rivera Rocabado, Ken-ichi Shimizu, Takayoshi Ishimoto, Shigeo Satokawa

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reactions over a supported cobalt catalyst. In their Research Article, Keigo Tashiro, Shigeo Satokawa, and co-workers reveal that lanthanum-doped ceria provides the oxygen vacancies which promote CO₂ reduction to CO, and the supported cobalt metals produce long-chain hydrocarbons via Fischer–Tropsch synthesis. As reported by the authors, the CO₂ direct Fischer–Tropsch reaction technology will contribute to reaching a bright carbon-neutral future. For more details, see the [Research Article by K. Tashiro, S. Satokawa, and co-workers \(DOI: 10.1002/cctc.202400261\)](#).

[Abstract](#) | [Full text](#) | [PDF](#) | [Request permissions](#)

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Cover Feature: Bifunctional Strontium Cobalt Molybdenum Oxide (Sr₂CoMoO₆) Perovskite as an Efficient Catalyst for Electrochemical Water Splitting Reactions in Alkaline Media (ChemCatChem 17/2024)

Shahan Atif, Abhisek Padhy, Pawan Kumar Jha, Dorothy Sachdeva, Dr. Prabeer Barpanda

First Published: 09 September 2024

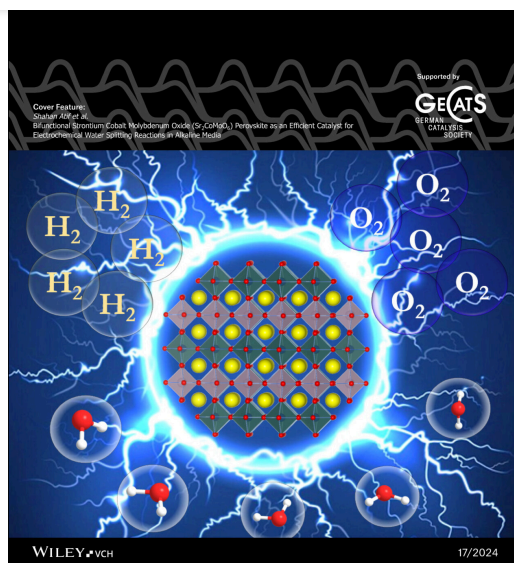
This article relates to: >

Bifunctional Strontium Cobalt Molybdenum Oxide (Sr₂CoMoO₆) Perovskite as an Efficient Catalyst for Electrochemical Water Splitting Reactions in Alkaline Media

Shahan Atif, Abhisek Padhy, Pawan Kumar Jha, Dorothy Sachdeva, Prabeer Barpanda

Volume 16, Issue 17, ChemCatChem | First Published online: June 24, 2024

The Cover Feature highlights the concept that, for water-splitting reaction and related clean energy technology, it is imperative to design earth-abundant low-cost electrocatalysts. In this spirit, the work by Abhisek Padhy, Prabeer Barpanda, and co-workers introduces double perovskite-based strontium cobalt molybdenum oxide (SCMO) as an efficient bifunctional electrocatalyst showing both hydrogen evolution reaction (HER) and oxygen evolution reaction (OER). Prepared by scalable autocombustion synthesis, the bulk SCMO perovskite exhibits stable electrocatalytic performance attributed to its substantial electrochemical active surface area. Double perovskite electrocatalysts can be harnessed for sustainable energy technologies. More information can be found in the [Research Article by Shahan Atif et al. \(DOI: 10.1002/cctc.202400217\)](#).



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Editorial

 **Free Access**

Special Collection: Holistic Development of Electrochemical Processes for Industrial Systems

Prof. Dr. Doris Segets, Prof. Dr. Ulf-Peter Apfel

First Published: 07 May 2024



Bridging the gap: This Guest Editorial introduces a Special Collection dedicated to the field of application-oriented electrochemical processes and contains a diverse selection of original research contributions in this field. It reaches from a fundamental electrochemical understanding, over catalyst material development, to engineering technology.

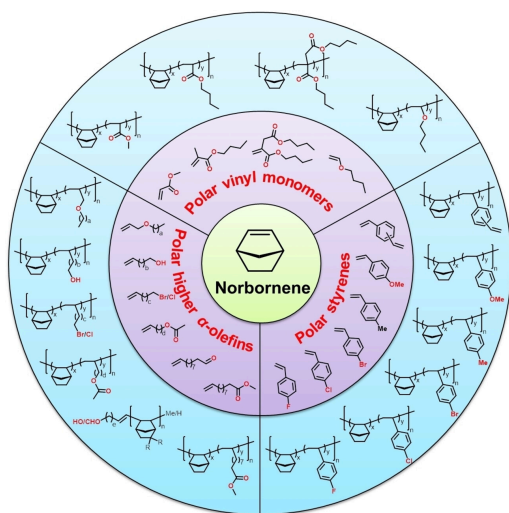
Review

 Open Access

Nickel- and Palladium-Catalyzed Copolymerizations of Norbornene with Polar α -Olefins

Mingyuan Li, Yueting Fang, Zhengguo Cai, Moris S. Eisen

First Published: 26 March 2024



Recent progress in the copolymerization of norbornene and polar monomers catalyzed by nickel and palladium catalysts is reviewed. The polar vinyl monomers, polar higher α -olefins, and polar styrenes are used to synthesize polar functionalized norbornene-based cyclic olefin copolymers that have diversified polymer microstructures and exhibit enhanced material performances.

[Abstract](#) | [Full text](#) | [PDF](#) | [References](#) | [Request permissions](#)

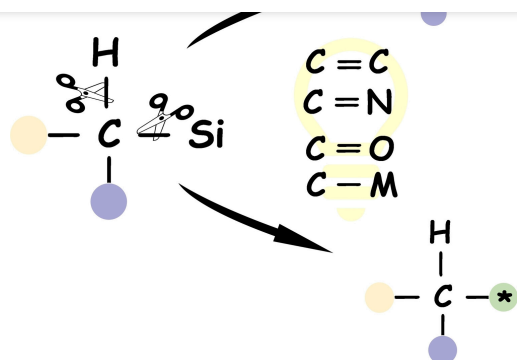
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Applications of Organosilanes in Visible Light-induced Catalytic Asymmetric Reactions

Liuzhen Hou, Prof. Weidi Cao, Prof. Xiaoming Feng

First Published: 27 March 2024

This review provides the overview of comprehensive advances in the chemistry of organosilanes in asymmetric photoredox catalyzed organic synthesis, which are introduced from the mechanism perspective including C–Si bond cleavage and C–H bond cleavage of organosilanes. It is hopeful to provide guidance and assistance for the development of this field in future.



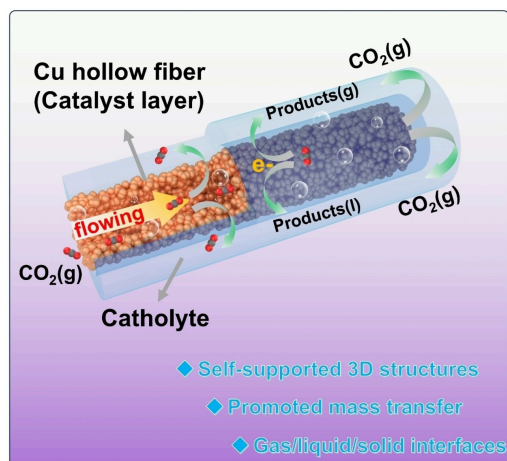
[Abstract](#) | [Full text](#) | [PDF](#) | [References](#) | [Request permissions](#)

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Advances in CO₂ Electroreduction over Hollow Fiber Gas Diffusion Electrodes

Yuanlin Gao, Xiaoyue Tu, Xiangjian Liu, Yu Zhang, Minghua Huang, Jiawei Zhu, Heqing Jiang

First Published: 02 April 2024



Hollow fiber gas diffusion electrodes (HFGDEs) provide rich triple-phase interfaces and achieve efficient mass transfer from its unique three-dimensional structure for CO₂ electroreduction (CO₂RR). In this review, we summarized the latest progress of HFGDEs applied in CO₂RR, and proposed current challenges as well as future development directions for accelerating application of HFGDEs in industrial CO₂ electrolyzers.

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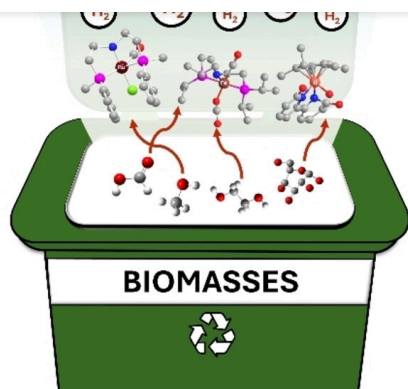
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Advances in the Homogeneously Catalyzed Hydrogen Production from Biomass Derived Feedstocks: A Review

Dr. Andrea Fasolini, Dr. Giulia Martelli, Dr. Andrea Piazzzi, Dr. Massimiliano Curcio, Dr. Jacopo De Maron, Prof. Francesco Basile, Prof. Rita Mazzoni

First Published: 10 April 2024

The review describes recent advances in homogeneously catalysed hydrogen production from biomass derived substrates, such as formic acid, alcohols, polyalcohols, sugars and cellulose. Role of bifunctional catalysts, bi-catalytic systems, catalysts immobilization, and mechanistic investigation is critically analyzed to draw a perspective from both sustainability and possible development on real application.



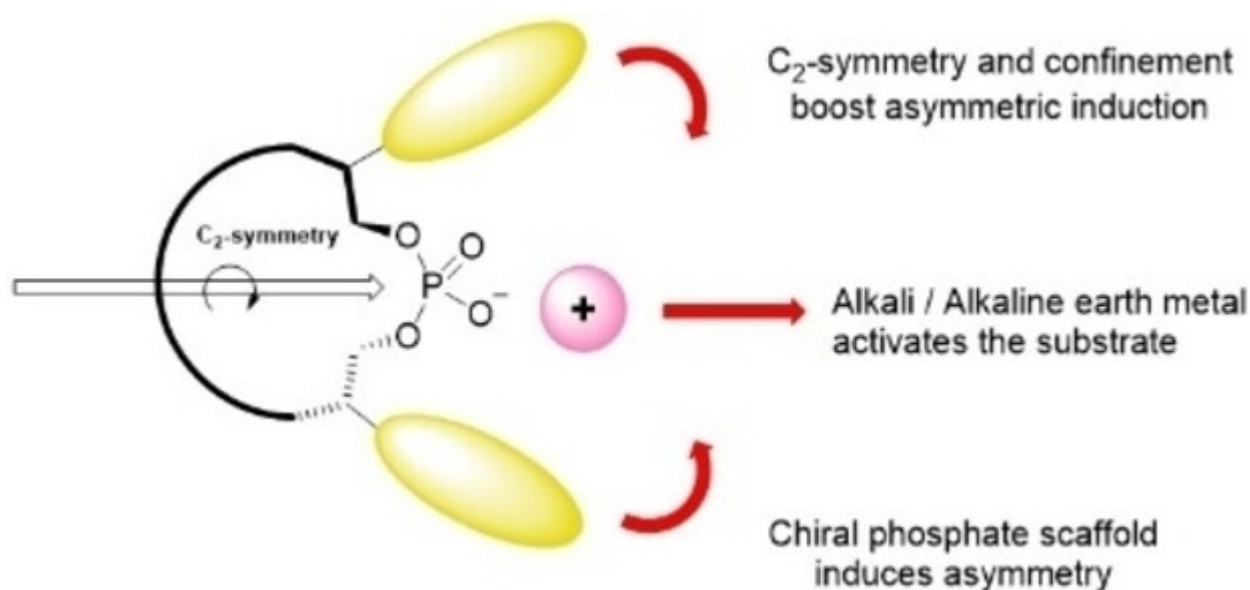
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Stereoselective Reactions Promoted by Alkali Metal Salts of Phosphoric Acid Organocatalysts

Emanuele Cocco, Dr. Achille Antenucci, Prof. Dr. Armando Carlone, Prof. Dr. Paola Manini, Dr. Fabio Pesciaioli, Prof. Stefano Dughera

First Published: 12 April 2024



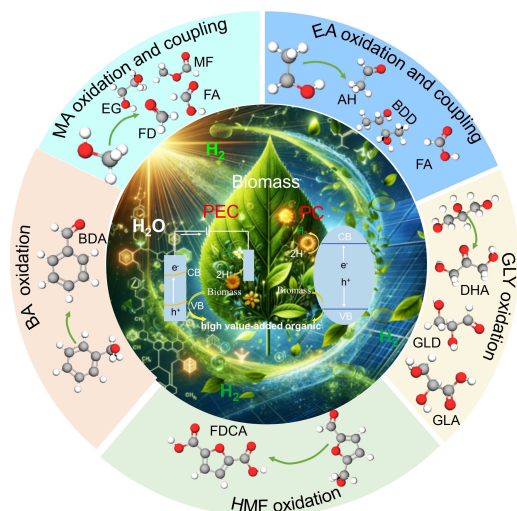
A comprehensive overview on asymmetric organic reactions catalyzed by alkali and alkaline earth metal phosphates following ACDC mechanistic pathways. The lower toxicity associated to such metal species, with respect to transition metals, offers food for thought to their further employment in asymmetric synthesis, also giving a nod to green chemistry.

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Dr. Prof. Yiming Liu, Assoc. Prof. Dr. Wanggang Zhang, B.A. Yue Wang, Dr. Rufeng Tian, Assoc. Prof. Dr. Jian Wang

First Published: 19 April 2024



Exploring the frontier of photocatalysis and photoelectrocatalysis, this study focuses on the transformative conversion of biomass into high-value organic compounds. By delving into reaction mechanisms and optimizing process parameters, we unveil the immense potential of coupled catalytic systems for sustainable chemical manufacturing, paving the way for future green energy and material developments.

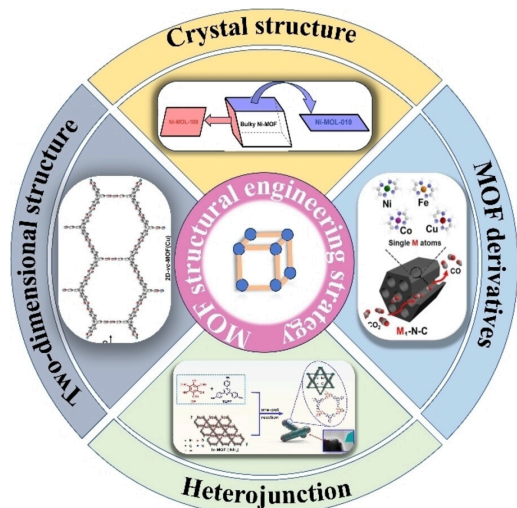
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Structural Engineering of Metal-Organic Frameworks for Efficient CO₂ Reduction Reaction

Mingjie Cheng, Xiaoli Zheng, Fuxiao Ma, Zhengkai Zhu, Qun Xu

First Published: 21 April 2024



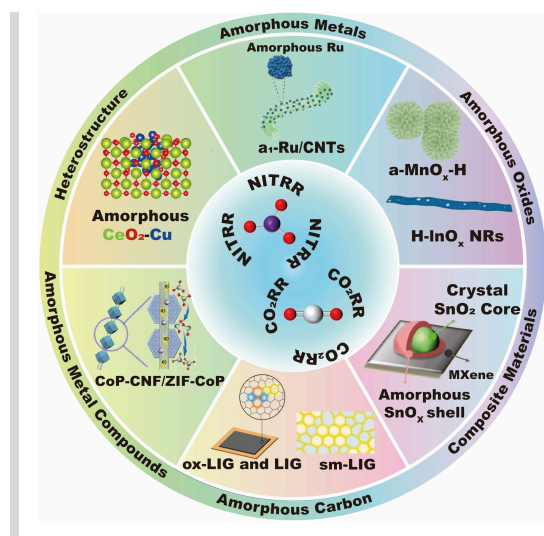
A rational structural engineering of metal-organic framework (MOF) catalysts to increase density and activity of active centers is one of the keys to build high-efficient catalysts. This review introduces crystal structure, 2D structure, heterojunction and MOF derivatives of MOFs structural engineering strategies, for enhancing the catalytic CO₂ reduction performance. And the challenges and future development direction of MOFs are emphasized.

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Kun Wang, Ziyao Cheng, Guanzheng Wu, Prof. Qing Qin

First Published: 26 April 2024



Efficient catalysts play a pivotal role in the nitrate (NO_3^-) reduction reaction (NITRR) and carbon dioxide reduction reaction (CO_2RR), with various amorphous materials demonstrating exceptional performance in both processes. By presenting practical applications of these amorphous materials in NITRR and CO_2RR , valuable insights are gained for the design of catalysts that are even more effective.

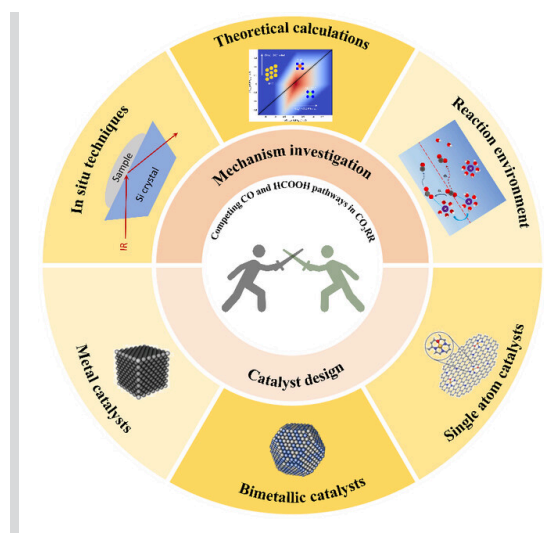
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Competing CO and HCOOH Pathways in CO_2 Electroreduction

Aiming Huang, Tian Zhou, Junjun Zhang, Yifan Zhang, Yang Wu, Yong Wang, Wen Luo

First Published: 01 May 2024



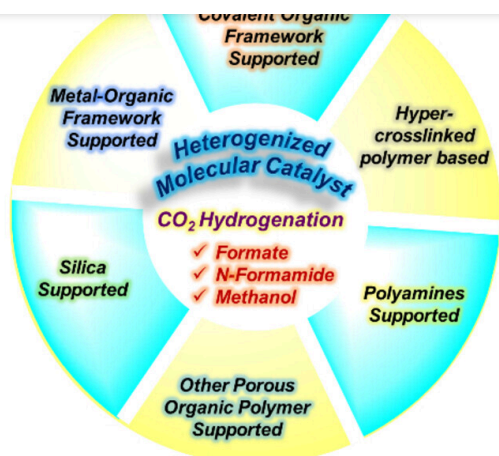
This review offers a comprehensive examination of the latest research on the selective reduction of CO_2 to CO and/or HCOOH, focusing on the development of the reaction mechanisms based on theoretical simulations and experimental investigations, and the design of electrocatalysts for tuning the CO/HCOOH selectivity.

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Single-Site Heterogenized Molecular Catalysts towards CO_2 Hydrogenation to Formates, Formamides and Methanol

Dr. Tanmoy Mandal, Ravi Kumar, Saurabh Kumar, Prof. Dr. Joyanta Choudhury



heterogenized molecular catalysts and showed their utility in the CO₂ hydrogenation reaction for the production of formic acid/formates, N-formamides, and methanol. This review aids in the understanding of the advancement of research and development of these techniques for heterogenization by examining the influence of the catalytic metal center, ligation environment, and immobilization procedure.

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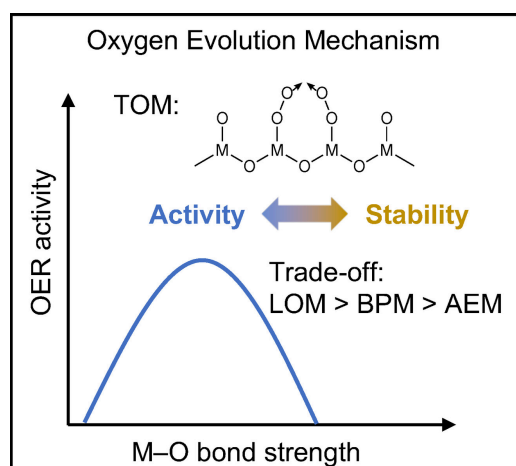
Perspective

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How to Break the Activity-Stability Conundrum in Oxygen Evolution Electrocatalysis: Mechanistic Insights

Dr. Tobias Binninger, Genevieve C. Moss, Ziba S. H. S. Rajan, Dr. Rhiyaad Mohamed, Prof. Dr. Michael H. Eikerling

First Published: 12 June 2024

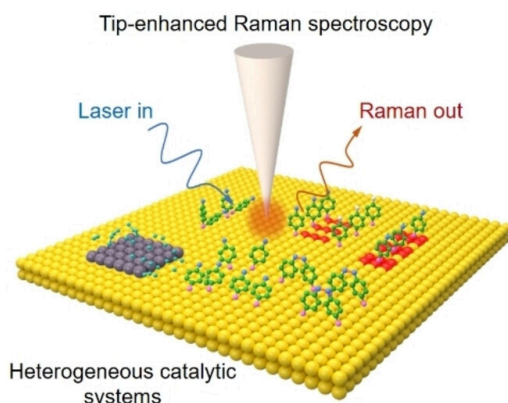


Common mechanisms of the oxygen evolution reaction (OER) involve the splitting of metal-oxygen bonds (M–O), requiring intermediate M–O bond strength according to the Sabatier principle. However, maximum bond strength is needed for optimal bulk oxide stability, which results in an activity-stability trade-off. The tetraoxidane mechanism (TOM) proceeds without breakage of M–O bonds, enabling both excellent OER activity and catalyst stability.

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First Published: 24 June 2024



Understanding the molecular mechanism of heterogeneous catalytic processes is fundamental to the design of high-performance catalysts and the development of energy conversion technology. This perspective summarized the key insights into heterogeneous catalysis by tip-enhanced Raman spectroscopy.

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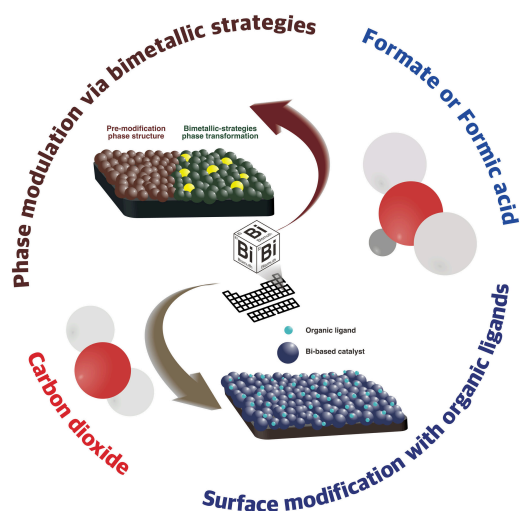
Concept

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Design of Bismuth-Based Electrocatalysts for Carbon Dioxide Electroreduction

Xin Wang, Muhammad Adib Abdillah Mahbub, Debanjan Das, Wolfgang Schuhmann

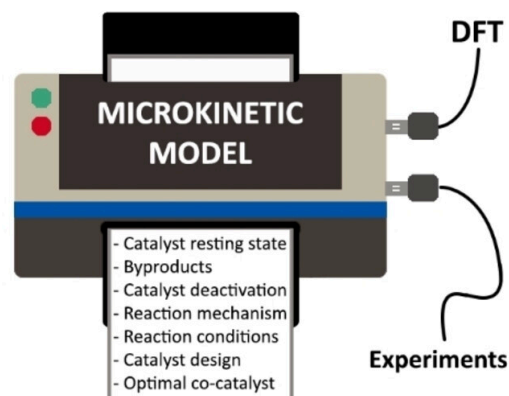
First Published: 05 May 2024



Phase modulation via heteroatom doping and surface modification with organic ligands enhance formate/formic acid production during the electrochemical CO₂ reduction reaction over Bi-based electrocatalysts.

[Abstract](#) | [Full text](#) | [PDF](#) | [References](#) | [Request permissions](#)[Open Access](#)

First Published: 12 April 2024



Microkinetic modeling built upon combining computational and experimental results is becoming a very helpful tool for the study of reaction mechanisms in homogeneous catalysis. In this concept, we provide the reader with examples of the valuable information that can be extracted from microkinetic models and how this technique can guide the catalyst design.

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Direct Catalytic Conversion of Carbon Dioxide to Liquid Hydrocarbons over Cobalt Catalyst Supported on Lanthanum(III) Ion-Doped Cerium(IV) Oxide

Dr. Keigo Tashiro, Hikaru Konno, Akihide Yanagita, Shunta Mikami, Prof. Shuhei Shimoda, Erika Taira, Dr. David S. Rivera Rocabado, Prof. Ken-ichi Shimizu, Prof. Takayoshi Ishimoto, Shigeo Satokawa

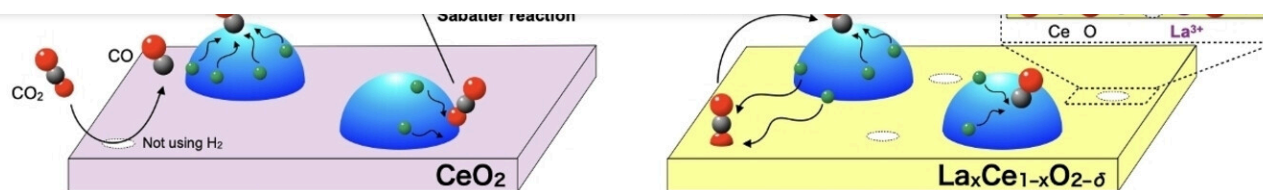
First Published: 28 May 2024

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Front Cover: Direct Catalytic Conversion of Carbon Dioxide to Liquid Hydrocarbons over Cobalt Catalyst Supported on Lanthanum(III) Ion-Doped Cerium(IV) Oxide (ChemCatChem 17/2024)

Keigo Tashiro, Hikaru Konno, Akihide Yanagita, Shunta Mikami, Shuhei Shimoda, Erika Taira, David S. Rivera Rocabado, Ken-ichi Shimizu, Takayoshi Ishimoto, Shigeo Satokawa

Volume 16, Issue 17, ChemCatChem | First Published online: September 9, 2024



Direct hydrogenation of CO_2 to produce liquid hydrocarbons by Fischer-Tropsch synthesis reaction is performed over a cobalt catalyst supported on La^{3+} -ion-doped cerium oxide. This reaction is promoted through reverse water gas shift reaction occurring due to the formation of extrinsic oxygen vacancy formed by La^{3+} -ion doping.

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Bifunctional Strontium Cobalt Molybdenum Oxide ($\text{Sr}_2\text{CoMoO}_6$) Perovskite as an Efficient Catalyst for Electrochemical Water Splitting Reactions in Alkaline Media

Shahan Atif, Abhisek Padhy, Pawan Kumar Jha, Dorothy Sachdeva, Dr. Prabeer Barpanda

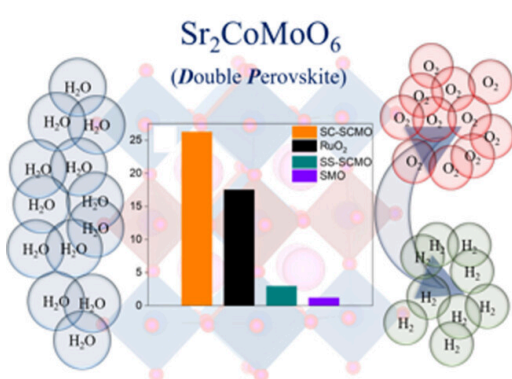
First Published: 11 May 2024

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Cover Feature: Bifunctional Strontium Cobalt Molybdenum Oxide ($\text{Sr}_2\text{CoMoO}_6$) Perovskite as an Efficient Catalyst for Electrochemical Water Splitting Reactions in Alkaline Media (ChemCatChem 17/2024)

Shahan Atif, Abhisek Padhy, Pawan Kumar Jha, Dorothy Sachdeva, Prabeer Barpanda

Volume 16, Issue 17, ChemCatChem | First Published online: September 9, 2024



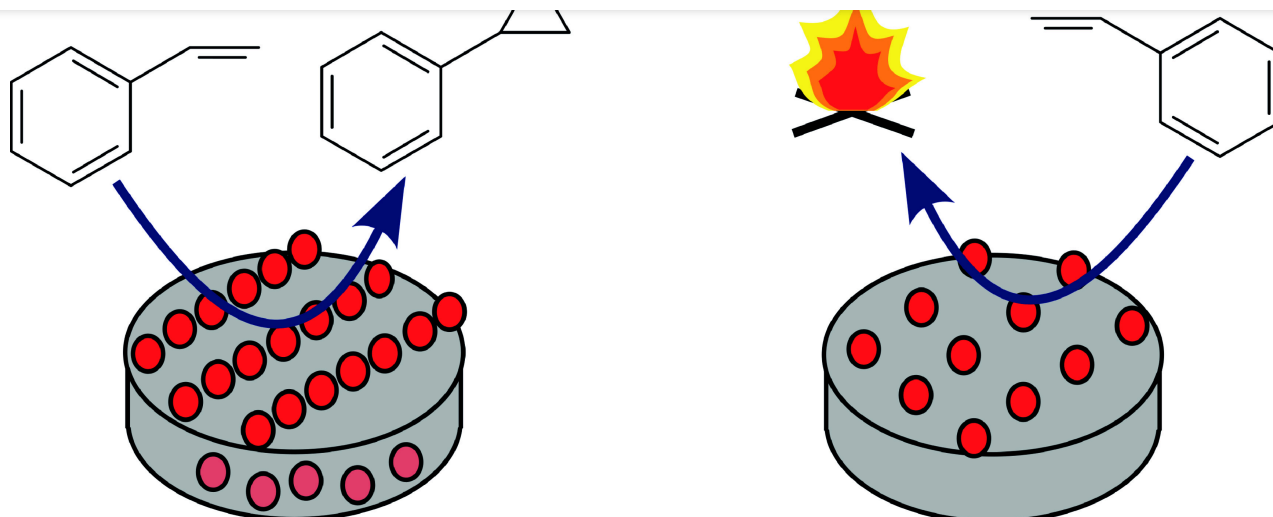
Strontium cobalt molybdenum double perovskite oxide is synthesized through solution combustion and solid-state approaches. The material exhibits a high electrochemical active surface area, significantly enhancing electrochemical water splitting in an alkaline medium, demonstrating bifunctional electrocatalytic activity (OER and HER) with remarkable durability.

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Heterogeneously Catalyzed Partial Oxidation of Styrene on a Silver Surface

Rasika E. A. Dissanayake, Arved C. Dorst, Kerim Benfreha, Daniel R. Killelea, Tim Schäfer



The epoxidation of olefins on silver surfaces is an important industrial process on a large scale. This paper presents microscopic insights of styrene oxidation on Ag(111) under well-controlled ultra-high vacuum conditions. Epoxidation exclusively takes place at elevated oxygen coverages, coinciding with the emergence of electrophilic oxygen. Upon depletion of electrophilic oxygen, residual nucleophilic oxygen triggers complete combustion.

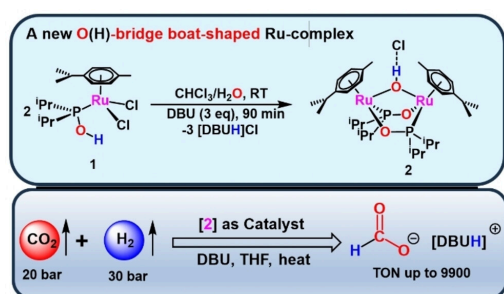
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An Air and Moisture Stable Boat Shaped Hydroxo-Bridged Ruthenium(II) Binuclear Complex for the Catalytic Hydrogenation of CO₂

Dr. Uttam K. Das, Dr. Graham J. Tizzard, Prof. Simon J. Coles, Prof. Gareth R. Owen

First Published: 16 April 2024



The deprotonation of a coordinated phosphinous acid ligand on a ruthenium p-cymene complex provides a two atom P–O bridging unit leading to a binuclear ruthenium complex featuring a bridging hydroxide ligand. The resulting complex was found to be highly active in the catalytic hydrogenation of CO₂ to formate salts with TONs up to 9900.

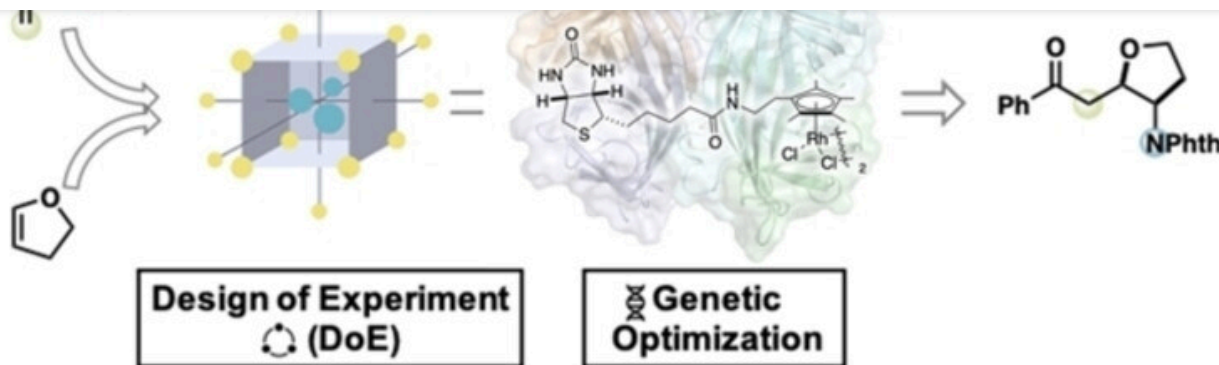
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Artificial Metalloenzyme-Catalyzed Enantioselective Carboamination of Alkenes

Kun Yu, Dr. Ryo Tachibana, Dr. Corentin Rumo, Dr. Nico V. Igareta, Kailin Zhang, Prof. Dr. Thomas R. Ward

First Published: 17 April 2024



An artificial metalloenzyme (ArM) based on biotin-streptavidin technology was repurposed for enantioselective nonannulative carboamination of alkenes. The combination of design of experiment (DoE) and genetic optimization led to a >630 % improvement in turnover number (TON).

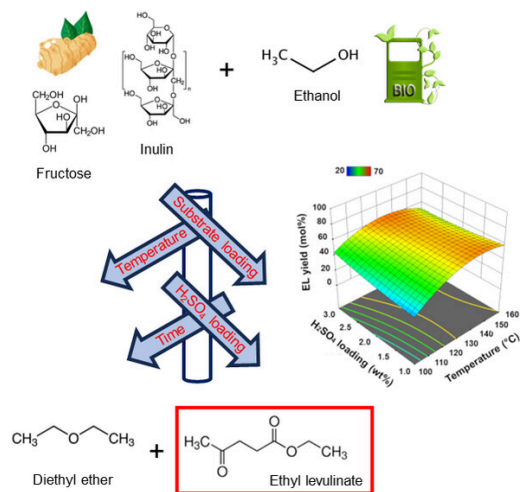
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In-Depth Investigation of the Reaction Parameters Tuning the Ethyl Levulinate Synthesis from Fructose and Inulin

Sara Fulignati, Claudia Antonetti, Anna Maria Raspolli Galletti, Lorenzo Bonaldi, Erika Ribechini, Marco Mattonai, Domenico Licursi, Nicola Di Fidio

First Published: 19 April 2024



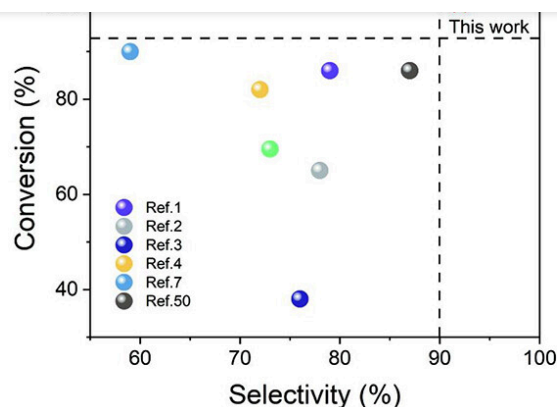
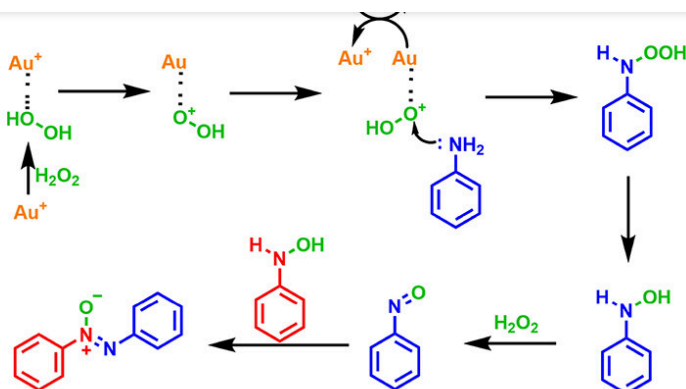
One-Factor-At-a-Time (OFAT) approach and the multivariate approach were adopted for the optimization of fructose and inulin one-pot ethanolysis, respectively, allowing to systematically elucidate the role of key reaction parameters (temperature, H₂SO₄ and inulin loadings, reaction time) and aiming at the maximisation of EL yield and concentration while minimising the formation of by-products, such as diethyl ether and solid char.

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Rb-Promoted Au/CeO₂ Nanocatalyst for Remarkably-Enhanced Aniline Conversion to Azoxybenzene with Ultrahigh Selectivity

Afsar Khan, Peiwen Ju, Zhengwei Han, Yu Xie, Ziyu Gan, Hui Zhong, Zhiguo He, Weiqi Xie



A novel Rb-doped Au/CeO₂ nanocatalyst (Rb–Au/CeO₂) was prepared and utilized as a highly efficient nanocatalyst for the selective oxidation of anilines to azo compounds using hydrogen peroxide as an oxidant, which reached ultrahigh selectivity (92 %) towards azoxybenzene and complete aniline conversion (100 %).

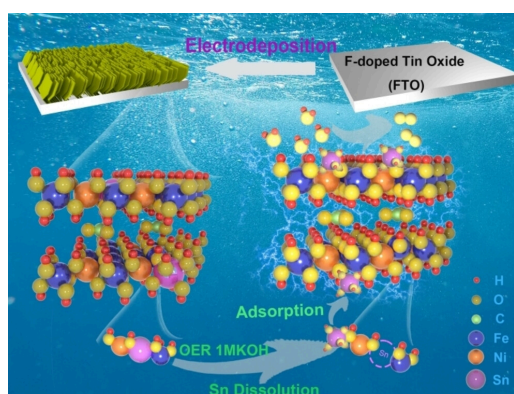
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Efficient Alkaline Water Oxidation Electrocatalysis Enabled *via* the Modulation of Sn-Containing Anions towards NiFe Oxyhydroxide

Jiaxin Xu, Ruotao Yang, Tianjue Hou, Jinxin Chen, Hongyuan Yang, Dr. Prashanth W. Menezes, Dr. Ziliang Chen

First Published: 21 April 2024



A critical role of Tin: During the alkaline OER process, Sn-doped NiFe-LDH precatalysts undergo in-situ evolution into NiFeOOH, which subsequently surface adsorbs $\text{Sn}(\text{OH})_6^{2-}$. These Sn oxyanions endow the NiFeOOH to display remarkable activity and stability through inhibiting Fe leaching, modifying the electronic structure, and enhancing OER reaction kinetics.

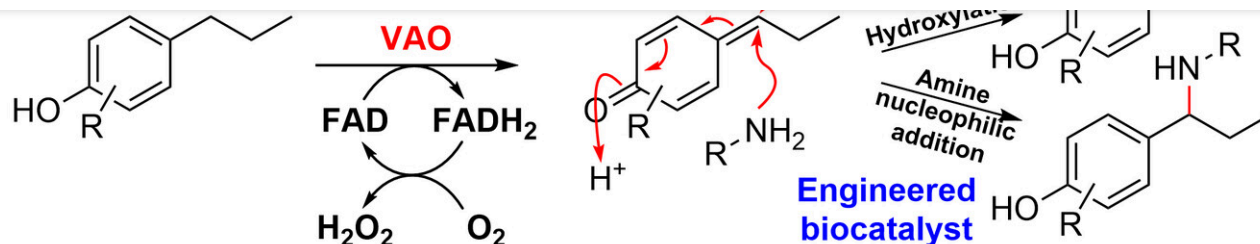
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Biocatalytic Oxidative Amination of *para*-Substituted Phenols

Dr. Yiming Guo, Dr. Ben Ashley, Dr. Ivana Marić, Dr. Mohammad Saifuddin, Tomás Dunleavy, Andrei Onet, Prof. Dr. Marco W. Fraaije

First Published: 21 April 2024



Vanillyl alcohol oxidases (VAOs) are catalytically promiscuous oxidases acting on *para*-substituted phenols. Engineering of a VAO-type biocatalyst permits a new chemoenzymatic reaction - release of and nucleophilic addition to a reactive electrophilic intermediate, yielding α -aminated and -thiolated *para*-alkylphenols.

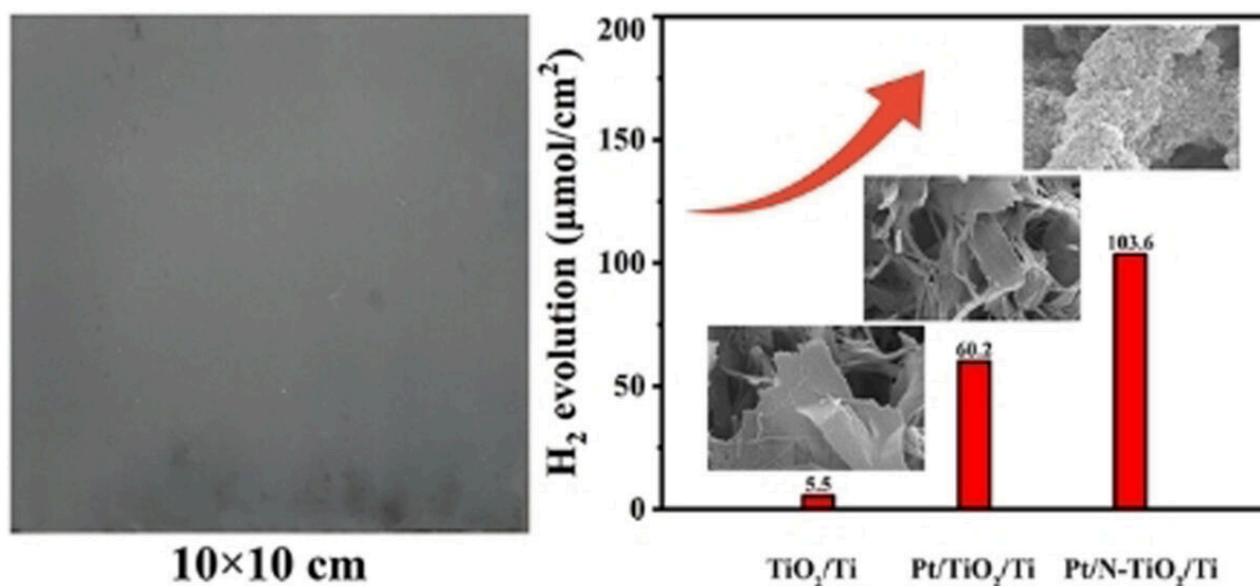
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Mesoporous Pt/N–TiO₂/Ti Photocatalytic Plate for Highly Efficient Hydrogen Production

Zhe Hua, Liu Yang, Dr. Jing Li, Junchao Wang, Lixin Chen, Liyuan Tan, Jiaming Guo, Prof. Jinlei Yao, Prof. Baodan Liu

First Published: 22 April 2024



Herein, a large-scale Pt/N–TiO₂/Ti photocatalytic plate with a granular and mesoporous structure was reported, which addressed the challenges of exposed active surface area and substrate adhesion of monolithic photocatalysts. Importantly, the in-situ fabrication, morphology tailoring and N doping of TiO₂ nanomaterials on Ti sheet was systematically investigated to obtain superior plate-like photocatalysts for hydrogen production.

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Dr. Michael Papadakis, Jana Mehrez, Iris Wehrung, Léa Delmotte, Dr. Michel Giorgi, Dr. Renaud Hardré, Dr. Maylis Orio

First Published: 22 April 2024



A new series of nickel-thiosemicarbazone complexes was synthesized with the methoxy group placed in different positions on the phenyl ring. Their ability to promote electrocatalytic proton reduction into hydrogen was investigated. The meta-substituted complex, **NiTSC-(m)-OCH₃**, outperformed all other tested complexes with a greatly increased TOF of 676.9 s⁻¹ compared to the reference catalyst, **NiTSC-(p)-OCH₃**, with a TOF of 90 s⁻¹.

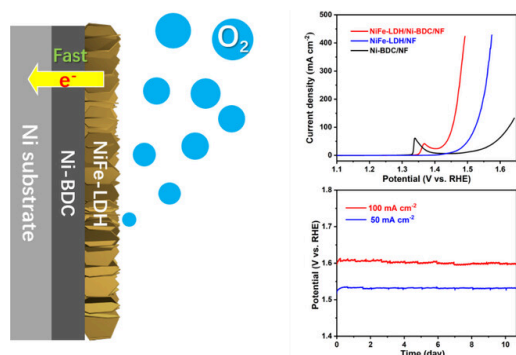
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Electrodeposited NiFe-LDH on the Surface of Ni-BDC for Electrocatalytic Water Oxidation

Dr. Yu Wei, Dr. Zhenze Han, Dr. Taolue Liu, Dr. Xin Ding, Dr. Yan Gao

First Published: 22 April 2024



A functional Ni-BDC MOF nanosheet layer was in-situ grown on the surface of nickel foam (NF). Consequently, the NiFe layered double hydroxides (NiFe-LDH) electrodeposited on the modified layer exhibited an excellent activity and an amazing long-term stability on electrocatalytic OER.

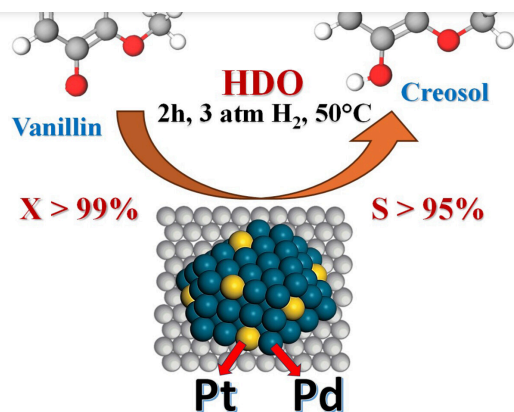
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Pd-Pt Bimetallic Catalysts for Enhanced Low-Temperature Hydrodeoxygenation of Vanillin

Simone Govoni, Dr. Alessia Ventimiglia, Prof. Camila P. Ferraz, Prof. Ivaldo Itabaiana Jr, Dr. Anthony Dufour, Prof. Andreea Pasc, Dr. Robert Wojcieszak, Prof. Nikolaos Dimitratos

First Published: 26 April 2024



efficiency and selectivity, with optimal Pd to Pt ratios favoring superior activity. The creosol yield was correlated to the Pd(0)/(Pd+Pt) ratio at the surface. Temperature and hydrogen pressure control reaction rates and product distribution, highlighting the importance of mild conditions.

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Achieving Regioselective Control for Mechanochemical Reactions: A Planetary Ball-Milling, Ru-Catalyzed Synthesis of 3,4- and 3,4,5-Isoxazoles

Dr. Rafael A. Hernandez R., Negin Nabavi, Stephanie J. Patterson, Prof. Pat Forgione

First Published: 24 April 2024



A mechanochemical Ru-catalyzed system allows to synthesize regioselectively 3,4- and 3,4,5-isoxazoles from hydroxyimidoyl chlorides and using terminal and internal alkynes. Mechanistic studies reveal that the catalytic activity stems from the *in-situ* generation of Ru-nanoparticles stabilized by incorporating eco-friendly polar liquid additives such as cyclopentyl methyl ether or acetone. This approach showcases sustainable chemistry 's potential to control selectively in regio divergent transformations.

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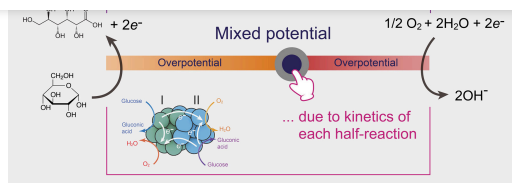
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Mixed-Potential-Driven Catalysis in Glucose Oxidation

Mo Yan, Rafiq Arsyad, Nuning Anugrah Putri Namari, Hiroaki Suzuki, Kotaro Takeyasu

First Published: 28 April 2024

Mixed-potential-driven catalysis is a new category of heterogeneous catalysis, in which a single catalyst particle facilitates a complementary pair of anodic and cathodic half-reactions. A theoretical framework suggesting that the catalytic activities of individual catalyst components



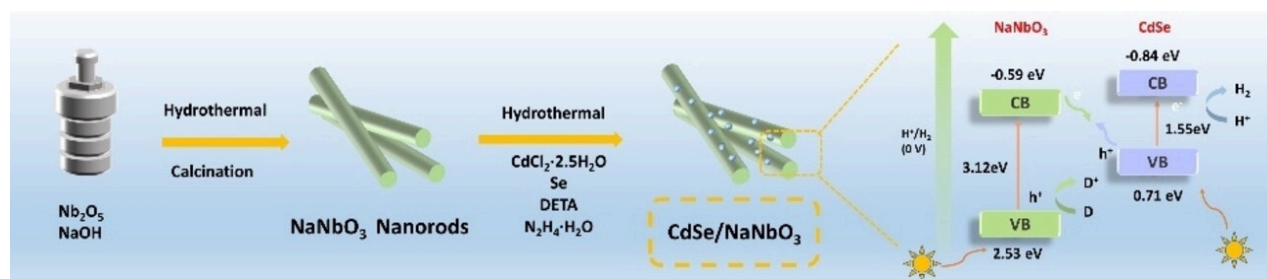
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Direct Z-Scheme Heterostructure of Nanoparticle-CdSe on Nanorod-NaNbO₃: Facile Hydro-thermal Construction and Superior Photocatalytic Activity and Stability in H₂ Evolution

Linlin Gao, Shengyuan Chang, Huajun Gu, Huihui Zhang, Yamei Huang, Xinglin Wang, Qin Li, Wei-Lin Dai

First Published: 25 April 2024



The CdSe/NaNbO₃ heterojunctions were fabricated through a hydrothermal approach, facilitating the in-situ growth of CdSe nanoparticles on the surface of NaNbO₃ nanorods and the heterojunction achieved a photocatalytic hydrogen production of 2510 $\mu\text{mol g}^{-1}\text{h}^{-1}$. The enhancement is contributed to the formation of a Z-scheme heterojunction by the close interface contact between CdSe and NaNbO₃.

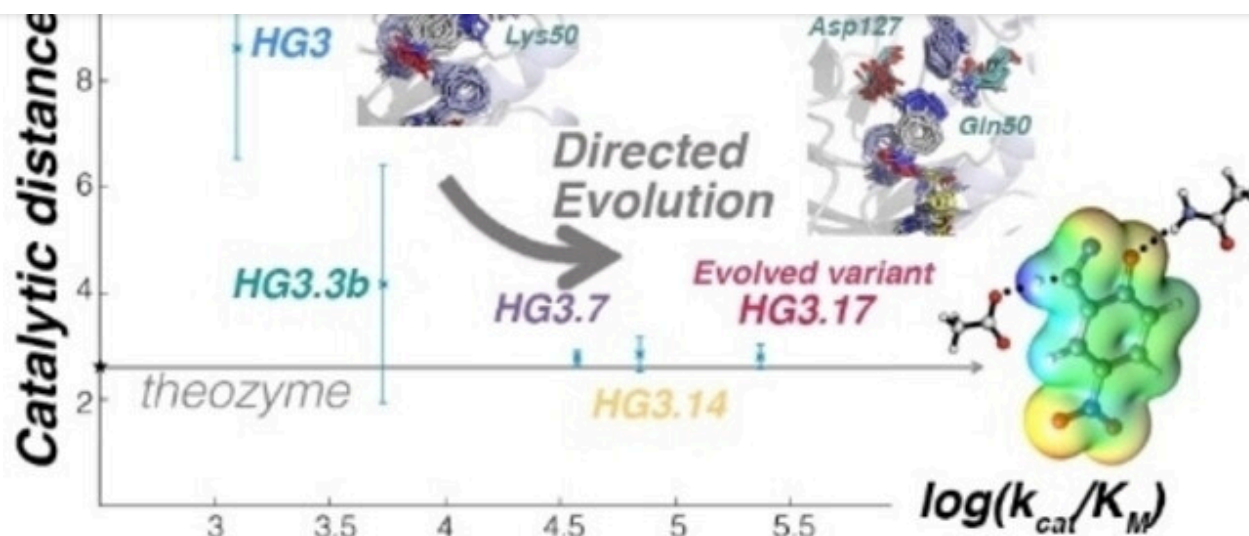
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Interplay Between Substrate Polarity and Protein Dynamics in Evolved Kemp Eliminases

Dr. Francesca Peccati, Dr. Elizabeth L. Noey, Prof. K. N. Houk, Prof. Silvia Osuna, Prof. Gonzalo Jiménez-Osés

First Published: 25 April 2024



Merging enzyme dynamics and electrostatics: Molecular dynamics simulations were performed on different lineages of computationally designed and laboratory-evolved Kemp eliminases. Various protein scaffolds, all of which were crystallographically characterized, and ligands with different polarities, were explored. Results underscore the importance of electrostatic preorganization in biocatalysis, highlighting trends toward optimal active site organization with specific substrates, with implications for enzyme design.

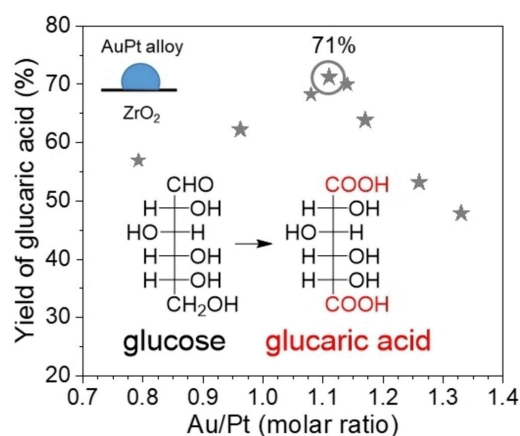
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Ultrasonication-Assisted Preparation of Au-Pt/ZrO₂ Catalysts for the Selective Base-Free Oxidation of Glucose to Glucaric Acid

Natalia Potrzebowska, Luis Cardenas, Elie Derrien, Philippe Marion, Catherine Pinel, Michèle Besson, Noémie Perret

First Published: 09 June 2024



ZrO₂ supported AuPt catalysts are very selective and stable for the oxidation of glucose to glucaric acid under base-free conditions. The method of preparation affect the formation of AuPt alloy which favors glucaric acid. The use of ultrasonication during impregnation increases the final yield of glucaric acid, up to 71 %.

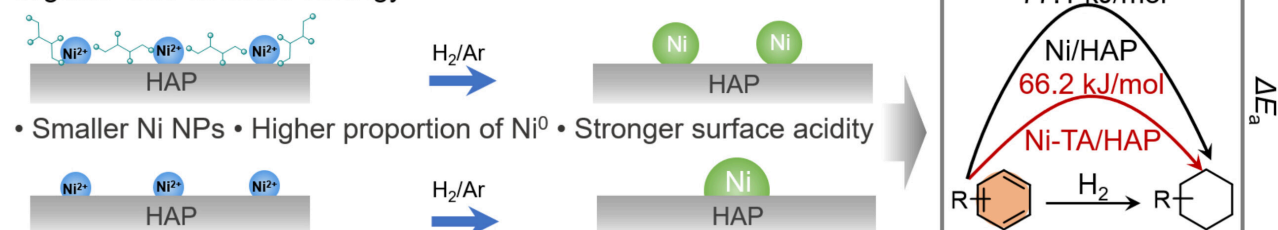
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Chengjie Duan, Kun Li, Dr. Wenbo Ye, Weitao Mao, Prof. Dr. Guangke He, Dr. Xiang Liu

First Published: 30 April 2024

Organic acid-assisted strategy



Exploring the impact of structural variations in organic acids on catalyst properties unveils crucial insights for enhancing arene hydrogenative activity. The Ni catalyst, supported by hydroxyapatite and aided by a hydroxy-dicarboxylic acid (tartaric acid) with an optimal ratio, resulted in relatively smaller Ni nanoparticles, a higher Ni⁰ proportion, and increased acidic sites, showcasing exceptional hydrogenation performance.

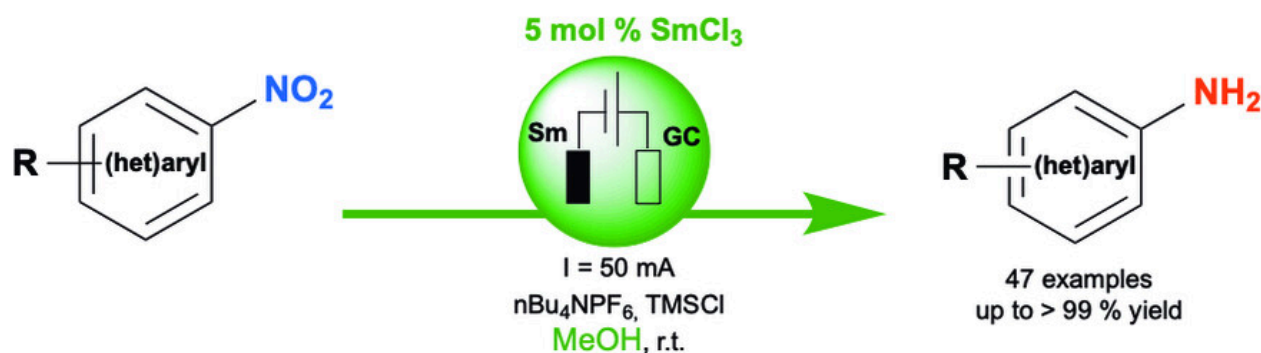
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Electrocatalytic, Sm-Promoted Synthesis of Aminoarenes from Nitroaromatic Derivatives in MeOH

Dr. Yu-Feng Zhang, Dr. Emmanuelle Schulz, Prof. Dr. Mohamed Mellah

First Published: 03 May 2024



The preparation of various aminoarenes is described based on the Sm-promoted catalytic electrochemical reduction of corresponding nitroarenes. This mild procedure tolerates a wide range of functional groups and yields the targeted products in almost all cases in excess of 90 %.

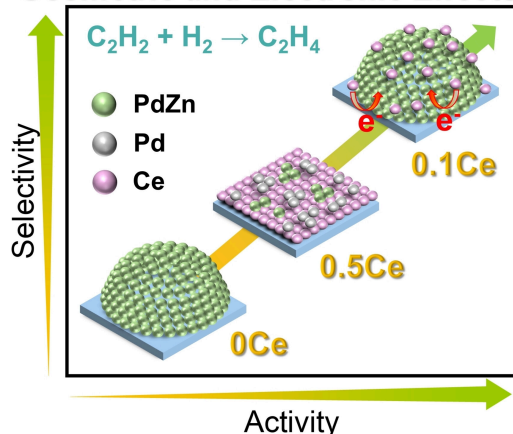
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The Geometric and Electronic Effects of Ceria on Promoting PdZn catalyst for Enhanced Acetylene Semi-Hydrogenation

First Published: 30 April 2024

Geometric and Electronic Effects



Using the combination of *in situ* spectroscopic techniques and electron microscopy imaging, we reported the promotional role of ceria in modifying the geometric and electronic structure of PdZn IMCs for enhanced acetylene semi-hydrogenation. Our results thus provide a new route for the design of PdZn catalyst by applying rare earth promoters towards high-performance acetylene semi-hydrogenation.

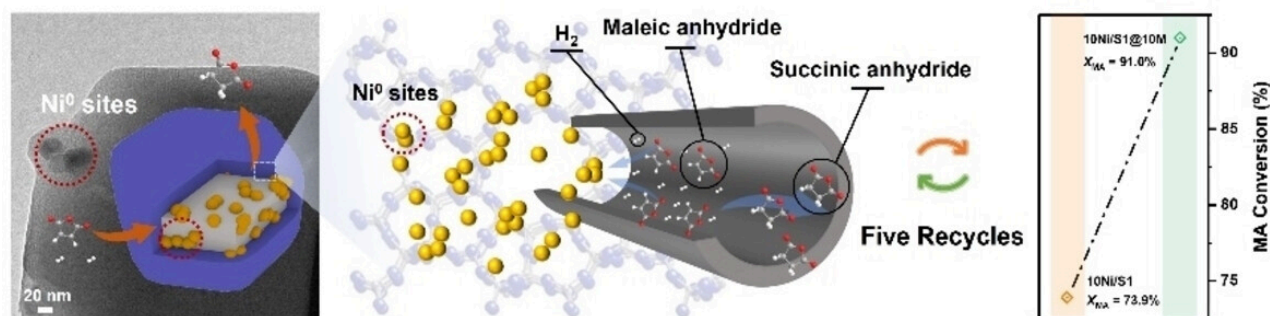
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Core-Shell Zeolite with Confined Nickel Particles as Prominent Catalyst for the Hydrogenation of Maleic Anhydride

Haidan Wu, Jianguo Zhuang, Siyan Yan, Zhaojie Su, Tianyun Wang, Jisheng Yu, Dr. Liyuan Li, Prof. Xuedong Zhu, Dr. Fan Yang

First Published: 01 May 2024



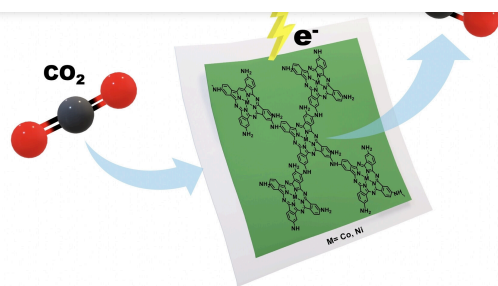
The core-shell catalyst derived from the modified Stöber route is a hierarchically porous material with tunable shell thicknesses, not only promotes diffusion ability and activity in the hydrogenation of maleic anhydride by reducing surface barriers and intra-particle hindrances but also prevents the leaching of metals and decelerates deactivation.

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Facile Preparation of Stable Ni^{II}- and Co^{II}-Tetraaminophthalocyanine Electropolymers for Highly Efficient Heterogeneous Carbon Dioxide Reduction

Dr. Jirapong Luangchaiyaporn, Permsak Chairat, Rapheepaew Sodkhomkhum, Prof. Mag. Dr. DDr. Niyazi Serdar Sariciftci, Prof. Dr. Patchanita Thamyongkit



facile electropolymerization of Ni^{II}- and Co^{II}-tetraaminophthalocyanines. Under optimized heterogeneous electrochemical CO₂ reduction condition in a customized flow cell, the target polymer films exhibited excellent catalytic performance for CO₂-to-CO conversion in terms of stability, productivity and selectivity. This study demonstrated a promising approach for development of scalable and

practical electrochemical CO₂ reduction process.

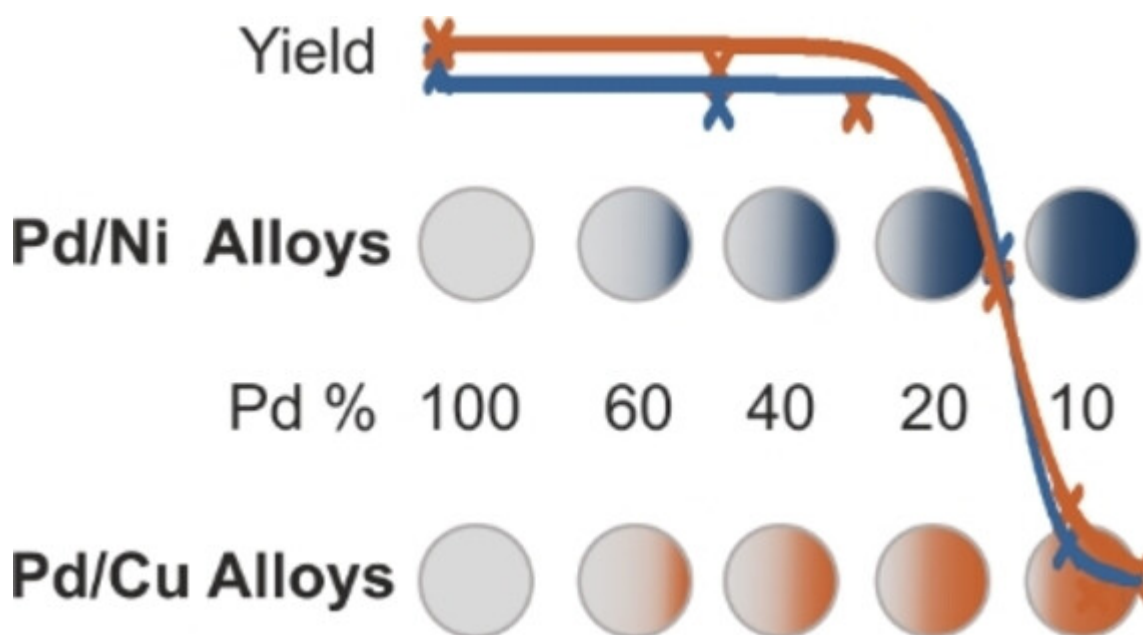
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Direct Mechanocatalysis with Pd Alloys

Wilm Pickhardt, Fabien Joel Leon Kraus, Maximilian Wohlgemuth, Dr. Martin Etter, Marius Spallek, Martin Schwensow, Zeynep Genç, Sven Grätz, Lars Borchardt

First Published: 02 May 2024



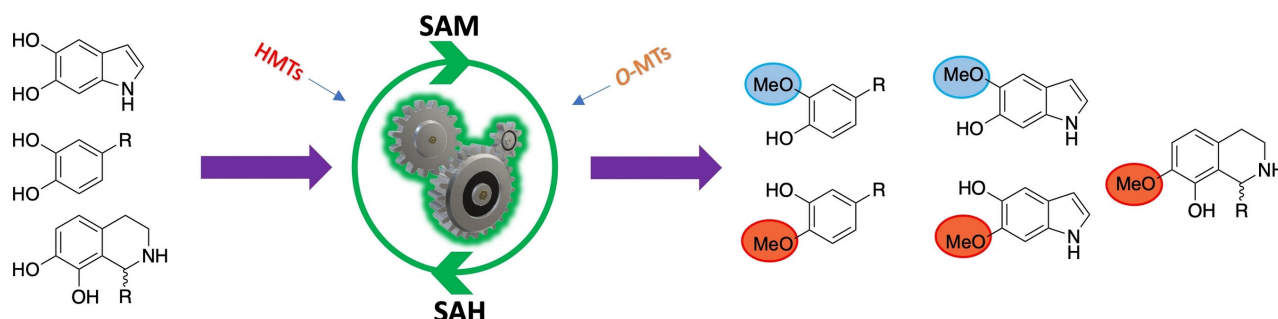
Milling balls made from Pd alloys were tested successfully for their catalytic activity on the Suzuki and Sonogashira coupling. By alloying Pd with Ni or Cu and even employing a HEA, the mechanical resilience of Pd was enhanced while preserving its catalytic activity. It was found experimentally that alloyed containing more noble metals perform better than those consisting of less noble alloys. State-of-the-art analysis methods revealed that the finding that the alloyed milling balls hardness has less impact on a successful coupling than the composition of the milling ball surface.

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Matthew T. Salinger, Daniel Castellano Garrido, Dr. Eleanor D. Lamming, Prof. John M. Ward, Prof. Thomas S. Moody, Dr. Jack W. E. Jeffries, Prof. Helen C. Hailes

First Published: 06 May 2024



A novel three-enzyme biomethylation cascade involving methionine adenosyltransferases (MATs), O-methyltransferases (O-MTs) and halide methyltransferases (HMTs) was developed for the regioselective SAM (S-adenosylmethionine)-dependent methylation of an array of O-methylated catechols, tetrahydroisoquinolines and indole. This was further complemented by investigations into alternative SAM regeneration methyl donors which are less toxic and environmentally damaging than methyl iodide (SAH is S-adenosylhomocysteine).

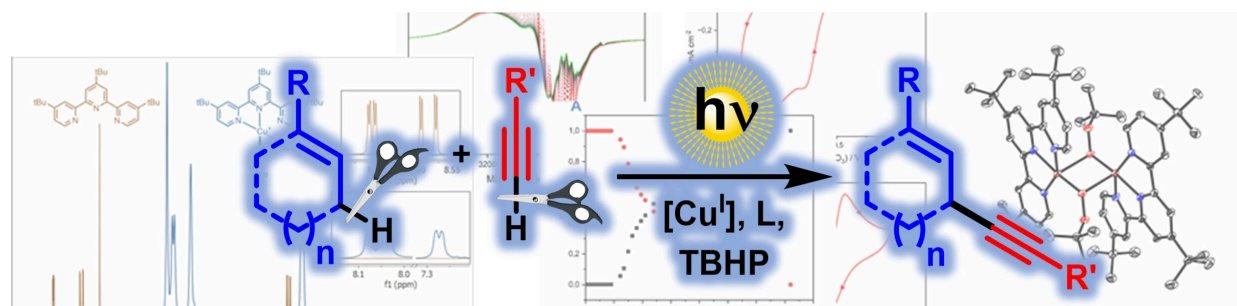
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Mechanistic Insights into the Copper-Catalyzed Cross-Dehydrogenative Allylic Alkynylation Reaction

Dr. Paul Hünemörder, Gustavo Alvarez, Leo Gräber, Maria Logotheti, Prof. Dr. Matthias Höhne, Prof. Dr. Esteban Mejía

First Published: 06 May 2024



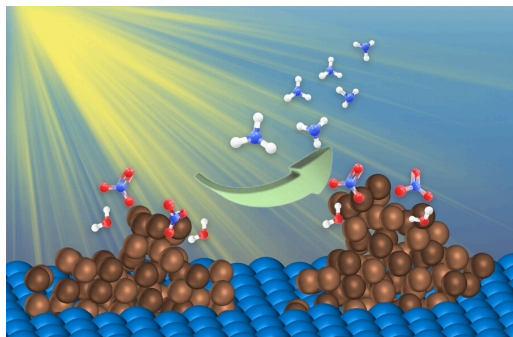
The copper-catalyzed oxidative C–H allylation reaction remains underdeveloped due to lacking a general concept and mechanistic understanding. The present study utilizes various spectroscopic techniques and DFT calculations to propose a reaction mechanism which resembles the Karash-Sosnovsky reaction. Notably, the results suggest no involvement of free organic radicals in this transformation.

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Chia-Che Chang, Yi-Chia Chen, Kuan-Chang Wu, H. N. Priyadarshini, Lo-Yu Lee, Jeng-Lung Chen, Chang-Ru Lee, Chih-Wen Pao, Di-Yan Wang

First Published: 08 May 2024



Subnanometer-sized CuO_x clusters decorated on TiO_2 NPs exhibited a good photocatalytic performance for nitrate reduction reaction with photocatalytic NH_3 yield rate of $153.09 \mu\text{g} \cdot \text{g}_{\text{cat}}^{-1} \cdot \text{h}^{-1}$ in 0.1 M KNO_3 electrolyte under illumination of 300 W Xenon light.

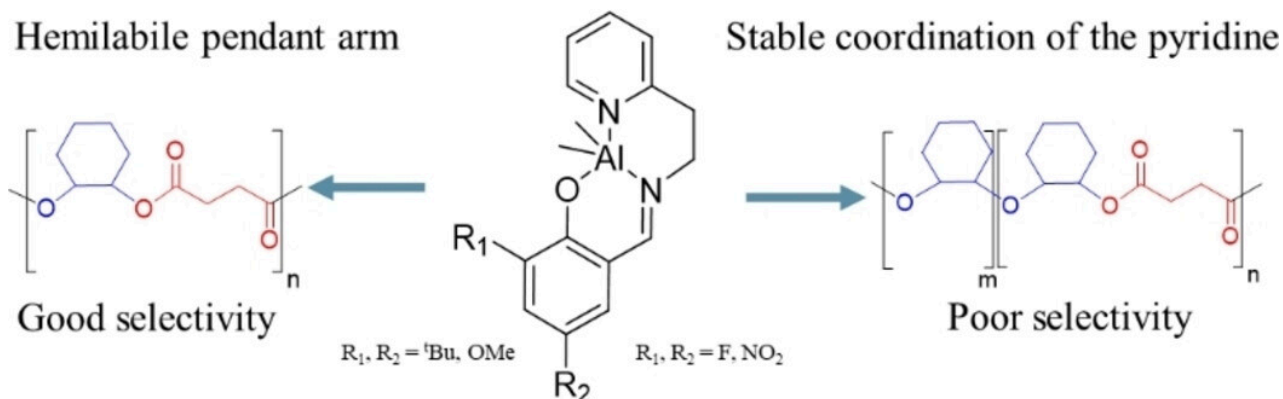
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Schiff-Base Aluminum Complexes as Bifunctional Catalysts for the Selective Ring-Opening Co-Polymerization of Cyclohexene Oxide and Succinic Anhydride

Simona Russo, Dr. Florence Isnard, Chiara Costabile, Marina Lamberti, Mina Mazzeo

First Published: 09 May 2024



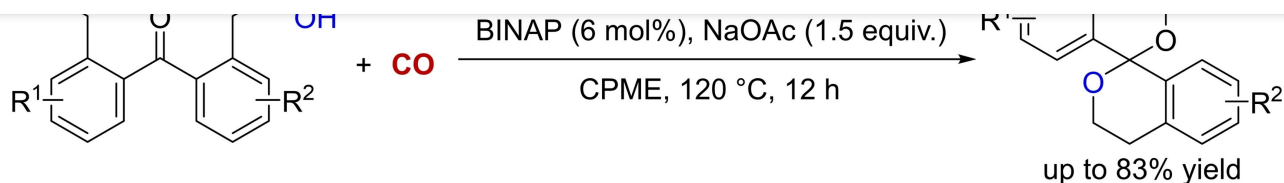
Simple bifunctional aluminum catalysts for the ring opening polymerization of cyclohexene oxide and succinic anhydride are described. Their selectivity in promoting an alternated copolymerization of the two monomers is depending on the hemilabile behavior of the nitrogen neutral donor of the pyridine pendant arm: the introduction of electron donating substituents on the phenoxy rings of the ancillary ligand promotes a complete selectivity.

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Modular Synthesis of [6,6]-Oxaspirolactones Enabled by Palladium-Catalyzed Carbonylative Spirolactonization

Ketema Alemayehu Asserese, Dr. Yongzheng Ding, Prof. Hanmin Huang



A new palladium-catalyzed tandem carbonylative spirolactonization reaction utilizes benzyl chlorides tethered hydroxyalkyl ketones and CO substrates, enabling efficient synthesis of diverse [6,6]-oxaspirolactones. The straightforward protocol ensures high atom economy and compatibility with various functional groups. Under optimized conditions, over 20 examples of the desired product are obtained.

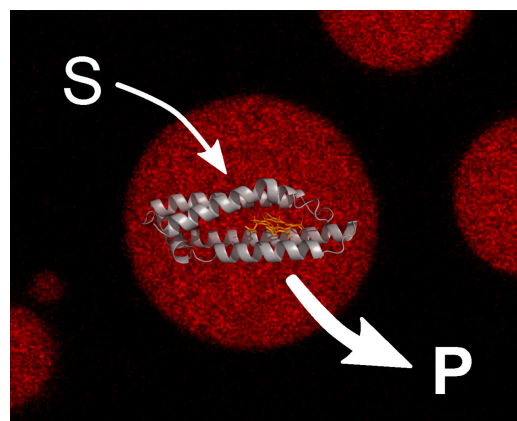
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Enhanced Catalytic Activity of a de novo Enzyme in a Coacervate Phase

Eugénie Kluczka, Valentin Rinaldo, Dr. Angélique Coutable-Pennarun, Dr. Claire Stines-Chaumeil, Prof. J. L. Ross Anderson, Dr. Nicolas Martin

First Published: 08 May 2024



Coacervate droplets increase the catalytic efficiency of a de novo enzyme with peroxidase activity. This augmented activity, attributed to changes in the enzyme conformational dynamics in the crowded coacervate phase, opens perspectives to rationally engineer biocatalytically active synthetic membraneless organelles.

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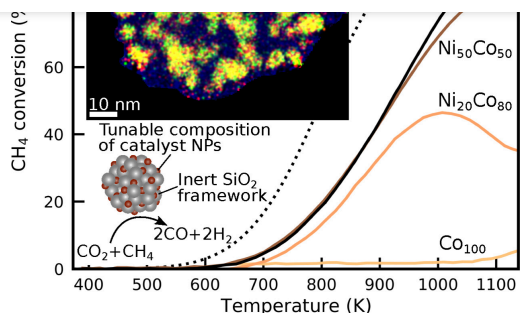
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Spray-dried Ni-Co Bimetallic Catalysts for Dry Reforming of Methane

Gerrit Küchen, Vinzent Olszok, Dr. Bjarne Kreitz, Dr. Christoph Mahr, Prof. Dr. Andreas Rosenauer, Prof. Dr. Thomas Turek, Prof. Dr. Alfred P. Weber, Prof. Dr. Gregor D. Wehinger

First Published: 10 May 2024

This study examines the potential of spray-dried bimetallic Ni-Co/SiO₂ catalyst nanoparticles for the Dry Reforming of Methane (DRM). Applying temperature scanning experiments (TPR, TPD, TPO) and accompanying offline diagnostics (STEM-EDXS, BET, XRD, XPS), Ni/Co ratios were identified with a superior activity and high specific metal surface area. Remarkably high TOFs were found for particles with compositions between Ni₈₀Co₂₀ and Ni₄₀Co₆₀.



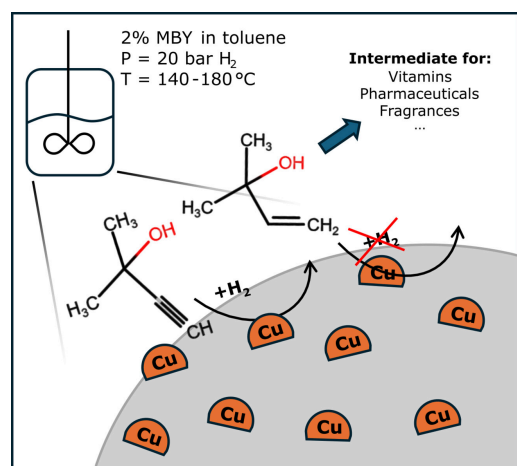
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Selective Hydrogenation of 2-Methyl-3-butyn-2-ol Over Supported Cu Nanocatalysts

Giorgio Totarella, Prof. Dr. Petra E. de Jongh

First Published: 12 May 2024



Silica-supported Cu nanoparticles (2 and 5 nm) are active in the liquid phase hydrogenation of 2-methyl-3-butyn-2-ol to 2-methyl-3-buten-2-ol, a relevant step in fine chemical synthesis. Selectivities ~100% at 50% conversion can be reached on Cu particles of 7nm.

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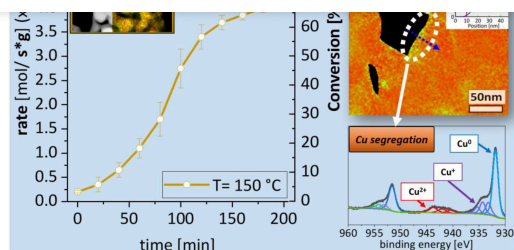
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Broadening the Realm of Nanoporous Gold Catalysts: Preparation and Properties When Emanating from AuCu as Parent Alloy

Jorge Adrian Tapia Burgos, Dr. Christoph Mahr, Dr. Alex Ricardo Silva Olaya, Dr. Lars Robben, Dr. Marco Schowalter, Prof. Dr. Thorsten Gasing, Prof. Dr. Andreas Rosenauer, Prof. Dr. Gunther Wittstock, Dr. Arne Wittstock, Prof. Dr. Marcus Bäumer

First Published: 12 July 2024

Nanoporous gold has emerged as a highly active oxidation catalyst, especially at low temperatures. While in the past it was predominantly synthesized from AuAg alloys, this study explores AuCu as starting material. Since residues of the less noble metal are co-catalytically involved, deviating properties are expected and were indeed observed.



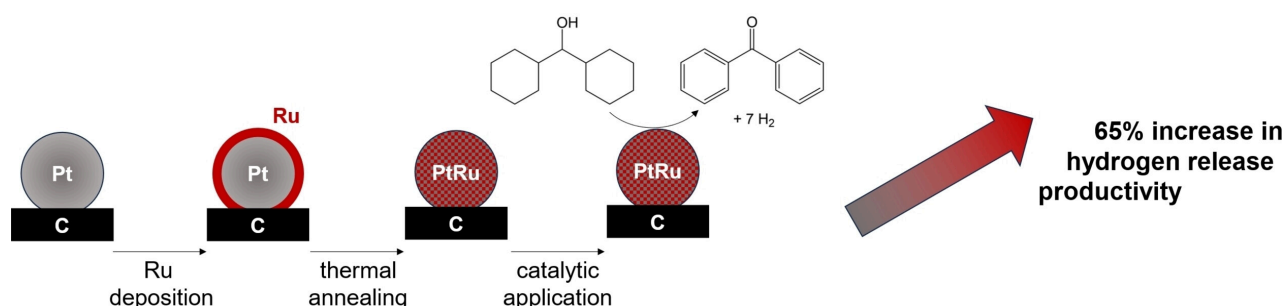
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Improving Hydrogen Release From Oxygen-Functionalized LOHC Molecules by Ru Addition to Pt/C Catalysts

Lukas A. Maurer, Chuyen v. Pham, Birk Fritsch, Henrik S. Jeppesen, Martin Etter, Andreas Hutzler, Reinhard B. Neder, Moritz Wolf, Franziska Auer, Simon Thiele, Peter Wasserscheid

First Published: 15 May 2024



Bimetallic PtRu/C catalysts were prepared by an innovative synthesis method. Various characterization techniques were applied to show that diffusion of Ru into the crystal structure of the Pt nanoparticles takes place during thermal annealing. The most active bimetallic catalyst exhibited a 65 % increase in hydrogen release productivity during the catalytic dehydrogenation of the LOHC compound dicyclohexylmethanol compared to monometallic Pt/C.

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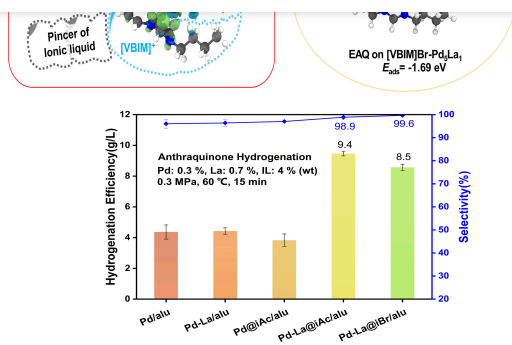
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Ionic Liquids Boost Anthraquinone Hydrogenation over Pd-based Bimetallic Pincer Catalysts

Xiaolei Li, Dr. Tiantong Zhang, Fuying Wang, Dr. Mao Peng, Prof. Jinli Zhang, Assoc. Prof. Chengzhi Gu, Assoc. Prof. Xiaoyan Li, Assoc. Prof. Wei Li

First Published: 13 May 2024

A novel kind of pincer catalyst Pd–M@IL is constructed through selecting a suitable ionic liquid with the imidazolium cation to modulate the microenvironment around bimetallic catalytic sites, aiming at boosting the activity for anthraquinone hydrogenation reaction. Over the pincer



significantly.

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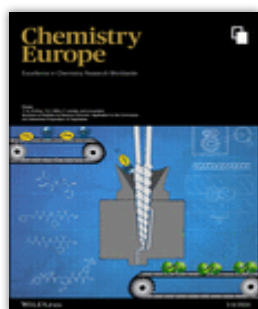
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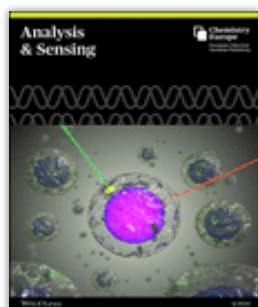
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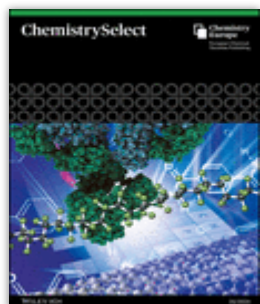
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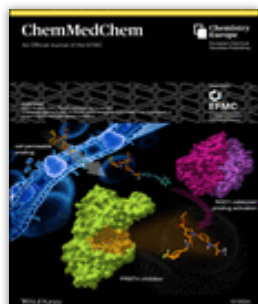
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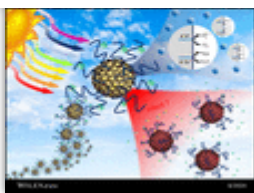
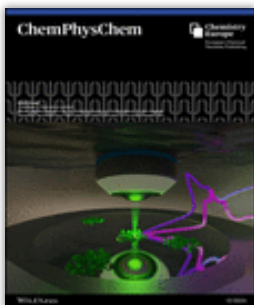
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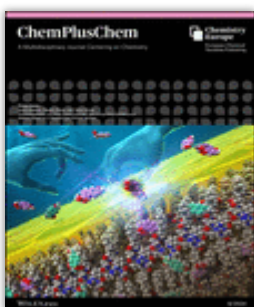
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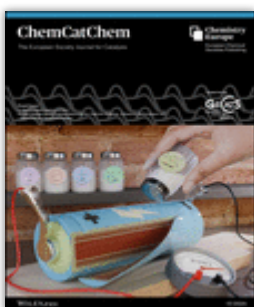
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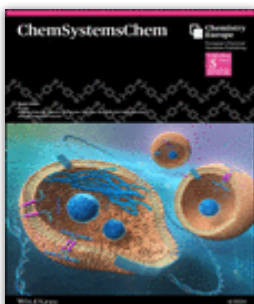
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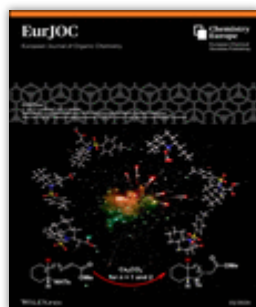
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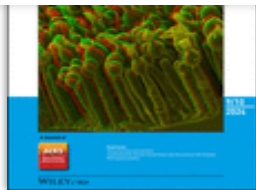
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