Intrinsic metal-support interactions break the activity-stability dilemma in electrocatalysis

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Significance and Relevance

We report the very first 'chemical steam deposition (CSD)' strategy armed with machine learning method to synthesize an integrated ruthenium-titanium-manganese ($RuTiMnO_x$) electrode featuring 'intrinsic metal-support interactions' (Figure 1). These interactions induced a self-healing mechanism during the OER for H_2 production, thereby enabling both high activity and stability across the full pH range. The CSD strategy enables 'bottom-up' atomic-scale nanomaterial synthesis, and 'intrinsic metal-support interactions' pave the way to overcome the activity-stability challenge in electrocatalysis.

Preferred and 2nd choice for the topic: H_2 storage and transportation, green H_2 production, hydrogen vectors; Advanced process with electrocatalysis and plasma utilization
Preferred presentation: Oral preferred or Short Oral

Introduction and Motivations

The global energy crisis and climate issues urgently require green energy technologies,[1] with electrocatalysis occupying a pivotal position in clean energy conversion processes essential for future technologies.[2] However, the long-standing dilemma between the activity and the stability of electrocatalysts poses significant constraints on the practical applications, particularly in the case of oxygen evolution reaction (OER) for producing H_2 and other solar fuels.[3]

Here, we report the very first 'chemical steam deposition (CSD)' strategy armed with machine learning method to synthesize an integrated $RuTiMnO_x$ electrode featuring 'intrinsic metal-support interactions' (Figure 1). Employing machine learning, we efficiently identified the optimal atomic metal-support ratio considering both activity and stability metrics, avoiding traditional trial-and-error approaches.

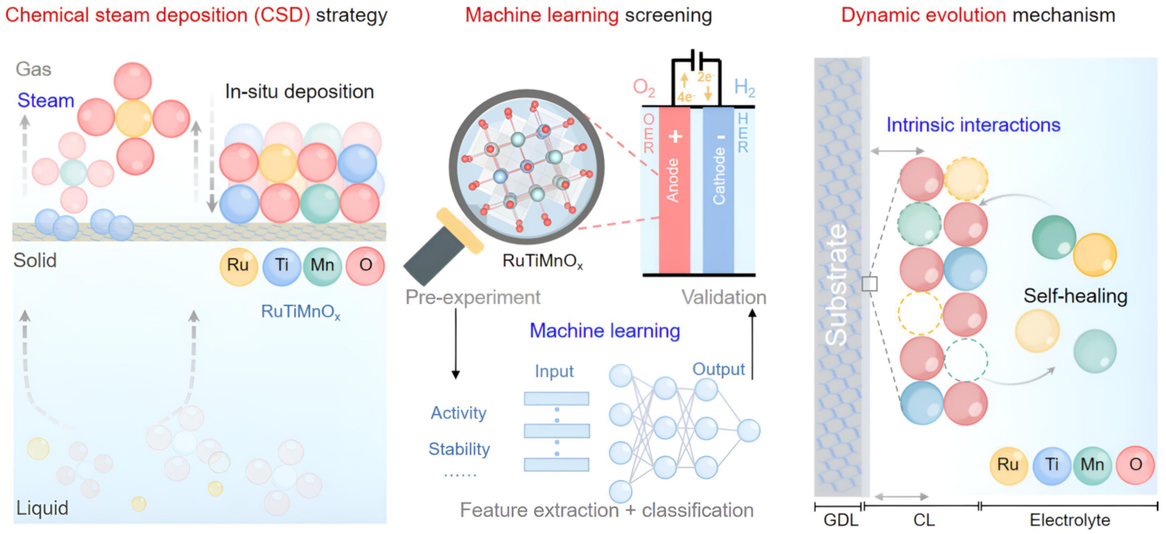

Figure 1. Chemical steam deposition synthesis, machine-learning-assisted screening and catalysis mechanism study of $RuTiMnO_x$.

Results and Discussion

The resulting electrodes achieved high pH-universal mass activities, 48.5, 112.8 and 74.6 times those of benchmark ruthenium oxides in acidic, neutral and alkaline conditions, respectively; and stable operation for up to 3,000 hours in the challenging pH=0 media, a multi-fold improvement in stability over the reported advanced catalysts (Table 1). Extensive in-situ characterizations combined with theoretical calculations have unveiled the pivotal role of intrinsic metal-support interactions and their dynamic evolution mechanisms in breaking the activity-stability dilemma in OER. Our findings open a new avenue of manipulating intrinsic metal-support interactions to overcome the activity-stability tradeoff dilemma in electrocatalysis.

Table 1. Comparison of catalytic performance of different OER catalysts

Media	Sample	η_{10} (mV)	Stable Time (h) @ 10 mA cm^{-2}	Electrolyte	Data source
Acidic	$RuTiMnO_x$	165.2	3000	0.5 M H_2SO_4	This work
	RuO_2	224.1	4	0.5 M H_2SO_4	This work
	$CoWO_4$-delaminated	288	175	0.5 M H_2SO_4	*Science* 384, 1373 (2024)
	LMCF	370	360	0.1 M $HClO_4$	*Science* 380, 609 (2023)
	Ni-RuO_2	214	200	0.1 M $HClO_4$	*Nat. Mater*. 22, 100 (2023)
Neutral	$RuTiMnO_x$	233.5	1500	0.5 M PBS	This work
	RuO_2	335.4	5	0.5 M PBS	This work
	Ru-VO_2	269	60	1.0 M PBS	*Adv. Mater*. 36, 2310690 (2024)
	Ni-$FeWO_4$@WO_3/NF	235	200	1.0 M PBS	*Adv. Mater*. 36, 2308925 (2024)
Alkaline	$RuTiMnO_x$	185.6	2000	1.0 M KOH	This work
	RuO_2	239.6	10	1.0 M KOH	This work
	FeCo–N_3O_3@C	298	240	0.1 M KOH	*Nat. Synth*. 3, 878-890 (2024)
	W-718a	320±10	48 h @ 5 mA cm^{-2}	0.1 M KOH	*Nat. Mater*. 23, 252-261 (2024)

References

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