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Energy Materials lie at the interface between materials science and electrochemistry and represents one of the most promising approaches for enabling renewable energy technologies to mitigate carbon emissions through the use of hydrogen fuel cells and the electrochemical reduction of CO_2. One of the key challenges is understanding how to achieve and sustain electrocatalytic activity under operating conditions for extended time periods, and such fundamental understanding calls for the use of time-resolve nanoscale *operando* analytical methods [1].

In this presentation, I will introduce our recent progress on developing *operando* electrochemical liquid-cell scanning transmission electron microscopy (EC-STEM), which simultaneously enables quantitative electrochemistry on microelectrodes and quantitative STEM based imaging, diffraction and spectroscopy [2]. *Operando* electrochemical 4D-STEM in liquid [3], driven by machine learning [4], has shown great potentials to interrogate complex structures of active sites of energy materials at solid-liquid interfaces. In particular, I will present my latest work on multimodal *operando* studies of combining EC-STEM and correlative synchrotron based X-ray methods [5, 6] to elucidate the longstanding enigmatic nature of Cu active sites as Cu nanograins for selective CO_2 electroreduction (Figure 1) [6, 7].

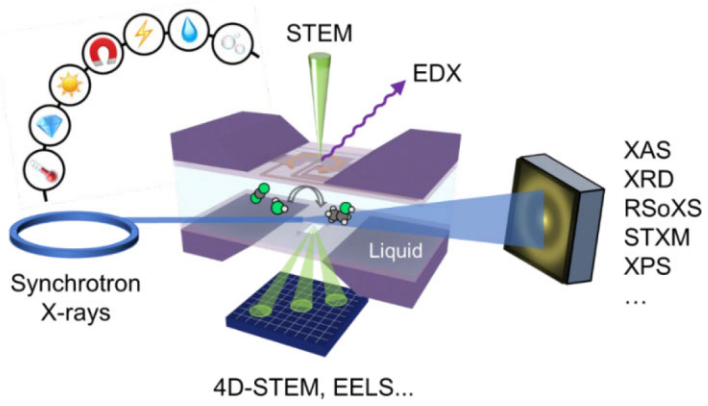

Figure 1 Multimodal *Operando* STEM and correlative X-ray methods: The upper left schematic includes a variety of stimuli (temperature, pressure, light, magnetic fields, electrical bias, liquid or gas environment) that may alter (electro)chemical reaction dynamics at solid-liquid interfaces. Figure was adapted from reference [1] (Copyright by the author).

References

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