Using APXPS to Probe the Solid/Liquid Interface Under Operando Conditions

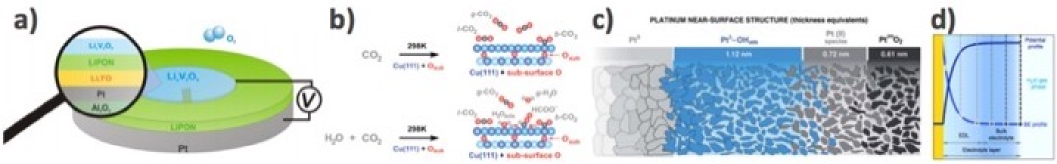
Ethan Crumlin

Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley, California, United States

Joint Center for Energy Storage Research, Lawrence Berkeley National Laboratory, Berkeley, California, United States

ejcrumlin@lbl.gov

Interfaces play an important role in nearly all aspects of life, and are essential for electrochemistry. Electrochemical systems ranging from high temperature solid oxide fuel cells (SOFC) to batteries to capacitors have a wide range of important interfaces between solids, liquids, and gases which play a pivotal role in how energy is stored, transferred, and/or converted. The ability to study these interfaces has proven to be difficult and is only further exacerbated by the limited number of techniques capable of operating under *in situ/operando* environments. To overcome these challenges, we use in situ/operando ambient pressure X-ray Photoelectron Spectroscopy (APXPS). APXPS is a photon-in/electron-out process that can provide both atomic concentration and chemical specific information at pressures greater then 20 Torr. Using synchrotron X-rays at Lawrence Berkeley Nation Laboratory, the Advanced Light Source has several beamlines dedicated to APXPS endstations that are outfitted with various *in situ/operando* features such as heating to temperatures > 500 °C, pressures greater then 20 Torr to support solid/liquid experiments and electrical leads to support applying electrical potentials supports the ability to collect XPS data of actual electrochemical devices while its operating in near ambient pressures. Previous studies at the solid/gas interface include an *operando* investigation of solid-state Li-air batteries (**Fig a**) [1] and an *in situ* study of CO_2 interaction on a copper surface (**Fig b**) [2]. This talk will introduce APXPS and provide several solid/liquid interface electrochemistry examples using *operando* APXPS including the probing of a Pt metal electrode undergoing water splitting reaction to generate oxygen (**Fig c**) [3], and the ability to probe the electrochemical double layer (EDL) (**Fig d**) [4]. Gaining new insight to guide the design and control of future electrochemical interfaces.



in situ and *operando* APXPS electrochemistry examples including: **a)** solid-state Li-air battery [1], **b)** CO_2 reduction on a copper surface [2], **c)** Pt metal electrode undergoing water splitting reaction to generate oxygen [3], and **d)** the ability to probe the EDL [4].

References

[1] Lu, Y.-C., Crumlin, E. J., Veith, G. M., Harding, J. R., Mutoro, E., Baggetto, L., Dudney, N. J., Liu, Z. & Shao-Horn, Y., *Scientific Reports* 2, doi:10.1038/srep00715 (2012).

[2] Favaro, M., Xiao, H., Cheng, T., Goddard, W. A. I., Yano, J. & Crumlin, E. J. *PNAS,* 114, 6706 - 6711, doi:10.1073/pnas.1701405114 (2017).

[3] Favaro, M., Valero-Vidal, C., Eichhorn, J., Toma, F. M., Ross, P. N., Yano, J., Liu, Z. & Crumlin, E. J., *J. Mater. Chem. A,* 5, 11634-11643, doi:10.1039/C7TA00409E (2017).

[4] Favaro, M., Jeong, B., Ross, P. N., Yano, J., Hussain, Z., Liu, Z. & Crumlin, E. J. *Nat Commun* 7, 12695, doi:10.1038/ncomms12695 (2016).