

Tuesday, May 04, 11am, IEM Conference Room

## **Operando Electrochemistry at the Nanoscale: Advancing Synchrotron Nanoprobe Capabilities**

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Electrochemical energy systems are increasingly explored under synchrotron radiation to capture their structural and chemical evolution during operation. At the Tarumã nanoprobe beamline, we have developed and optimized a suite of electrochemical environments, including cells, electrolyzers, microreactors, and battery holders; designed to fully exploit a highly focused X-ray beam ( $\approx 180 \times 180 \text{ nm}^2$  at 10 keV). These platforms ensure chemical stability, low X-ray attenuation, and compatibility with multimodal measurements. By integrating X-ray fluorescence (XRF), X-ray absorption spectroscopy (XAS), and coherent scattering techniques such as ptychography and Bragg coherent diffraction imaging (BCDI), we enable spatially resolved and chemically sensitive operando studies. This approach provides direct insight into catalyst redox dynamics, dissolution and redeposition, morphological evolution, and nanoscale strain.

More broadly, the continued advancement of sample environments at CARNAÚBA significantly broadens the experimental landscape for operando studies of electrochemical and catalytic systems. By enabling increasingly realistic and information-rich measurements, these developments contribute to a deeper mechanistic understanding of energy-conversion processes and support the next generation of sustainable technologies, including green hydrogen production, advanced energy storage, and efficient catalytic systems.

Itamar Neckel is currently a beamline scientist at the Carnaúba beamline of Sirius, he works on the development of instrumentation for *in situ* and *operando* experiments in the sample environment of the Tarumã end-station. The main focus of this work is the in-situ characterization of smart materials using multi-technique X-ray methods, such as nano-fluorescence, nano-diffraction, nano-absorption, and Bragg Coherent diffraction imaging (BCDI).

Itamar Neckel holds a Bachelor's degree in Physics from the Federal University of Paraná (2006), as well as a Master's and a Ph.D. in Materials Engineering and Science from the Federal University of Paraná (2009). He has experience in the field of Condensed Matter Physics, with an emphasis on Materials Engineering, focusing primarily on the growth and characterization of thin magnetic and ferroelectric films. From 07/2015 to 07/2016 he joined the measurement and sensor technology group at the TU Chemnitz, working under the supervision of Prof. Christian Muller.

