

Protochips™ in-situ Electron Microscopy Solutions: Capabilities and Applications

New innovations are transforming the Transmission Electron Microscope (TEM) from a simple high-resolution image acquisition tool into a nanoscale materials research and development laboratory. Researchers can now better understand material behavior by analyzing samples in real-world gas or liquid environments, at high temperature and with ultra-low noise electrochemical and electrical biasing techniques. With the new in situ tools from Protochips, materials research occurs in highly controlled environments at high resolution without sacrificing the analytical capabilities of the TEM such as EDS. Applications for these tools include heterogeneous catalyst reactions, imaging of living cells, nanostructure nucleation and growth, battery and fuel cell materials, high temperature nanoparticle behavior, soft materials, and semiconductor devices.

In this presentation we show the most recent results using the Protochips Atmosphere™ gas cell, the Protochips Poseidon™ Select flowing liquid and electrochemistry cell, and the Protochips Fusion™ heating and electrical biasing system.

The Protochips Atmosphere™ system combines the Protochips patented silicon carbide MEMS heating technology, closed-cell holder design, and gas handling manifold, with our innovative Clarity workflow driven software allowing for atomic-scale resolution at gas pressures up to 1 atm and sustained temperatures up to 1000°C. Especially for applications in the field of catalysis the system allows gas mixing and independent control of gas flow and pressure, as well as the integration at gas analysis equipment (RGA). Atmosphere is also compatible with analysis tools including EDS and EELS. Recent results on gas-phase catalyst reactions will be presented.

The Protochips Poseidon™ Select liquid cell surrounds samples in a self-contained, fully hydrated, hermetically sealed chamber directly within the TEM. Poseidon comes with a wide range of applications, from life science to battery research and corrosion studies. It features in situ electrochemistry capabilities, which enables the observation and characterization of electrochemical reactions in realistic reaction environments in real-time, and now offers liquid heating, for experiments in growth and reaction kinetics and temperature sensitive samples. Poseidon™ Select can also be used to capture high resolution images of living cells and biological processes in their native, hydrated environment.

Protochips Fusion™ offers best in class in-situ TEM heating and electrical biasing performance, simultaneous heating and biasing (electro-thermal mode),

and features closed-loop temperature feedback without introducing significant thermal drift. Like Atmosphere, Fusion is based on the Protochips patented silicon carbide heating technology, and the user-friendly Clarity workflow software.

Sample preparation methods using Focused Ion Beam techniques were developed to address the different challenges emerging from *in situ* heating and biasing experiments. We will show that high quality TEM foil containing a singular resistive memory device can be prepared and connected to the Fusion™ holder in a few hours.

A full Clarity software suite allows for the control of experiments, data recording and analysis as well as the seamless integration of in-situ data into TEM camera software.