In Situ and *Operando* X-Ray Diffraction Under Non-Ambient Conditions: Recent Application Examples

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By combining structural and compositional information obtained from X-ray diffraction (XRD) with controlled non-ambient conditions in *in situ* or *operando* experiments, researchers gain a comprehensive and multidimensional understanding of material behavior. This approach enables real-time monitoring of how materials respond to variations in temperature, pressure, gas atmosphere, humidity, or electrochemical environment. As a result, it provides deeper insight into structural stability, reaction pathways, phase evolution, and functional performance. Such detailed knowledge of structure-property relationships is essential for the design and optimization of advanced materials in fields including catalysis, energy storage, electrochemistry, pharmaceuticals, and functional ceramics.

As experimental strategies become increasingly sophisticated, XRD technology continues to evolve in parallel. Modern instrumentation is designed to deliver precise, reproducible, and high-resolution data even under demanding non-ambient conditions. Instrument manufacturers are developing integrated solutions that combine robust hardware and intelligent software, and advanced sample environments to ensure reliable performance and efficient workflows.

In addition, complementary analytical techniques – such as Raman spectroscopy or total scattering/PDF analysis – are being incorporated to broaden applicability of non-ambient XRD and deepen structural insight. At the same time, established hardware platforms are continuously refined and adapted to emerging applications, ensuring flexibility, scalability, and long-term value for users across research and industrial environments.

The presentation will highlight selected application examples of non-ambient XRD, including temperature-dependent order-disorder phase transitions in LCO battery cells during charging, PDF experiments under non-ambient conditions to probe local structural changes, and the investigation of solid-state phase formation mechanisms in piezoceramics at elevated temperatures. In addition, we will showcase the hardware solutions employed, outline the required experimental configurations, and provide practical guidance for successful implementation.