2026 Helmholtz – OCPC – Program

for the involvement of postdocs in bilateral collaboration projects

PART A

Title of the project:

Development of holistic electron microscopy characterization for sensitive battery systems in FIB/S(T)EM

Helmholtz Centre and/or institute:

Karlsruhe Institute of Technologie (KIT), Institute of Nanotechnologie INT)

Project leader:

Prof. Dr. Christian Kübel, Prof. Dr. Xiaoke Mu

Contact Information of Project Supervisor: (Email, telephone)

Email: christian.kuebel@kit.edu,
Phone: +49 160 5882170

Web-address:

www.int.kit.edu/kuebel.php

Department: (at the Helmholtz centre or Institute)

Advanced Electron Microscopy in Materials Research

Programme Coordinator (Email, telephone)

Name: Oliver Kaas
Phone: +49-721-608-45323
Email: oliver.kaas@kit.edu

Description of the project (max. 1 page)**:**

Vision and Motivation

Progress in battery research is increasingly limited by the ability to observe degradation processes across length scales. Critical phenomena such as solid–electrolyte interphase (SEI) formation, interfacial reconstruction, nanoscale phase transformations, and local chemical heterogeneity evolve at atomic to nanometre length scales. Understanding these processes is essential for a targeted battery development. However, the structural evolution associate with these phenomena is also highly sensitive to air exposure, temperature, and electron beam effects. In conventional workflows, the time and handling required between electrochemical cycling, focused ion beam preparation, and TEM analysis often alter or erase precisely those features that are most scientifically relevant.

This project is driven by the vision that nano-scale characterization of battery electrodes should occur as close as possible—in space and time—to the preparation process itself. Recent advances in dual-beam (FIB–SEM) instrumentation, cryogenic sample handling, and transmission-capable electron detectors create a unique opportunity to realize this vision. By enabling transmission SEM measurements combining chemical (EDX), morphological (SE, ADF-STEM) and atomic structure information (4D-STEM, TKD) immediately after (cryo)-FIB preparation without any instrumental transfer, the dual-beam microscope can evolve from a preparation tool into a powerful nano-analytical platform for battery materials capable of addressing length scales from millimetres down to the atomic level.

Objective and Scope

The overarching objective is to establish a new, methodologically robust approach for transmission characterization of (cycled) battery electrodes in a dual-beam FIB/SEM. Rather than focusing on a single material system, the project emphasizes the method development and validation, aiming to define a broadly applicable workflow that can become a reference standard for sensitive battery materials.

Methodological Innovation

Combining the cutting-edge transmission SEM architecture with FIB sample reparation strategy to enable online structural analysis of sensitive materials. Electron-transparent sections will be prepared from electrode interfaces using optimized cryogenic FIB protocols protecting the native structure. Without any transfer process, the sample will be analysed using the full range of (transmission) detectors available in the dual-beam system. ADF-STEM imaging will provide nano-scale Z-contrast for morphology and interface analysis, EDX will provide chemical composition information and 4D-STEM will enable local crystallo-graphic, phase, and strain analysis. The correlative use of these modalities enables a level of structural and chemical insight that is already sufficient to answer most key questions in battery degradation research, while avoiding the risks associated with conventional transfer-based TEM workflows.

Impact and Outlook

By preserving fragile SEI layers and air-sensitive electrode phases, this methodology is expected to fundamentally address the oxidation and moisture-induced degradation during nano-scale battery characterization, thereby providing a reliable technical pathway for accurate structural analysis of battery interfaces and strengthening the structure–property correlations. This development can be readily transferred to other functional environ-mentally sensitive materials. In this way, the project redefines the role of the dual-beam FIB/SEM, positioning it as an enabling platform that bridges preparation and with holistic structural and chemical analysis at the nanoscale.

Description of existing or sought Chinese collaboration partner institute (max. half page)**:**

This project will be carried out in collaboration with Prof. Dr. Xiaoke Mu, affiliated with the School of Materials and Energy at Lanzhou University, who conceived this project together with Prof. Christian Kübel at KIT-INT.

Lanzhou University, located in Lanzhou, Gansu Province, China, is a comprehensive research university directly affiliated with the Ministry of Education and included in the national "Double First-Class", "Project 985", and "Project 211" initiatives. Materials Science at Lanzhou University is ranked within the top 1% globally according to the Essential Science Indicators (ESI).

Xiaoke Mu specializes in electron microscopy method development and its applications in materials science, with particular emphasis on 4D-STEM techniques and battery materials. He has direct scientific collaboration with KIT-INT over the past decade. Between 2014 and 2024, he worked at KIT-INT, where he established his independent research profile and acquired third-party funding as Principal Investigator from DFG (Grant No. MU 4276/1-1) and the Helmholtz Imaging Platform (HIP, Grant No. BRLEMM). During this period, he developed several 4D-STEM methodologies for the characterization of amorphous structures and electromagnetic fields, as well as improvements in electron optical instrumentation. Subsequently, Xiaoke Mu joined Lanzhou University and was awarded the Excellent Young Scientists Fund of the National Natural Science Foundation of China. To date, he has authored or co-authored more than 60 peer-reviewed publications in journals including Ultramicroscopy, Advanced Materials, and Nature Communications, with over 4,900 citations.

Required qualification of the postdoc:

- PhD in physics, materials or chemistry
- Experience with advanced electron microscopy techniques (hands-on and theory)
- Additional skills in image/data processing, electrochemistry is benifitial
- Language requirement: good written and spoken Englisch