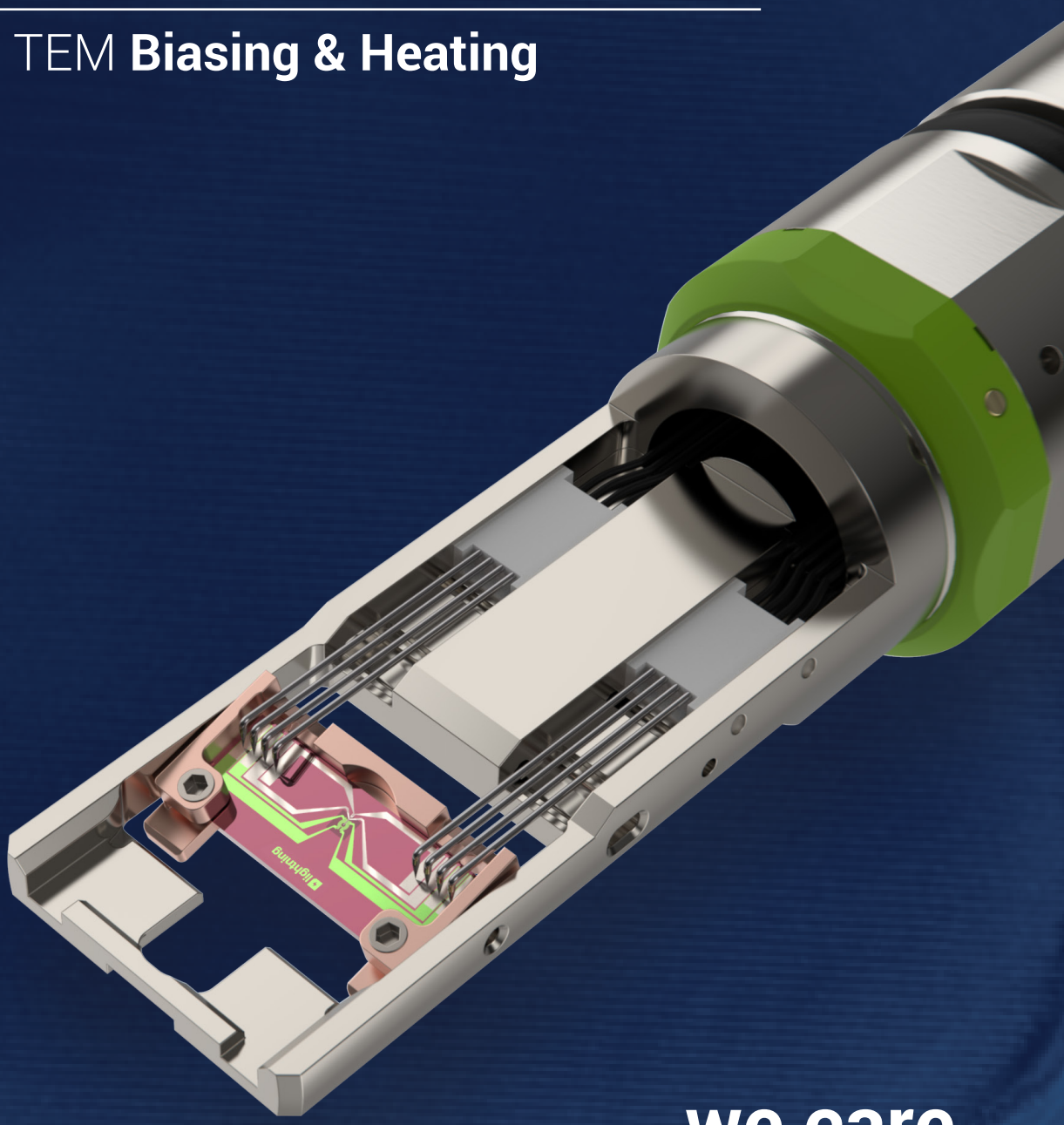
DENS solutions

Lightning

In Situ TEM **Biasing & Heating**



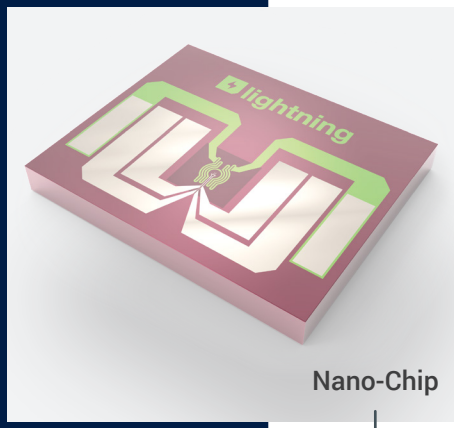
we care
we innovate
we deliver

Introduction

The Lightning In Situ TEM Heating and Biasing Solution allows to observe real-time dynamics of your specimen under a controllable electrical and thermal environment while maintaining optimal TEM performance.

The Lightning system expands the application space of your TEM, providing the unique possibility to link processing conditions with the structure, properties and performance of your materials and devices.

Our state-of-the-art Nano-Chip features a 4-point-probe method to accurately control biasing and heating and retrieve meaningful data. Its design sustains the highest reachable electrical fields and temperatures, either individually or simultaneously.

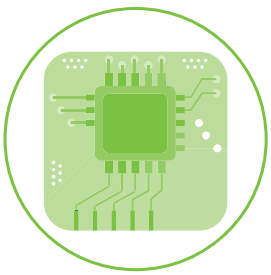


Nano-Chip

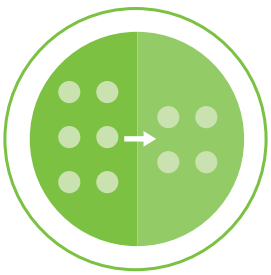
Sample holder

Typical applications

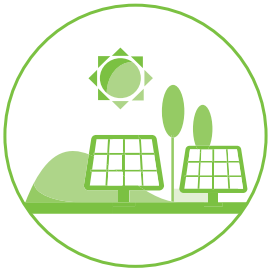
Solid state batteries



ReRam & functional oxides



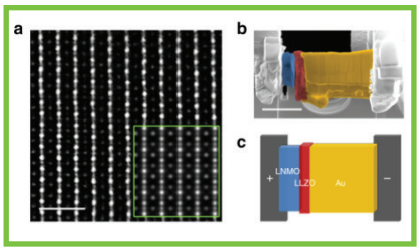
Phase transformations



Semiconductor nanodevices

Selected Publications

Li-ion battery research



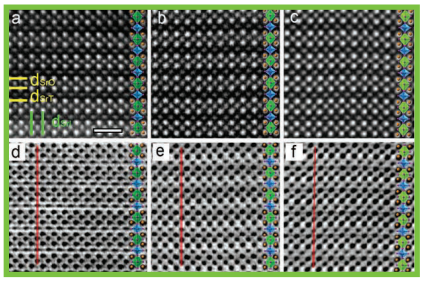
Configuration of the assembled all-solid-state lithium-ion battery and the atomic structure of LNMO a Atomic scale HAADF-STEM of the pristine LNMO cathode along the <112> zone axis. The simulation HAADF-STEM image is shown in a green rectangle which agrees perfectly with the experiment result. b SEM image of the assembled all-solid-state lithium-ion battery, and its corresponding schematic (c).

Most technologically important electrode materials for lithium-ion batteries are essentially lithium ions plus a transition-metal oxide framework. However, their atomic and electronic structure evolution during electrochemical cycling remains poorly understood. Here the authors report the in situ observation of the three-dimensional structural evolution of the transition-metal oxide framework in an all-solid-state battery.

The in situ studies $LiNi_{0.5}Mn_{1.5}O_4$ from various zone axes reveal the evolution of both atomic and electronic structures during delithiation, which is found due to the migration of oxygen and transition-metal ions. This study not only shows the importance of atomic scale three-dimensional characterizations for improving our understanding on the dynamic process and fundamental mechanisms of delithiation but also sheds light on optimization of the structural stability, as well as the cycle-ability of all-solid-state battery.

Yue, Gong et.al. Nature Communications 9 (2018) 3341

ReRam & functional oxides

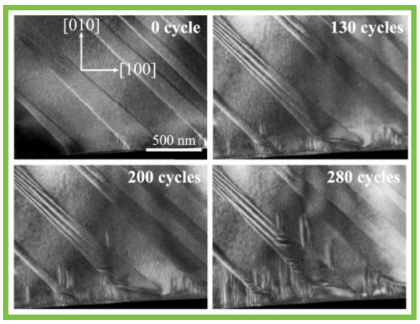


Evolution of lattice and oxygen occupancy in three states.

Oxygen ion transport is the key issue in redox processes. Visualizing the process of oxygen ion migration with atomic resolution is highly desirable for designing novel devices such as oxidation catalysts, oxygen permeation membranes, and solid oxide fuel cells. Here the authors show the process of electrically induced oxygen migration and subsequent reconstructive structural transformation in a $SrCoO_{2.5-\sigma}$ film by scanning transmission electron microscopy.

Zhang, Qinghua et al. Nature Communications 8.1 (2017) 104

Ferroelectrics and multiferroics



A series of TEM images showing the evolution of domain structure in PMN-0.38PT under a cyclic electric field.

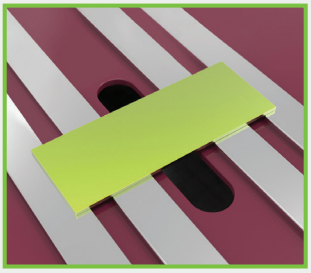
Ferroelectric degradation, induced by cyclic electric loadings in ferroelectric materials, has been a major obstacle in the application of ferroelectrics in devices where reliability is crucial.

Here the authors discover the change of charge distribution in thin ferroelectrics during cyclic electric loadings via our Lightning system. They find that charge accumulation at domain walls is the main reason for the formation of *c* domains, which are less responsive to applied electric fields. The rapid growth of these frozen *c* domains then leads to ferroelectric degradation. The discovery of this ferroelectric degradation mechanism not only strengthens the understanding of ferroelectric degradation at nanoscale, but also provides guidance on the design of ferroelectric nanodevices.

Huang, Qianwei et al. Nature Communications 12 (2021) 2095

Why Lightning?

1



Simplified sample preparation

1. High success rate
Expereince a simplified procedure with our dedicated FIB Stub, Nano-Chip and detailed workflow.

2. Best quality FIB lamellae
Perform final thinning directly on the chip without affecting the heating and biasing performance.

2

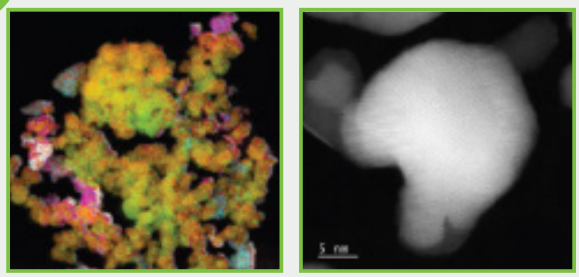
Reliable stimuli control

1. Heating & biasing accuracy
4-point probe heating & biasing provides the most accurate temperature, voltage and current control.

2. Wide in situ stimuli range
MEMS-based Nano-Chips are designed to sustain the highest temperatures and electric fields, individually or simultaneously.

3. Reliable temperature
Temperature verified directly in TEM using EELS and SAED techniques.

3



High impact results

1. New insights
Perform thermal studies while simultaneously measuring I-V with true pA current sensitivity.

2. High Stability
Less than 200 nm displacement and short stabilization time even if ΔT = 1000 °C, as well as atomic resolution routinely achievable even at high electric fields.

3. Unaffected S/TEM performance
Minor Z-displacement (bulging) preserves the ultimate resolution without tedious stage movements.

Software for accurate heating and biasing control

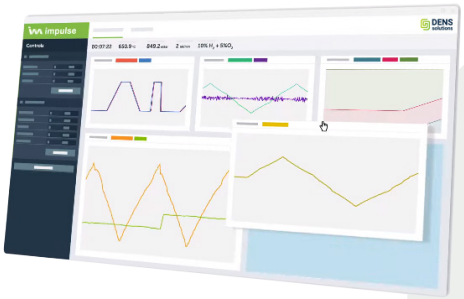
Impulse 1.1

Intuitive In Situ experiment control and automation software

Impulse 1.1 grants you complete control over your stimuli. It offers an integrated control interface that is flexible to adapt to your experiment. You can even design your In Situ experiment from your desk. Decide which sample conditions you want to be met at which time and Impulse will do the rest.

Smart automation

- Easily design your experiment with the drag-and-drop profile builder.
- Smart automation keeps track of measurements and ensure that your sample conditions are met.
- Accurately reproduce your experiments.

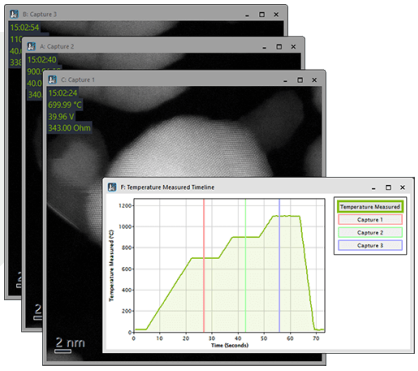


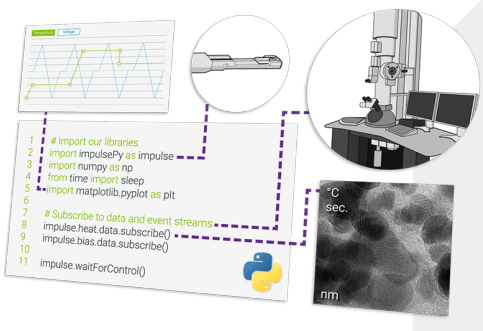
Flexible dashboard

- Plot any number of parameters that are important for your experiment.
- Arrange and resize the graphs so that you never miss a thing.
- Quickly find correlations and make real-time decisions.

Data integration

- Synchronize your stimuli data with other data from your experiment.
- Provide your camera and detector images with stimuli annotations in seconds.





Experimental freedom

- The Impulse application programming interface (API) and Python module lets you control your system using Python scripts. This offers unbound freedom in experiment control.
- Automate and synchronize data collection of cameras and detectors with the control of the stimuli.

System specifications

	Lightning HB+	
	JEOL	Thermo Fisher Scientific
Heating & biasing control	Closed 4-point probe feedback loop	Closed 4-point probe feedback loop
Number of contacts	8	6
Temperature range	RT - 1,300 °C	RT - 1,300 °C
Membrane breakdown voltage	≥ 150 V at RT/900 °C	≥ 150 V at RT/900 °C
Attainable E-fields	≥ 300 kV/cm at RT/900 °C	≥ 300 kV/cm at RT/900 °C
Detectable current range	1 pA to 100 mA	1 pA to 100 mA
AC measurement	Up to 100 Hz	Up to 100 Hz
Polepiece compatibility	All	C-TWIN, TWIN, X-TWIN, S-TWIN
Alpha tilt range*	URP, FHP ≥ ± 8 deg HRP, WGP ≥ ± 20 deg	≥ ± 22 deg
Beta tilt range*	URP, FHP ≥ ± 15 deg HRP, WGP ≥ ± 25 deg	≥ ± 25 deg
Attainable resolution**	≤ 60 pm	≤ 60 pm
Drift rate**	≤ 0.5 nm/min	≤ 0.5 nm/min
Temperature accuracy	≥ 95 %	≥ 95 %
Temperature homogeneity	≥ 99.5 %	≥ 99.5 %

** Tilt ranges are dependent on the exact pole piece gap, microscope configuration and EDX detector used and might vary from the listed specifications.*

*** Listed specifications are dependent on microscope configuration.*

Complete ‘plug & play’ package

1. Lightning heating & biasing TEM specimen holder
2. Nano-Chips starter pack
3. Heating control unit
4. Laptop with Impulse software
5. FIB stub 3.0
6. Keithley 2450 source measuring unit (optional)

Including:
Supporting tools

Service and Support

Product warranty	24 months with optional extension
Regulatory compliance	CE, RoHS, FCC
Radiation safety	According to TEM manufacturers compliance regulations

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Wildfire
Heating

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Heating + Biasing

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Stream
Liquid + Biasing or Heating

Version 3.1