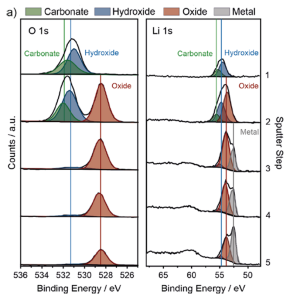
PHYSICAL ELECTRONICS
A DIVISION OF ULVAC-PHI

Full-Scale Battery Materials Characterization

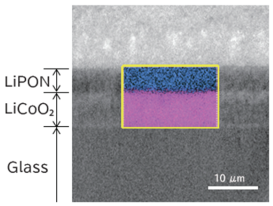
Solutions over small (nm) to large (cm) scales by Physical Electronics

Chemistry



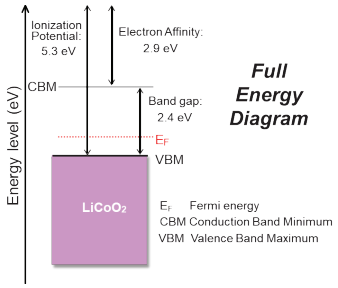
Morphology

Overlay of Li Chemical Map with SEM



Auger map - Li from LiPON
Auger map – Li from $LiCoO_2$

Electronic properties



Sample handling

Transfer Vessels for all sample holders

4-contact holder

Electrochemical cell

Information:

- SEI composition
- Chemical structure
- Purity of battery components

Techniques:

- TOF-SIMS
- XPS/HAXPES
- AES/EDS/EBSD/BSD

Information:

- Morphology
- Bulk compostion
- Microscopic structure
- Chemical heterogeneity

Techniques:

- TOF-SIMS
- XPS/HAXPES
- AES/EDS/EBSD/BSD
- Depth profiling using mono Ar^+, GCIB, and C_{60}

Information:

- Electronic structure
- Band gap
- Work function

Techniques:

- UPS
- LEIPS
- REELS

Information:

- Compostion and structure after testing

Capabilities:

- *In-situ* heating/cooling
- *In-situ* polarization studies
- Inert transfer from test to instrument
- Glove box attachment

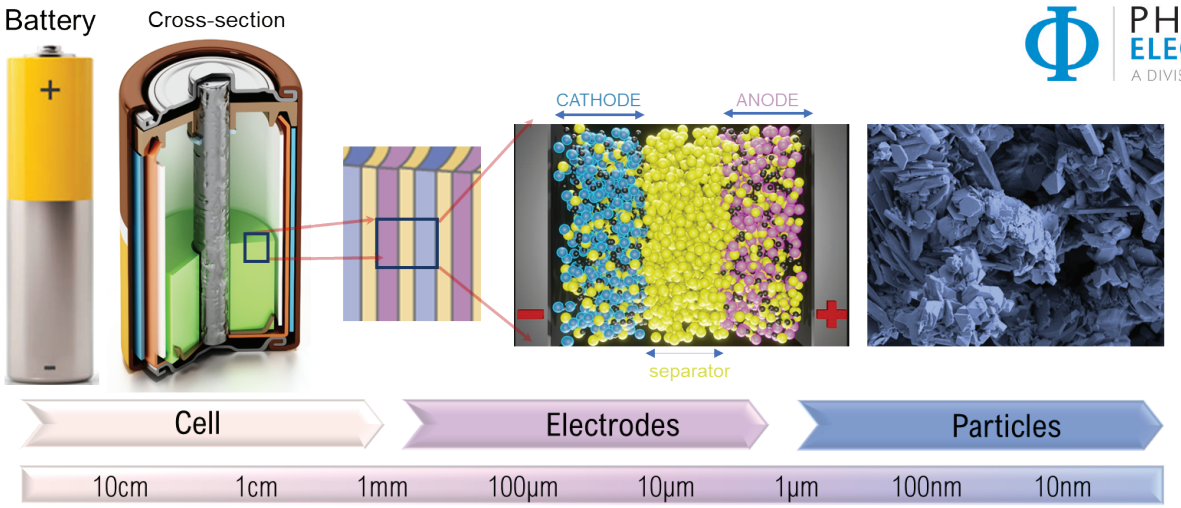
Surface analytical techniques provide critical information for predicting the performance and understanding the stability of batteries:

- Chemical analysis of interfacial layers beween electrodes and electrolyte.
- Morphological analysis over nano- to micro scales.
- Probing surface and bulk properties through depth profiling.
- Dendrite identification.
- Probing changes in structural and chemical properties of components after battery cycling.

X-ray photoelectron spectroscopy

Time-of-flight Secondary Ion Mass Spectrometry

Auger Electron Spectroscopy



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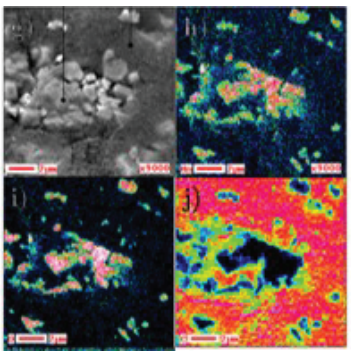
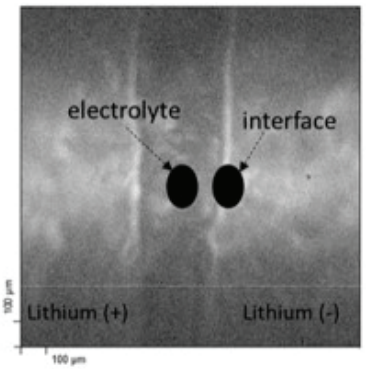
CATHODE



SEM and **AES** elemental maps of LMO electrode after discharge cycle, highlighting the need for high spatial resolution for use with rough sample surfaces.

J. Mater. Chem. A, 2017, 5, *15315*

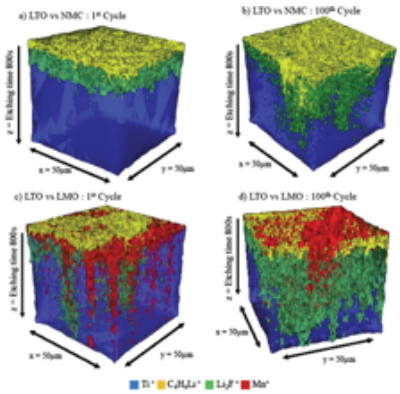
ELECTROLYTE



Secondary X-ray induced Electron (SXI) imaging using 10 µm X-ray spot in XPS is used to locate lithium/electrolyte interface.

J. Phys. Chem. A, 2021, 125, *1069*

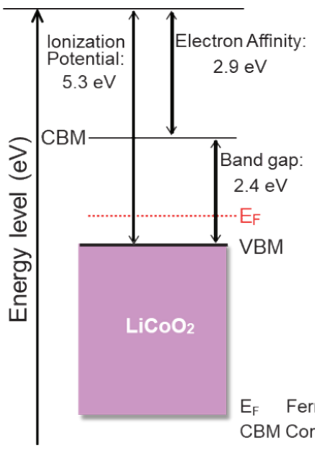
ANODE



Trace level metal species detected using **TOF-SIMS** from the electrode, suggesting diffusion through the electrolyte.

App Surf Sci, 2020, 501, *44266*

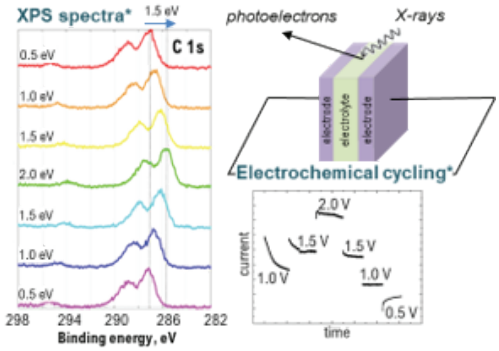
ELECTRONIC STRUCTURE



The full energy diagram can be obtained using **UPS/LEIPS.** LEIPS uses a low-energy electron beam, which ensures damage-free energy diagram evaluation! Performing XPS and UPS/LEIPS in the same area provides a direct link between chemical properties and electronic structure of the electrolyte/electrode interface.

E_F Fermi energy
CBM Conduction Band Minimum
VBM Valence Band Maximum

OPERANDO XPS



Operando XPS can probe the evolution of the chemical structure and the surface potential at the electrode/electrolythe interface of lithium-ion batteries under electrochemical conditions.

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