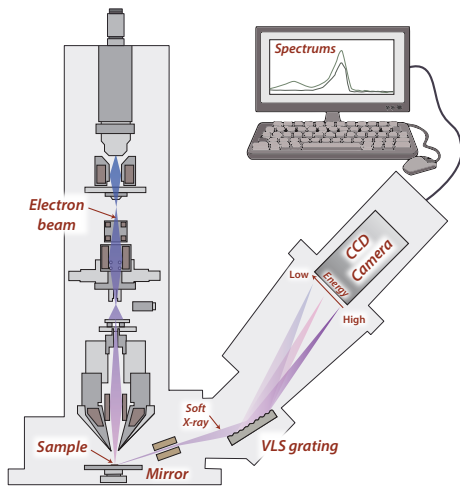## Principle and features



Characteristic X-rays are generated by the electron beam from the sample and guided, by the focusing mirror, to the newly developed diffraction varied-line-spacing (VLS) grating. X-rays diffract from the grating according to their wavelength; different characteristic X-rays are detected simultaneously by a parallel detection system (CCD camera) and displayed as a spectrum.

### Benefits:

✓ **Extreme spectral resolution** ⟶ **chemical state analysis** of light elements

✓ Excellent **light element detection** (Li, Be, B, C, etc..)

✓ **High sensitivity** ⟶ Example: a few Boron ppm in steel can be detected

✓ **High stability** and **reproducibility**
⟶ No moving parts, possibility to switch between gratings

## Study case: Li K emission spectra, chemical bond effect

### • Methodology

Ref: *H Takahashi et al 2016 IOP Conf. Ser.: Mater. Sci. Eng. 109 012017*

Three samples of a lithium-ion battery anode with different charging conditions are analyzed with **SXES**: 0 % (A), 30 % (B), and 100 % (C)

⟶ **3 maps constructed** in 3 energy ranges crresponding to *satellite of Li-K*, *Li-K* and *C-K*
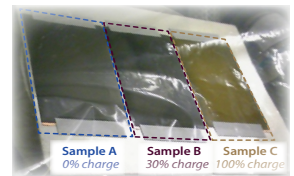
### • Results: maps and spectra

**Li-K Satellite Map**: The map due to the *satellite of Li-K* (**Fig 1**) showed an increase in relative intensity with increasing charge of the anode material.

**Li-K Map**: The metallic lithium is formed locally and distributed heterogeneously under the fully charged condition.

**C-K(n=3) Map**: The map indicates the intensity distribution due to graphite; the other constituent of the anode. Under the fully discharged condition, the intensity was strongest. The intensity reduced substantially when the amount of charging increased by 30 % and stayed at this level when the amount of charging increased to 100 %.
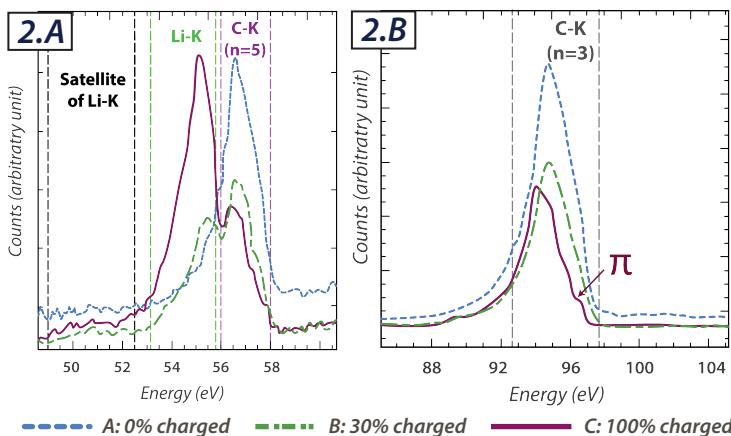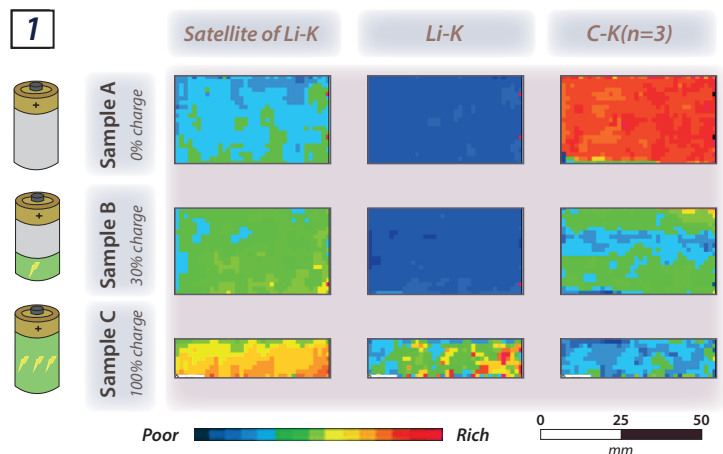


**High resolution:** The spectra corresponding to the three charge states are extracted from the maps in **Fig1**. They cover all energy ranges of the *satellite Li-K*, *Li-K* and *C-K(n=5)* (**Fig 2.A**), as well as C-K(n=3) (**Fig 2.B**). Thanks to the **high energy resolution of the SXES**, the peaks of *Li-K* and *C-K(n=5)*, which have a very close energy, are clearly distinguished.

**Fast and accurate interpretation of results:** The discharged anode does not show any Li peak unlike the two charged anodes (**Fig 2.A**). On the contrary, the discharged anode shows the strongest C peaks, while the 100% charged anode shows the smallest peaks (**Fig 2**). Moreover, the intensity of the π sub-peak in the *C-K(n=3)* (**Fig 2.B**) represents the battery state of charge: the more pronounced the peak, the more charged the battery is and vice versa.

⟶ Thus, for each sample, the intensities of the Li and C peaks are representative of the battery's state of charge.

----- A: 0% charged    --- B: 30% charged    — C: 100% charged

### • In summary

High spectral energy resolution ⟶ ability to **distinguish the close energy peaks** between the *Li-K* emission and *C-K(n=5)*

**High potential** for the **characterisation of lithium** ion battery anodes

A wide area distribution of **chemical state spectral Li map** can be provided by EPMA/SEM-SXES