Master thesis

Title of the research topic	In-situ SEM micro-indentation study of active materials in Li-ion and Na-ion batteries throughout cycling
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Scientific Project :

To answer the world demand in energy, devices such as Li-ion, Na-ion or even all solid state batteries are in constant development to increase capacity and security for a lower price. During cycling, the active materials will undergo modifications which can alter their performances such as volumetric change upon cycling, crack apparition. Those evolutions will have an impact on the mechanical properties of the active materials. Scalco de Vasconcelos et al.[1] have set up a micro-indentation plan to follow the heterogeneity of hardness and elastic modulus on composite electrode. Xu et al.[2] studied the electrochemical and mechanical evolutions of $LiNi_xMn_yCo_zO_2$ during cycling and showed that the mechanical properties depends on the active material lithiation state. By DFT computation, the young's modulus of graphite upon lithiation has been determine to increase threefold[3] inducing strain accumulation upon cycling. In all solid state batteries, the mechanical properties of the solid electrolyte are of importance to supress the dendrite formation while using metallic lithium at the negative electrode[4]. However, there is still only a few recent studies on the evolution of the mechanical properties at the active materials scale and their electrochemical performances.

During this project, the mechanical properties of active materials constituting the anode in Li-ion and Na-ion batteries will be investigated. A particular interest will be given to the determination of the hardness and elastic modulus behaviour throughout the cycling process. In this aim, the student will perform *in-situ* SEM micro-indentation analyses coupled with SEM and EDX analyses to follow the morphological, chemical and mechanical evolutions at different charging state.
The results obtained during this master thesis will allow to propose links between electrochemical performance and mechanical properties of the active materials giving new insight on the importance of such study in the battery field.

Techniques used :

Scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS);
Microindentation (elastic modulus and hardness)
Electrochemical analysis

Recent publications related to the topic :

1. Vasconcelos, L. S. de, Xu, R., Li, J. & Zhao, K. Grid indentation analysis of mechanical properties of composite electrodes in Li-ion batteries. *Extrem. Mech. Lett.* **9,** 495–502 (2016).
2. Xu, R., Sun, H., de Vasconcelos, L. S. & Zhao, K. Mechanical and Structural Degradation of $LiNi_xMn_yCo_zO_2$ Cathode in Li-Ion Batteries: An Experimental Study. *J. Electrochem. Soc.* **164,** A3333–A3341 (2017).
3.Qi, Y., Guo, H., Hector, L. G. & Timmons, A. Threefold Increase in the Young's Modulus of Graphite Negative Electrode during Lithium Intercalation. *J. Electrochem. Soc.* **157,** A558 (2010).
4. Yu, S. *et al.* Elastic Properties of the Solid Electrolyte $Li_7La_3Zr_2O_{12}$ (LLZO). *Chem.* **28,** 197–206 (2015)