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Utilizing beams of MeV ions for measurements of kinetics in materials on the atomic scale

To meet the sustainable development goals of the United Nations we have to transform our global economy into energy-smart, sustainable, cyclic societies. The materials we nowadays employ for storage and conversion of energy but also for regulation of energy transport are commonly complex compound systems often containing light chemical elements such as hydrogen, lithium or oxygen, either intentionally, or as contaminations, significantly altering materials properties. Characterization of the above-mentioned systems, during design, manufacturing and operation is challenging, due to the comparably weak electronic signature of these species.
Materials analysis methods based on energetic ions, due to their unique characteristics providing depth-resolved information on material composition and sensitivity also to light chemical species provide a unique toolbox to be exploited for such characterization. They are commonly non-destructive and robust in applicability rendering them excellent probes for studying materials modification processes while they occur, i.e. in in-situ or even in-operando investigations.
In this contribution, several recent studies using keV and MeV ion beam analytical tools for in-situ and in-operando characterization of a number of material systems with high relevance for energy-related applications will be presented.

Experiments were conducted at the 5MV 15-SDH-2 pelletron accelerator at Uppsala University which can provide a broad spectrum of beams in the energy range of 2 to ~50 MeV to multiple end-stations some of which capable of in-situ synthesis or materials modification [1]. The ion-beam based characterization was complemented by atom probe tomography, X-ray diffraction and transmission electron microscopy.

We performed high-resolution depth profiling of Li and O in thin film batteries using primary beams of He and Li at energies up to 10 MeV. By recording transmitted particles in coincidence, we could observe reversible transport of Li and quantify the material transport during charging and discharging of the battery stack [2][3][4].

Oxidized rare-earth metal hydrides can feature reversible photochromism at ambient conditions with huge potential for passive regulation of energy flow. To better understand the nature of the photochromic effect, we combined ion beam analysis with in-situ reactive growth and oxidation [5]. From this work and further complementary studies, a dual-phase nature is proposed and the photochromism is related to high residual stress levels in the films [6].

We furthermore explored the potential of ion beam analytical techniques capable of directly and indirectly sensing hydrogen in real space at a true atomic length scale. As a result, we succeeded to probe the specific lattice location and vibrational amplitude of H in crystalline matrices, specifically investigating Fe/V superlattices as model systems for studying effects of proximity and dimensionality. [7].

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