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Understanding Degradation Processes in MXene Anodes by In-situ Liquid Cell STEM

Juhan Lee[1], Dahnan Spurling[2], Oskar Ronan[2], Weiqun Li[3], Ioannis Siachos[3], Valeria Nicolosi[4] and B. Layla Mehdi[5]

[1]Department of Mechanical, Materials and Aerospace Engineering, University of Liverpool, Liverpool L69 3GH, UK, Liverpool, England, United States, [2]Trinity College Dublin, United States, [3]Department of Mechanical, Materials and Aerospace Engineering, University of Liverpool, Liverpool L69 3GH, UK, United States, [4]Centre for Research on Adaptive Nanostructures and Nanodevices (CRANN) and Advanced Materials and Bioengineering Research (AMBER) Research Centers, Trinity College Dublin, Dublin 2, Ireland, United States, [5]Department of Mechanical, Materials and Aerospace Engineering, University of Liverpool, Liverpool L69 3GH, UK, England, United Kingdom

The rising demand for extended driving ranges for electric vehicles has created the need for improved performance in Li-ion batteries; specifically, higher energy density and high-power capability. However, the current commonly used graphite anodes in Li-ion batteries do not allow for fast solid-state diffusion processes to occur and therefore high-power output is not possible for these novel electric vehicle applications. Additionally, while the lithiation potential of graphite is very low, which is good for producing a high cell voltage, it is not ideal as it enables the formation of lithium dendrites, which are both flammable and impose a limitation on the cycling stability of the cells. [1, 2, 3] In order to address above issues we need to explore new battery nanomaterials used in combination with high stability electrolytes to obtain an in-depth understanding of how batteries can be developed to meet future requirements.

MXene anodes have now emerged as potential alternatives to graphite and are perhaps the most promising new candidate for anode materials in Li-ion batteries due to both their unique and tailorable 2-D transition metal carbide and nitride structures and their higher lithiation potential than graphite. Furthermore, the wider interlayer spacing (~1nm) in MXenes potentially allows for quicker intercalation of Li^+ with minimal lattice distortion and improved rate performance along with better cycling stability. One of the most significant challenges in the use of MXene anodes is a rapid degradation and energy storage capacity after first few cycles, which currently leads to rapid anode failure and a decreased cycle lifetime. [3] Understanding the degradation mechanisms in MXene anodes is therefore of critical importance in order to meet the requirements of the future anode materials.

In this work we utilize *in-situ* electrochemical liquid cell STEM (*e*-STEM) that has previously applied to probe a wide range of battery materials and electrolytes, to study processes taking place in MXenes.[4] Specifically, we study degradation of the $Ti_3C_2T_x$-type MXene anode material during the nanobattery cycling in a full-cell configuration. The direct observation of dynamic processes at high spatial and temporal resolution allows us to identify a wide range of complex phenomena such as chemomechanical degradation of the electrodes, electrolyte decomposition, SEI formation, and Li intercalation/deintercalation processes at the electrolyte/MXene interface. Consequently, these results increase our understanding of MXene anodes and will help to develop new strategies for enhancing their performance. [5]

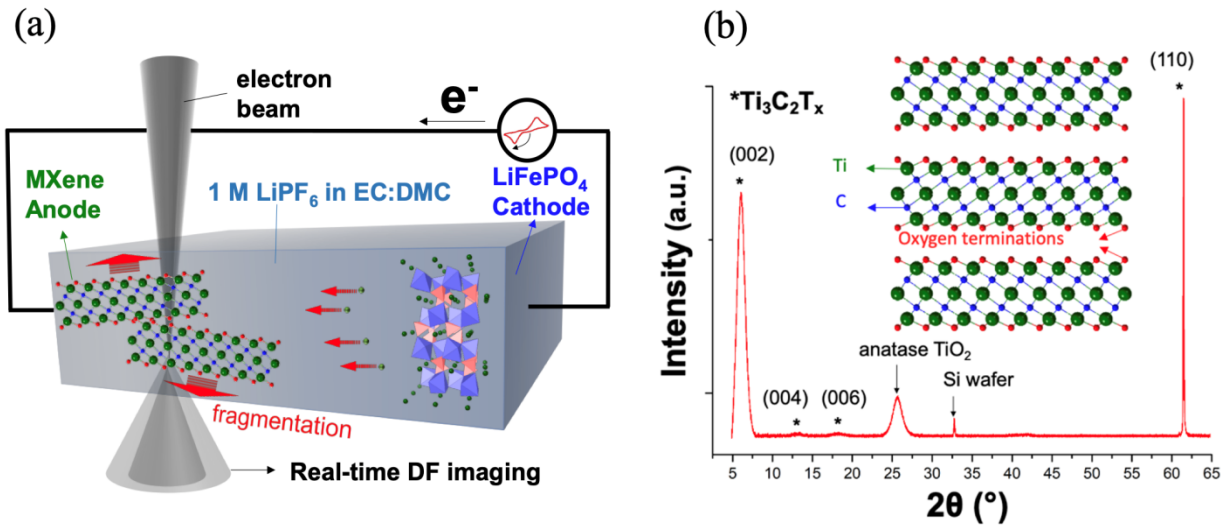

Figure 1. (a) Schematic of the in situ electrochemical STEM nanobattery cell with MXene anode and LiFePO4 cathode in 1M LiPF6 in EC/DMC. (b) X-ray diffraction pattern of the MXene-coated Si substrate. The crystal structure of the Ti3C2Tx-type (Tx for surface terminations) Mxene is illustrated in the inset.

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