Micro and nano-engineered silicon for high energy density lithium ion cells

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Lithium-ion Batteries (LIBs) are currently the most prominent choice for energy storage applications, especially for portable electronic devices, cordless power tools and electric vehicles thanks to their high energy density, long cycle life and low weight, compared to other energy storage technologies. However, there is a continuous need to improve the overall electrochemical performance of lithium-ion batteries, as the constant technological advances in the fields of automotive industry and portable communication device industry demand higher specific energy and energy density (>400 Wh/kg and >800 Wh/L) than actually commercially available cells.

Commonly, LIBs use graphite-based anodes (negative electrode), which have a capacity limitation due to the theoretical specific capacity of graphite versus Li/Li^+, ~372 mAh/g, with a lithiation phase of LiC_6. The most promising material to replace graphite is silicon (Si) with a maximum specific capacity, at room temperature, of 3579 mAh/g at the lithiation phase of $Li_{15}Si_4$, offering, in addition, a low potential vs Li/Li^+, abundance, non-toxicity and huge know-how processing from the microelectronic industry. However, pure silicon anodes are not ready to be commercialized, as silicon expands during lithiation (up to 300% of its initial volume) resulting to electrode cracking, material pulverization and Solid Electrolyte Interphase (SEI) fracture and regrowth. Consequently, electrodes demonstrate a continuous capacity fading upon cycling leading to limited cell cycle life. During the past years, there has been extensive ongoing research on improving the cycle life of silicon electrodes. Different approaches have been adopted to address silicon's expanding problem, by focusing on different aspects of the electrode. One approach has been the preparation and investigation of Si nanostructures that can accommodate the volume expansions during cycling, by manipulating the size, the surface and morphology of silicon particles. Furthermore, in order to enhance the electrical conductivity of silicon and offer a protective layer for SEI formation, the use of carbon-based coatings has been proposed, preventing the continuous cracking and growth of SEI. A promising approach focuses on combining two of the above-mentioned strategies, i.e. the creation of silicon nanostructures and the use of a carbon-based shell/coating. By managing to create a void space in between silicon and the carbon shell the nanoparticle can swell during lithiation without fracturing the outer shell and the corresponding SEI that is formed on the carbon shell surface.

The scope of this work is to present a brief summary of the technological challenges towards a silicon-based anode with high specific capacity and long-term stability.