LMS Seminar

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Dendrite formation in the electrolyte of solid-state lithium-ion batteries

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ABSTRACT

While solid electrolytes have the potential to suppress the formation of dendrites from the surface of lithium metal anodes, it is observed that lithium invades them in batteries in the form of metal filaments. Such phenomena stand in the way of the exploitation of the superior energy density of metal electrodes. This presentation summarizes computational modelling aimed at understanding the formation of filaments in solid electrolyte. For this purpose, a model is developed for redox kinetics at an interface between a single ion conducting solid electrolyte and lithium metal, including the effect of mechanical stress across the interface, thereby extending the Butler-Volmer equation. The extended Butler-Volmer equation is used to assess cracking of the solid electrolyte caused by insertion of lithium into a pre-existing flaw adjacent to a lithium anode that is being plated. The crack-opening is submicron, so that plastic flow of the lithium is subject to constraint leading to high magnitudes of hydrostatic compression, whereas unconfined lithium has a yield strength of 1 MPa and creeps at room temperature. As a result, the lithium deposited in the crack wedges it open, although lithium can flow out of the crack into the anode due to plastic yielding. When the crack grows, the lithium can fill the extended crack, forming a dendrite or lithium filament that eventually short-circuits the battery when the extending dendrite reaches the cathode. In some cases, the lithium cannot fill the crack as quickly as it propagates, forming partially occupied dendrites, as observed in some experiments. In other cases the lithium inserted into the crack keeps pace with the extension of the crack. Numerical results are obtained for the rate of dendrite extension as a function of current density. It is found that the predictions agree well with experimental results for symmetric cells.

BIOGRAPHY

Robert McMeeking earned a BSc in Mechanical Engineering with First Class Honours at the University of Glasgow, Scotland in 1972. He completed his PhD in solid mechanics at Brown University in 1976 and then was Acting Assistant Professor at Stanford University for 2 years. Thereafter he joined the faculty of the Theoretical and Applied Mechanics Department in the University of Illinois at Urbana-Champaign. He moved to the University of California, Santa Barbara (UCSB) in 1985 as Professor of Materials and of Mechanical Engineering, and was Chair of the Department of Mechanical Engineering 1992-1995 and again during 1999-2003. McMeeking is currently Tony Evans Distinguished Professor of Structural Materials and Distinguished Professor of Mechanical Engineering at UCSB. He is also Sixth Century Professor Emeritus at Aberdeen University in Scotland and holds a Leibniz Chair at the Leibniz Institute for New Materials in Saarbrücken, Germany. He has published over 300 papers on a diversity of topics in mechanics of materials. McMeeking was Editor-in-Chief of the Journal of Applied Mechanics from 2002 to 2012, and is currently Secretary-General of the International Union of Theoretical and Applied Mechanics. He is a member of the U.S. National Academy of Engineering, Fellow of the American Society of Mechanical Engineers, Fellow of the U.K. Royal Academy of Engineering and Fellow of the Royal Society of Edinburgh. He held a Humboldt Award for Senior Scientists in 2006, again in 2013, and received a Humboldt Alumni Award in 2018. He was given the Brown Engineering Alumni Medal in 2007, the 2014 William Prager Medal of the Society of Engineering Science, and the 2014 Timoshenko Medal of the American Society of Mechanical Engineers. In 2018 McMeeking was recognized with the honorary degree of Doctor of Engineering by the University of Glasgow and in 2023 he was awarded the Platinum Medal of the UK Institute of Materials, Minerals and Mining.