Current Density Imaging in Lithium-Ion Batteries

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Introduction: Development of new and more efficient batteries is one of the main priorities worldwide. With the introduction of lithium-ion batteries, batteries became lighter, had higher energy density and less memory effects than most previous types of batteries. However, with lithium batteries there are still several unsolved problems, among which growth of dendrites is the one that severely impedes further development of the batteries. Growth of dendrites on lithium metal electrodes poses a great risk of fire in the batteries. Consequently, lithium metal, which would be an ideal anode material and would enable much better battery capacity, is not in use. In this study, MR microcopy is used to study: a) conditions under which dendrites grow in a lithium symmetric cell, and b) how the dendrites influence the flow of electric currents in the cell.

Methods: A symmetric lithium cell as a lithium battery model system [1] was made of 8 mm thick block of peek plastic into which a cubic hole with dimensions 16 x 4 mm^2 was machined. In argon atmosphere, the cell was assembled by filling it with $LiPF_6$ in EC/DMC electrolyte and then sealing it on both sides with a sandwich of a lithium metal foil (electrode), a thin copper wire (electric contact), silicon rubber and a peek plastic side that was screwed on the block. The cell was then inserted into a 9.4 T NMR magnet in an orientation with the electrodes parallel to both B_0 and B_1 magnetic fields thus ensuring optimal reception of the MR signal [2]. The cell was repeatedly scanned with the regular 3D spin-echo and 3D current density imaging (CDI) sequence [3], both at parameters: field of view, 20 x 10 x 5 mm^3, imaging matrix, 128 x 64 x 32, TE/TR, 22/2000 ms. To induce growth of dendrites, between each pair of in total 11 scan blocks, electric charge needed for a transfer of 5 % electrode mass was flown at current densities ranging from 4 A/m^2 to 40 A/m^2 (in different experiments). In the CDI sequence currents of 5 mA were induced in the *xy* plane between the electrodes and then used to calculate current density from the magnetic field change B_{c_z} using the relation $(j_x, j_y) = \left(\partial B_{c\_z}/\partial y, -\partial B_{c\_z}/\partial x\right)/\mu_0$.

Results and discussion: Magnitude and the corresponding current density (CD) images in Fig. 1 clearly show growth of dendrites and how they influence current pathways. In the experiments it was found that the amount of formed dendrites is not dependent only on the transferred electric change, but also correlates with the applied current density. CD images were calculated from just one component of magnetic field change, which is sufficient under assumption that the electric currents are planar. Measured geometry of dendrites enables also simulation of current density distribution and its comparison with the measured one.

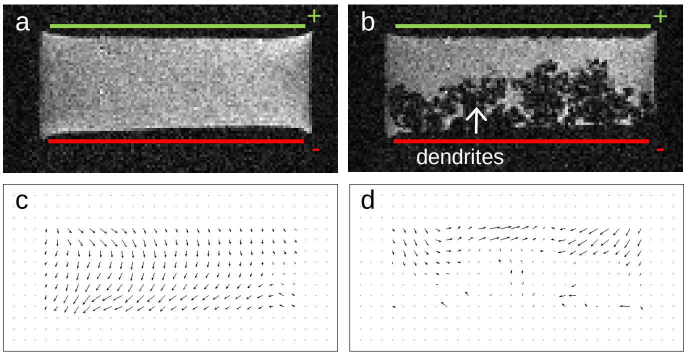

Fig. 1: Central slice ^{1}H images of the plane between the electrodes (up and down) shown by magnitude images a,b and the corresponding measured vector fields of current density distribution c,d of a fresh cell a,c and after the charge transfer of 50 As at 40 A/m^2 that induced dendrite growth.

Conclusion: In the study it was demonstrated that CDI can be applied also to study current distribution in a model battery and thus enable studying of various current-related phenomena in different battery configurations.

References: [1] Ilott, PNAS (2016). [2] Serša, JMR (2018), [3] Scott, JMR (1992).