Batterieforum Deutschland
20.01. - 22.01.2026

Enormous Increase in the Lifetime of Lithium-Ion Batteries with Silicon-Graphite Blend Electrodes by Partial Use of Silicon

Mathias Rehm[1], Yannis Riedel[1], Franz Roehrer[1], Moritz Guenthner[1], Andreas Jossen[1]

[1]Technical University of Munich, School of Engineering and Design, Department of Energy and Process Engineering, Chair of Electrical Energy Storage Technology, Arcisstraße 21, 80333 Munich, Germany

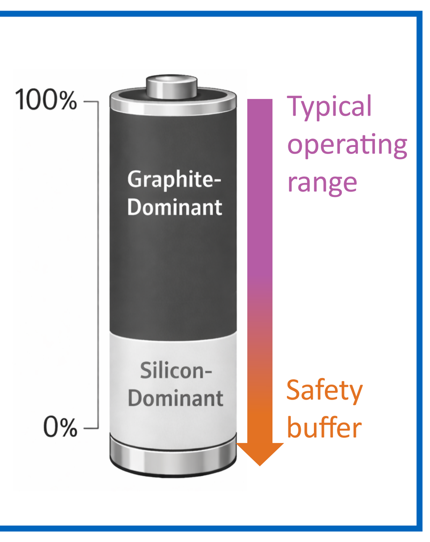
Motivation and Introduction

► Adding silicon to graphite anodes increases the energy density, but leads to higher degradation due to volume expansion of silicon of over 300% [1].

► Silicon is predominantly used at low full-cell SOCs due to the higher potential vs Li/Li+ of silicon compared to graphite [2].

► In mobile applications, especially flight applications, the cells are rarely completely discharged as the low SOC region serves mainly as a safety buffer.

► Avoiding fully delithiation of silicon reduces aging. However, correlation between usage of silicon capacity and additional aging is not known yet.



Main findings

► Partial use of silicon capacity does not lead to increased aging of the full-cell up to a certain threshold (1/3 of its capacity), using only 2/3 of the silicon capacity still at least doubles lifetime compared to full usage (disch. to 0% SOC).

► With increasing degree of usage of silicon both loss of active silicon and loss of lithium increase in a strongly nonlinear way.

► Sporadic usage of silicon does not lead to strong additional aging.

► Two cell types with different silicon contents show transferability of the results to cells with different silicon contents.

Test matrix

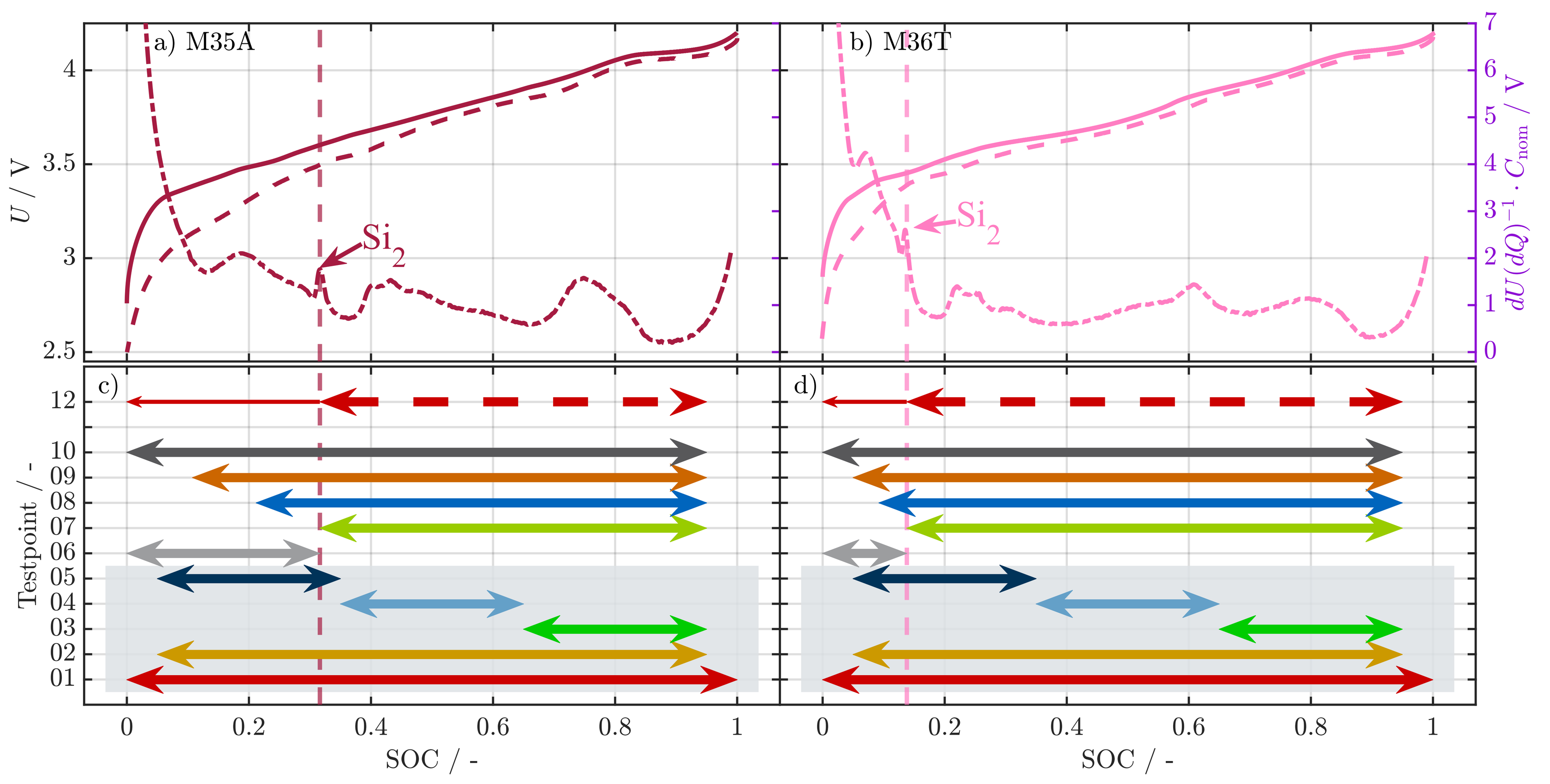


Figure 1 The Si_2 peak defines silicon-dominant (low) and graphite-dominant (high) SOC regions (a, b). Cycling uses silicon-only (TP06), graphite-only (TP07), 1/3 to full silicon use (TP08 to TP10), sporadic full silicon use (TP12), plus fixed SOC references (TP01 to TP05; gray shade).

Experimental

► A total of 63 cells were cyclically aged over 1600 equivalent full cycles (EFC), additional 144 cells were calendar aged as reference.

► Two 18650 cell types with different silicon contents, namely Molicel M35A and LG M36T were used. Cyclic aging was done with C/2 CCCV for charge and discharge.

► The anodic capacity provided by silicon is ~30% for the M35A (~8 wt% SiOx) and ~15% for the M36T (~3 wt% SiOx).

► Based on the Si -peak in the DV of the discharge pOCV, the SOC is split into a silicon-dominant region (low SOC) and a graphite-dominant region.

► Cyclic tests are performed at fixed SOCs (TP01 to TP05) as reference.

► To quantify impact of partial silicon use, cells are cycled starting from 95% SOC in the graphite-dominant region (TP07) and then using one third, two thirds, or all of silicon capacity (TP08 to TP10).

► Occasional use of silicon (19 cycles TP07; one cycle TP10) to show path dependency of silicon usage (TP12).

► Degradation mode analysis (DMA) separating silicon and graphite losses [3].
→ framework available at https://github.com/tum-ees/DegradationModeAnalysis

Impact of (partial) silicon usage

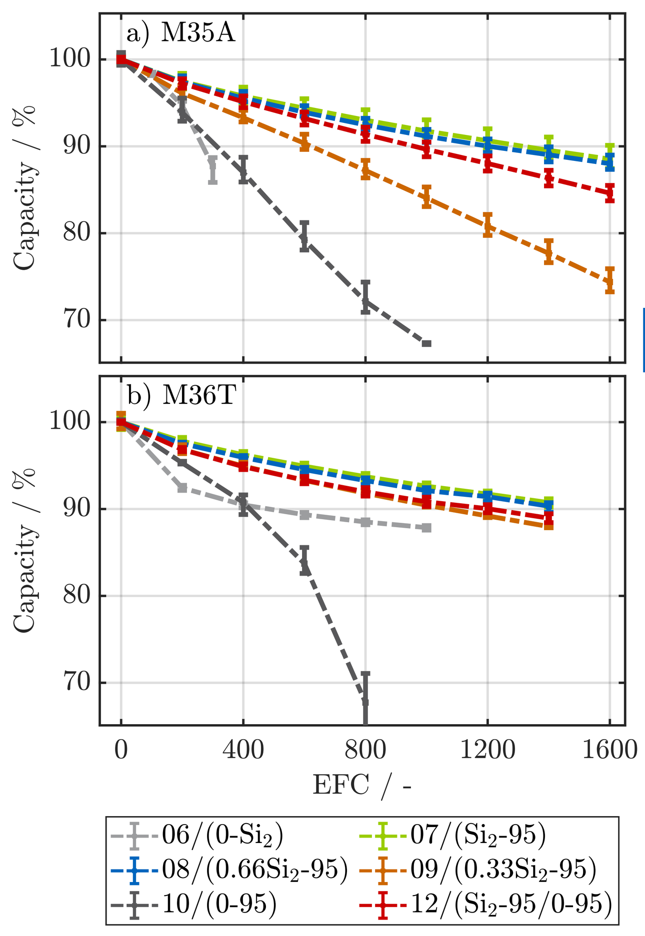


Figure 2 Capacity decay vs silicon usage degree. Min and max per testpoint are shown (three or two cells).

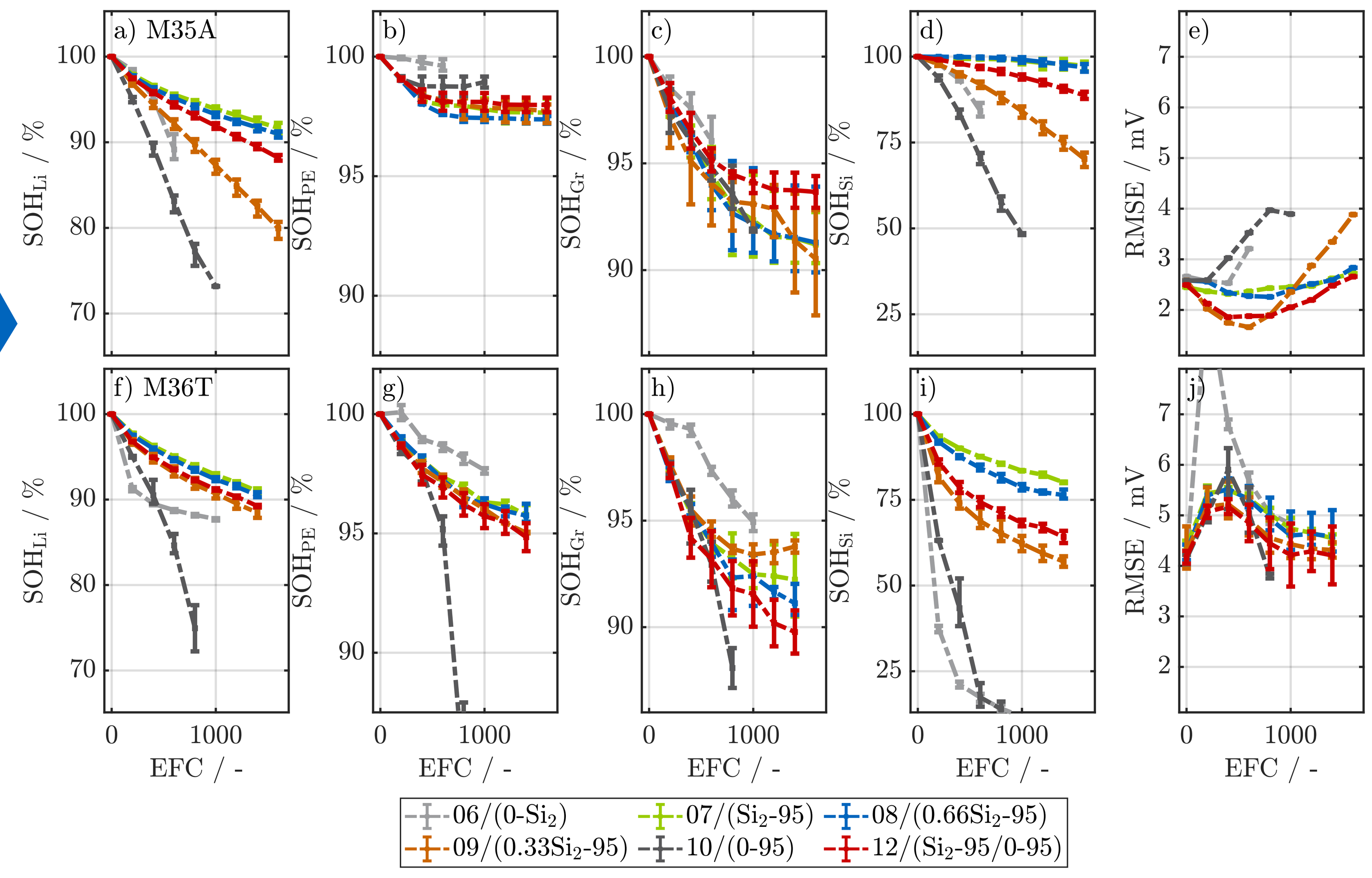


Figure 3 Degradation modes differentiating between loss of active silicon (LAM_{Si}) and losses of graphite are determined by minimizing the difference between the measured and reconstructed pOCV and corresponding DV in discharge direction [3].

Parameterization

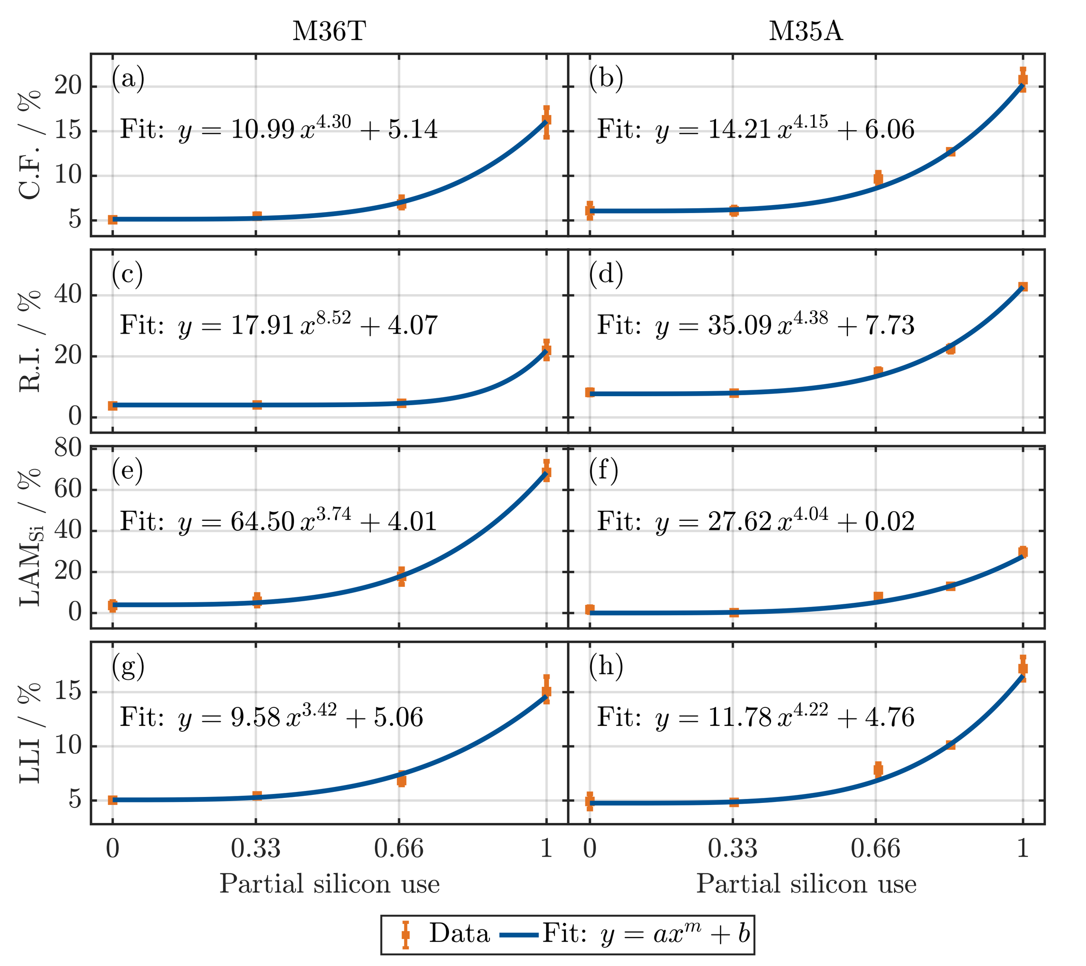


Figure 4 Impact of degree of silicon usage (TP07 to TP10 at 600 EFC) on both cell types follows a power law, showing aging increases stronlgy nonlinearly with higher silicon use.

Resistance increase

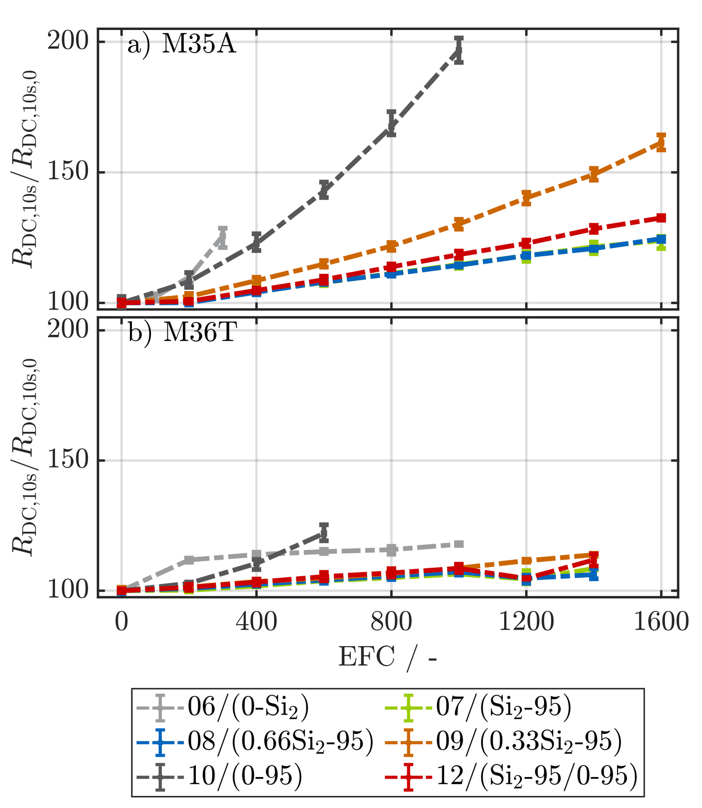


Figure 5 Resistance increase vs silicon usage degree. Min and max per testpoint are shown (three or two cells).

Reference tests

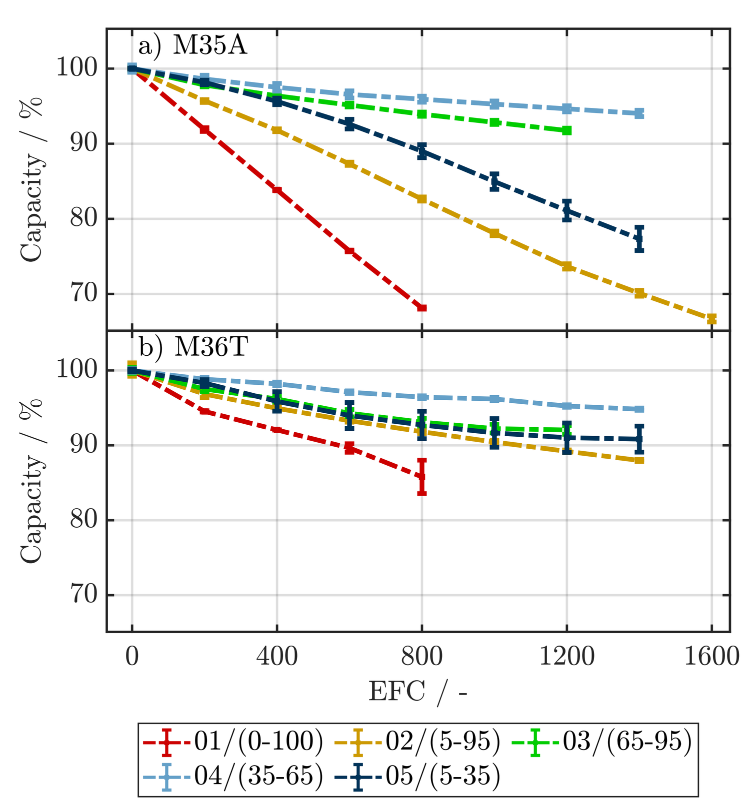


Figure 6 Capacity decay of testpoints in fixed SOC regions. Min and max per testpoint are shown (three or two cells).

Discussion

► Two cell types with different silicon contents confirm transferability to other silicon contents.

► Using only part of the silicon capacity strongly reduces aging: 1/3 silicon capacity usage adds negligible fade (TP08 vs TP07), while using 2/3 of silicon capacity (TP09, 10-95% SOC for M35A, 5-95% SOC for M36T) still doubles lifetime vs full discharge (TP10).

► As silicon use increases, capacity fade rises nonlinearly. DMA links it to added LLI with strong LAMSi driving the fade.

► Capacity fade, LAM , and LLI scale with silicon capacity use via a power law in both cell types with similar exponents (here shown for 600 EFC).

► Sporadic discharge (each 20th cycle) to end-of-discharge voltage does not lead to strong additional LLI or LAM .

Outlook

► Parameterization will be used for more precise modeling of aging of LIBs with silicon-containing anodes in PyBaMM.

Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

Acknowledgements

This work was supported by the Federal Ministry for Economic Affairs and Climate Action, Germany within the project ProMoBiS [03ETE046A].

References

[1] Kirkaldy, N.; Samieian, M. A.; Offer, G. J.; Marinescu, M.; Patel, Y. Lithium Ion Battery Degradation: Measuring Rapid Loss of Active Silicon in Silicon Graphite Composite Electrodes. ACS Applied Energy Materials **2022**, 5, 13367–13376. doi: 10.1021/acsaem.2c02047
[2] Ai, W.; Kirkaldy, N.; Jiang, Y.; Offer, G.; Wang, H.; Wu, B. A Composite Electrode Model for Lithium Ion Batteries with Silicon Graphite Negative Electrodes. Journal of Power Sources **2022**, 527, 231142. doi:10.1016/j.jpowsour.2022.231142.
[3] Rehm, M.; Natterer, J.; Eizenhammer, J.; Guenthner, M.; Korkmaz, C.; Roehrer, F.; Jossen, A. How to determine the degradation modes of lithium-ion batteries with silicon-graphite blend electrodes. Preprint **2025**, doi:10.2139/ssrn.5958815.