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Silicon-Carbon Composite-Based Anodes for Lithium-Ion Batteries

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MOTIVATION

- Large demand for new electrode materials with high specific capacities for high energy lithium-ion batteries (LIBs)
- Development of a scalable manufacturing process of novel silicon-carbon composite-based anode materials (Si/C) for lithium-ion batteries
- Optimization of slurry homogenization and binder configuration

METHODOLOGY / COMPOSITE PREPARATION

- Embedding silicon nanoparticles into a protective carbon matrix
- Thermally activated transformation of a carbon precursor
- Abundant and sustainable carbon source

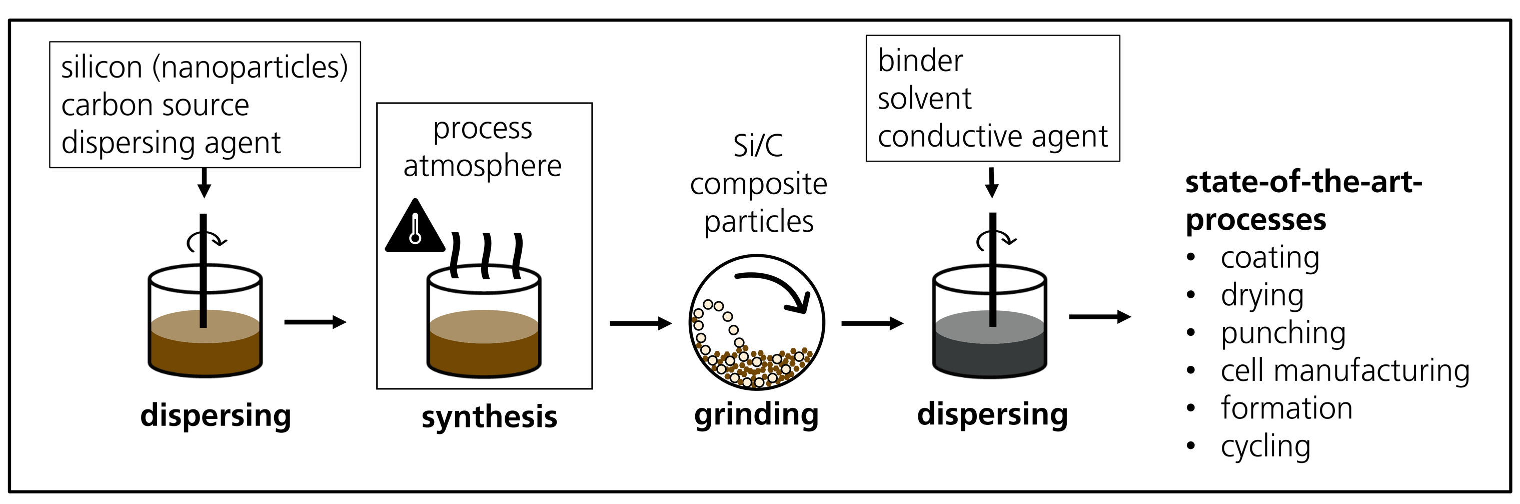

Fig. 1 Process scheme for manufacturing of Si/C based electrodes for LIBs

BINDER EVALUATION

Electrodes were prepared using 80 wt.-% active material, 10 wt.-% binder and 10 wt.-% conductive agent

- Half cells: Si/C vs. Li/Li$^+$ in CR2032 coin cells (~ 1 mg·cm^{-2} Si/C)
- Formation: 1st cycle CC at 300 mA·g^{-1} Si/C
- CCCV cycling at 1C (based on the delithiation capacity of the formation cycle, CV cut-off at C/10)
- First cycle efficiency of recent publications for silicon-based anodes essentially ranges between 50 % and 90 %[1]

Binder	First cycle efficiency	Standard deviation
CMC	86.05 %	± 0.05 %
CMC-SBR	85.88 %	± 0.04 %
PVDF	52.02 %	± 3.54 %
Polymer binder	85.85 %	± 0.15 %
Crosslinked polymer binder	86.15 %	± 0.68 %

Fig. 2 First cycle lithiation efficiency of different binders (data averaged for three cells)

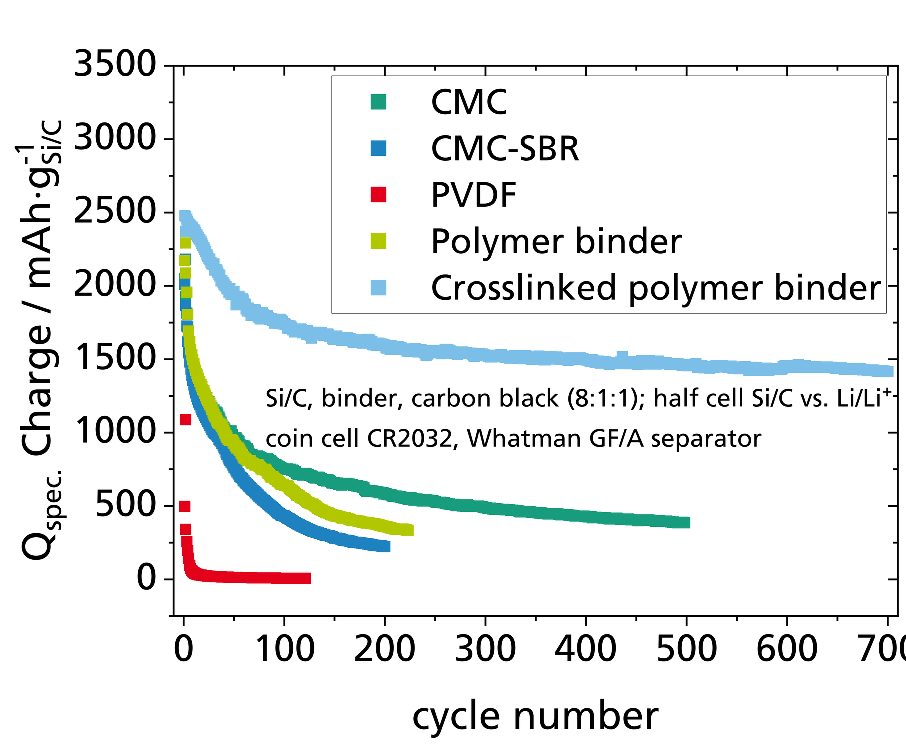

Fig. 3 Impact of different binders on the capacity retention during cycling

[1] Wu et al., Carbon Energy. 2019;1:57–76, DOI: 10.1002/cey2.2

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CONCLUSION

- Si/C-based electrodes show high initial lithiation capacities in half cells vs. Li/Li$^+$
- Electrodes achieve comparatively high first cycle lithiation efficiencies of ~ 85 % with several binders in water-based slurries
- Binder selection plays a crucial role in the capacity retention during cycling
- Fast charging with up to 4C can be performed in pre-lithiated full cells achieving > 85 % state of charge during constant current (CC) phase

PRE-LITHIATION

- Electrochemical pre-lithiation using a lithium counter electrode and an external circuit (half cell setup)
- Constant current cycling at C/10
- One lithiation and delithiation cycle is performed followed by a limited lithiation to 953 mAh·g^{-1} silicon (equals atomic Si:Li-ratio 1:1)

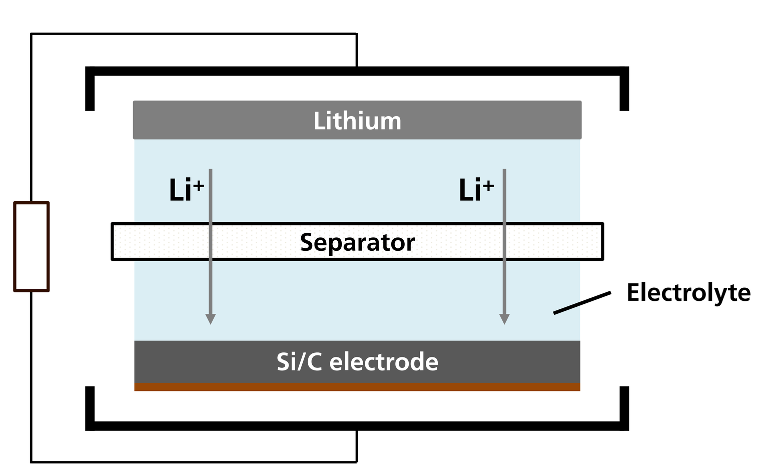

Fig. 4 Setup for electrochemical pre-lithiation in a CR2032 coin cell

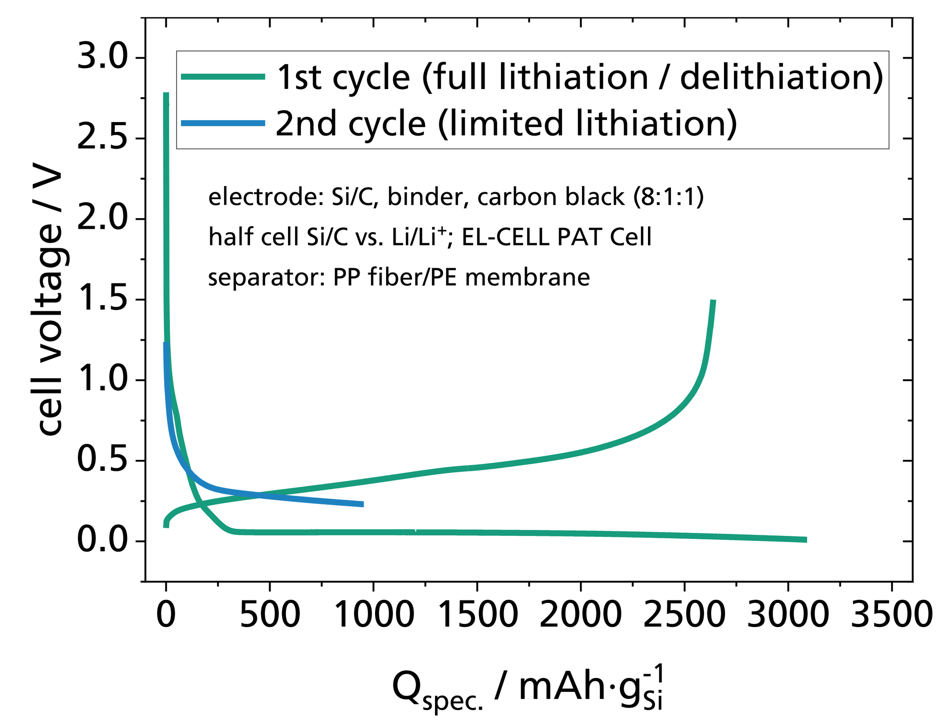

Fig. 5 Potential curve of Si/C pre-lithiation

C-RATE TEST FOR BATTERY FULL CELLS

- Pre-lithiated Si/C anode vs. NMC 622 cathode
- C-rate test at 0.5C, 1C, 2C, 4C (1C = 1 mA·cm^{-2})
- EL-CELL PAT Cell with PP/PE separator and carbonate-based electrolyte

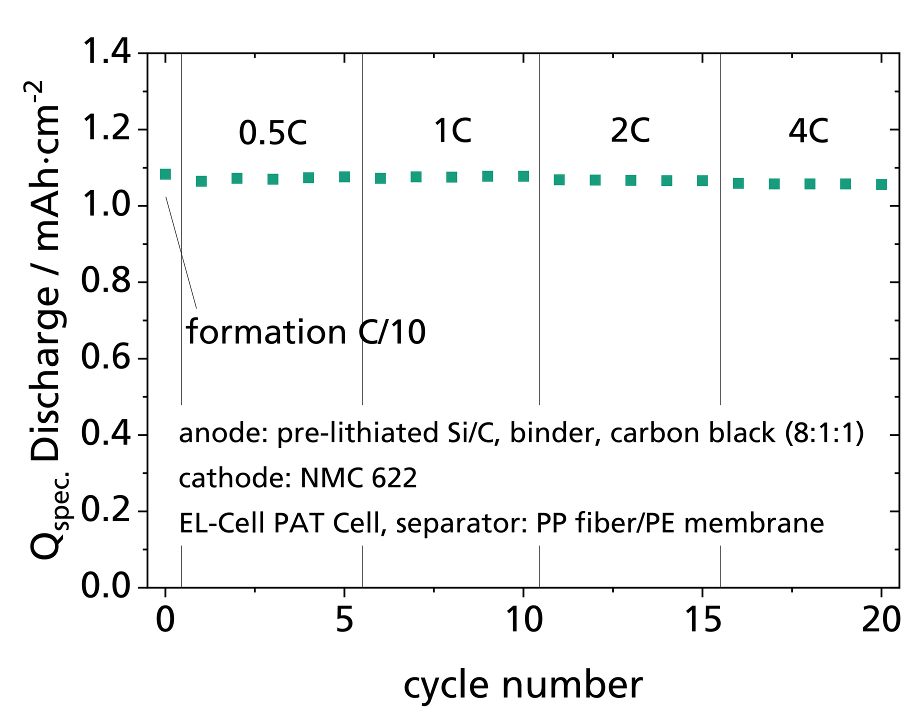

Fig. 6 Full cell C-rate test Si/C vs. NMC 622

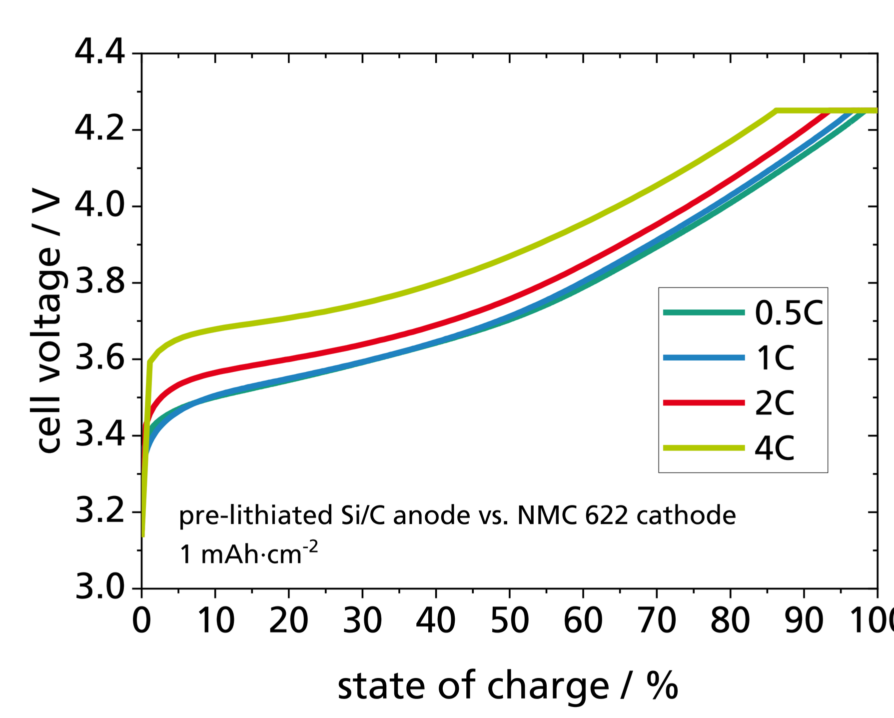

Fig. 7 Cell voltage vs. state of charge for different C-rates

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