

Germanium-based Lithium Ion Batteries: from fundamentals to practical testing in research laboratories

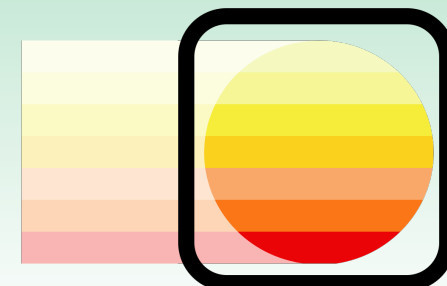
Valentina DIOLAITI

Aprile 16th, 2026

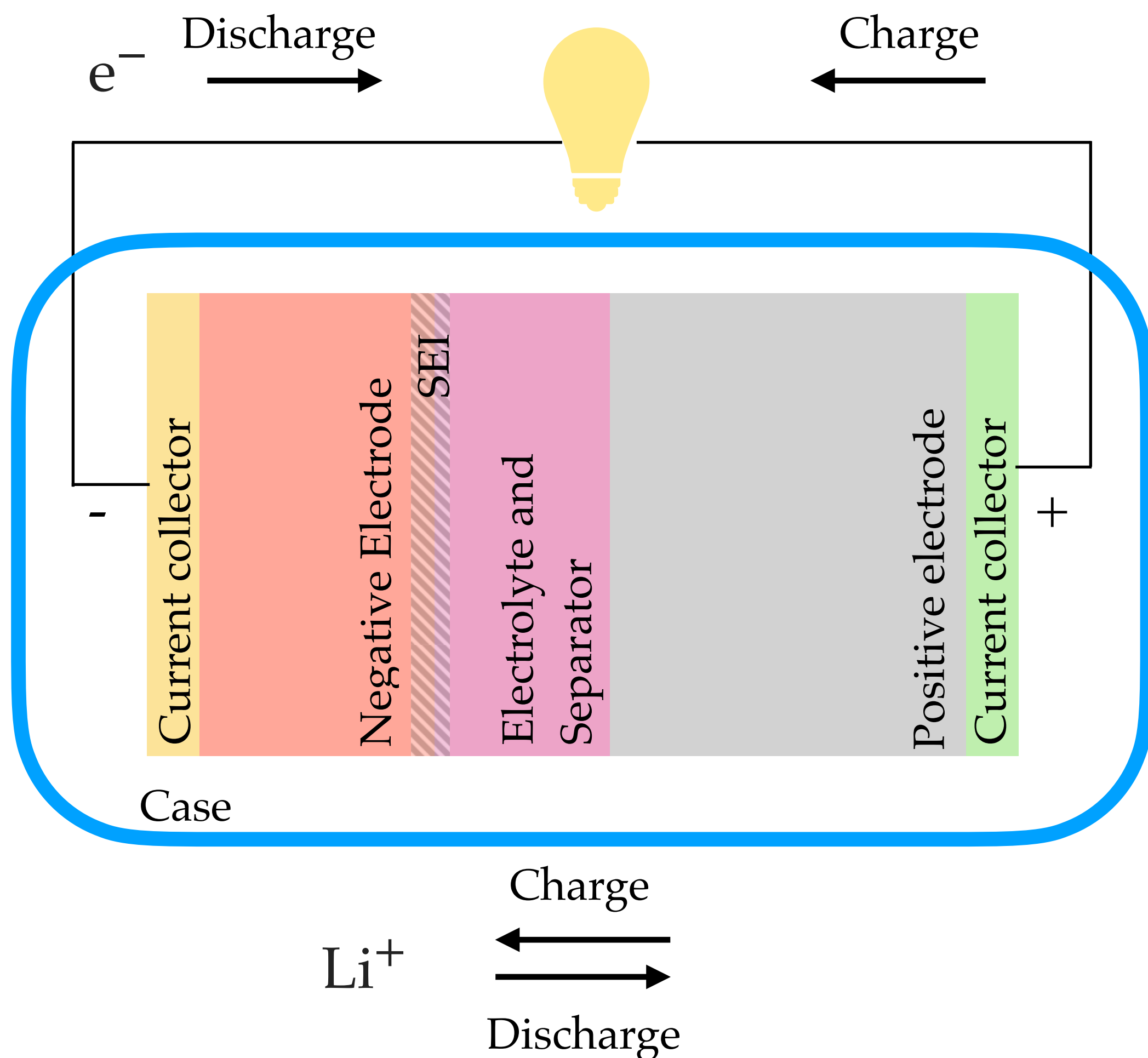
GIAKOVA Battery Workshop @ UNIFE



Dipartimento
di Fisica
e Scienze della Terra



At the core LIBs convert **chemical energy** into **electrical energy** via **redox reactions**.



LIBs elements

- ⊙ Negative electrode in which **oxidation** takes place.



- ⊙ Positive electrode in which **reduction** takes place.

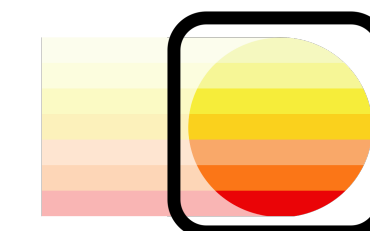


- ⊙ Current collectors

- ⊙ Separator (Whatman) & Electrolyte (LP30)

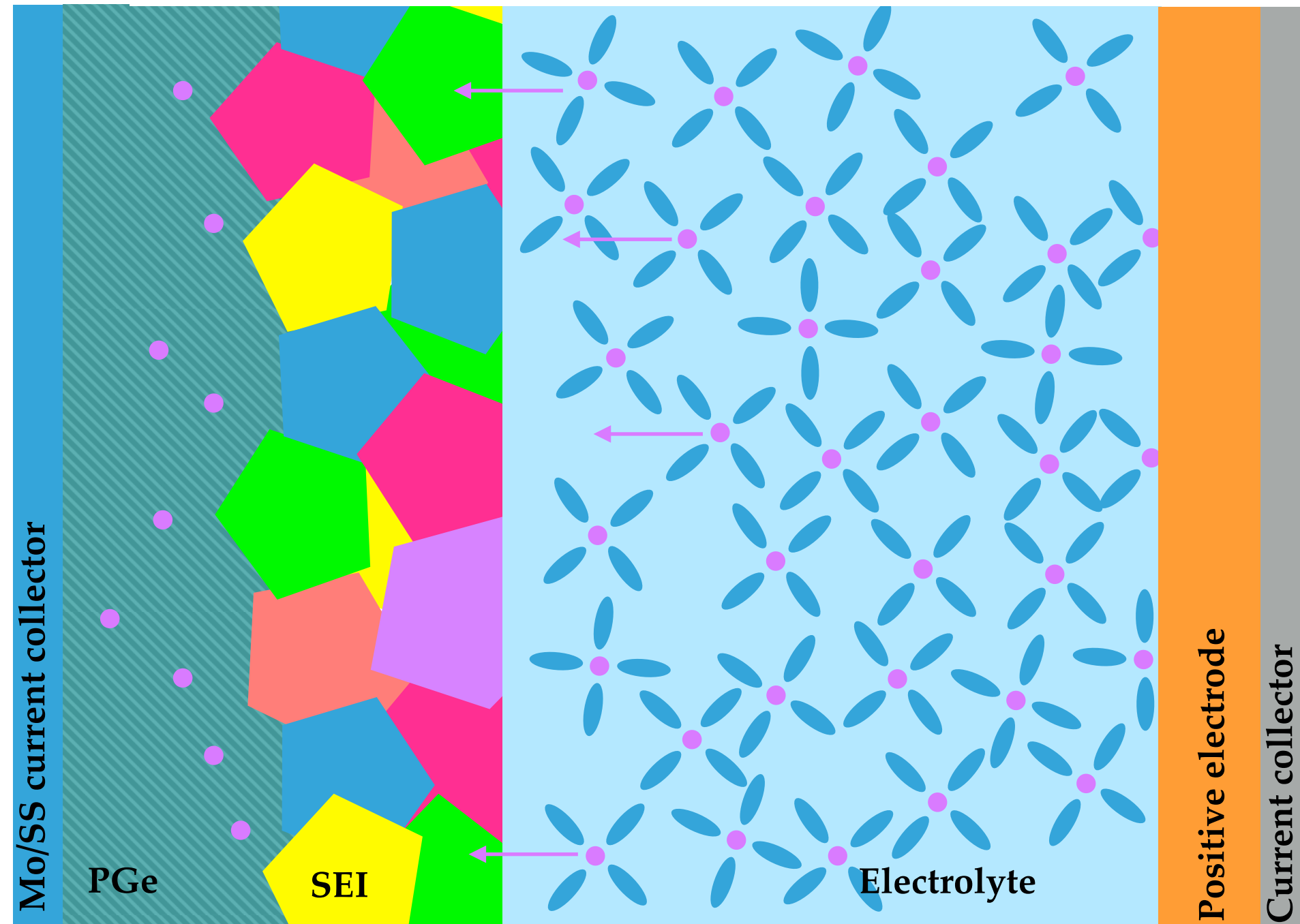
- ⊙ Case

The voltage delivered depends on the **cell chemistry** hence on the **material** that forms it.



The Solid Electrolyte Interface

a thin passivating layer that forms on the surface of the negative electrode during the first few cycles.



~ 100 – 120 nm

- Forms due to electrolyte decomposition at the electrode surface
- Typical inorganic compounds LiF , Li_2O and organic components such as ROCO_2Li
- It prevents the continuous decomposition of the electrolyte
- It protects the electrode material
- Reduce capacity fading over time

The goal is to have a stable, compact and flexible SEI layer rich in LiF .

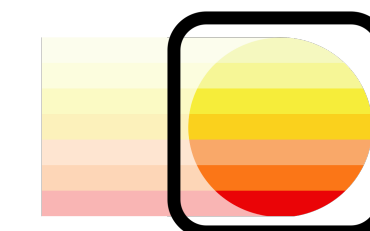
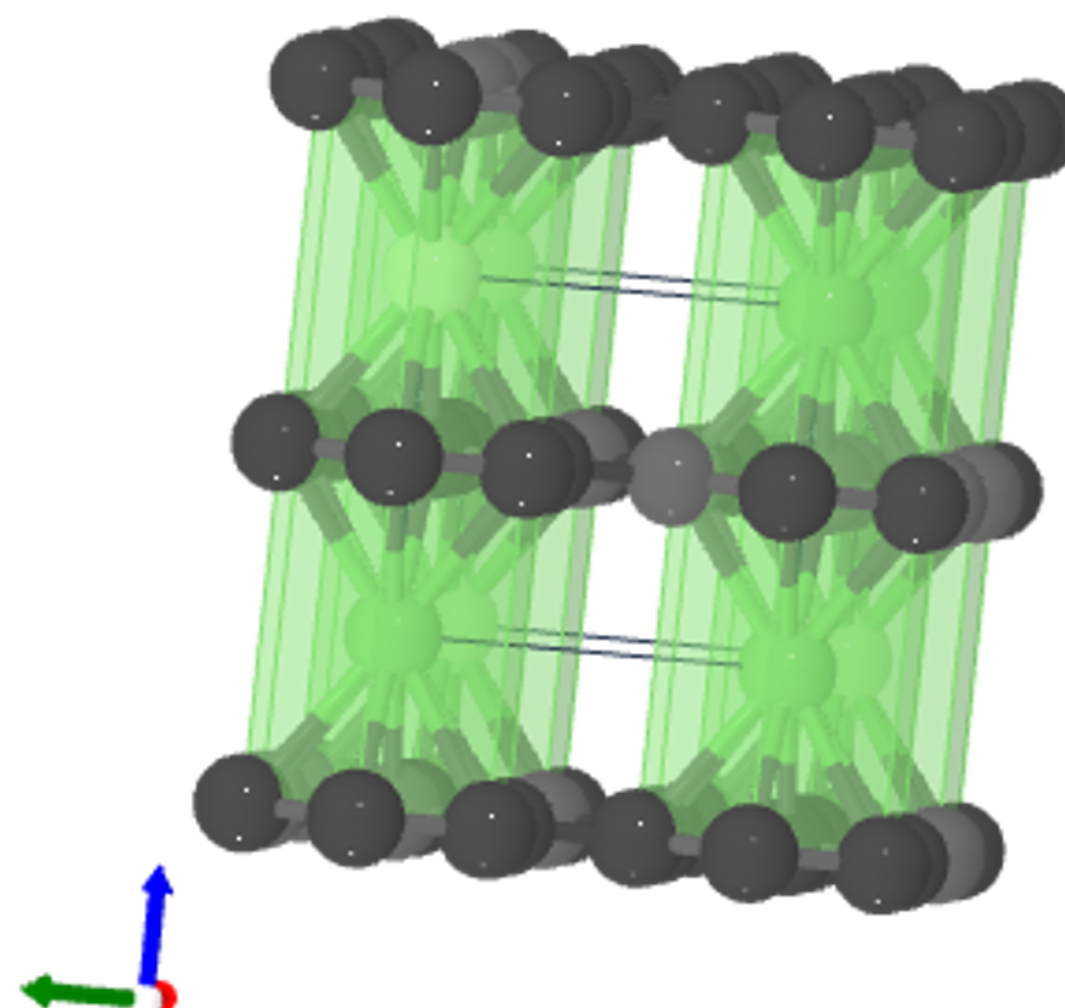
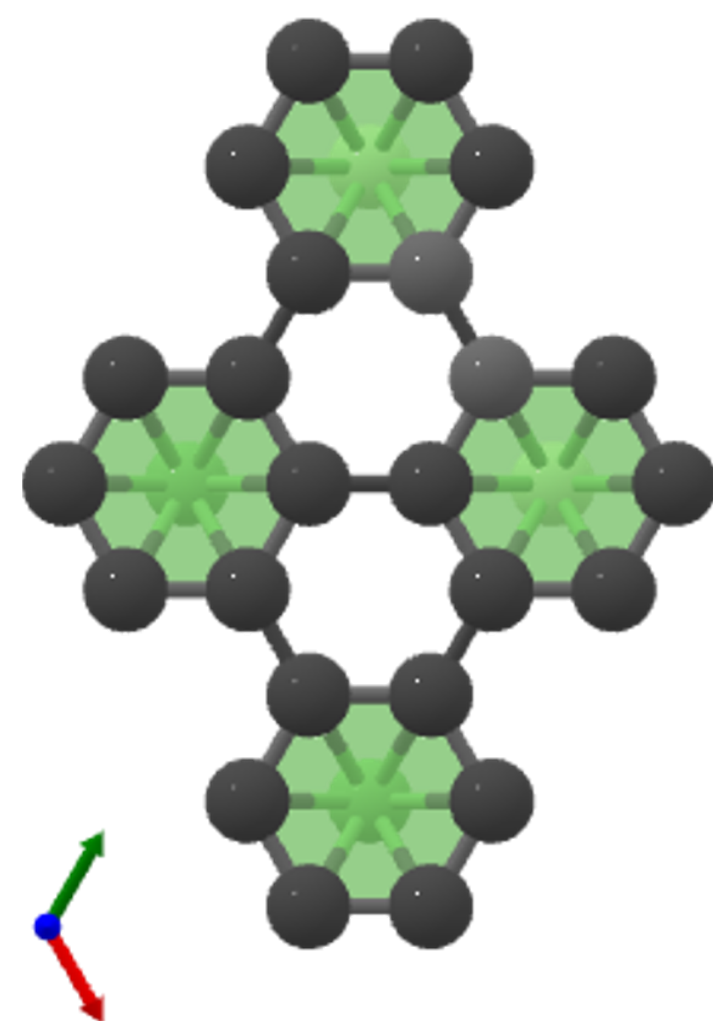
Electrode material	C	Li	Si	Ge
Lithiated phase	LiC ₆	Li	Li ₂₂ Si ₅	Li ₂₂ Ge ₅
Theoretical specific capacity [mAh/g]	372	3 862	4 200	1 624
Volume change [%]	12	-	420	370

Standard materials used in commercial LIBs

BUT



- ✗ Low capacity
- ✗ Poor rate capabilities



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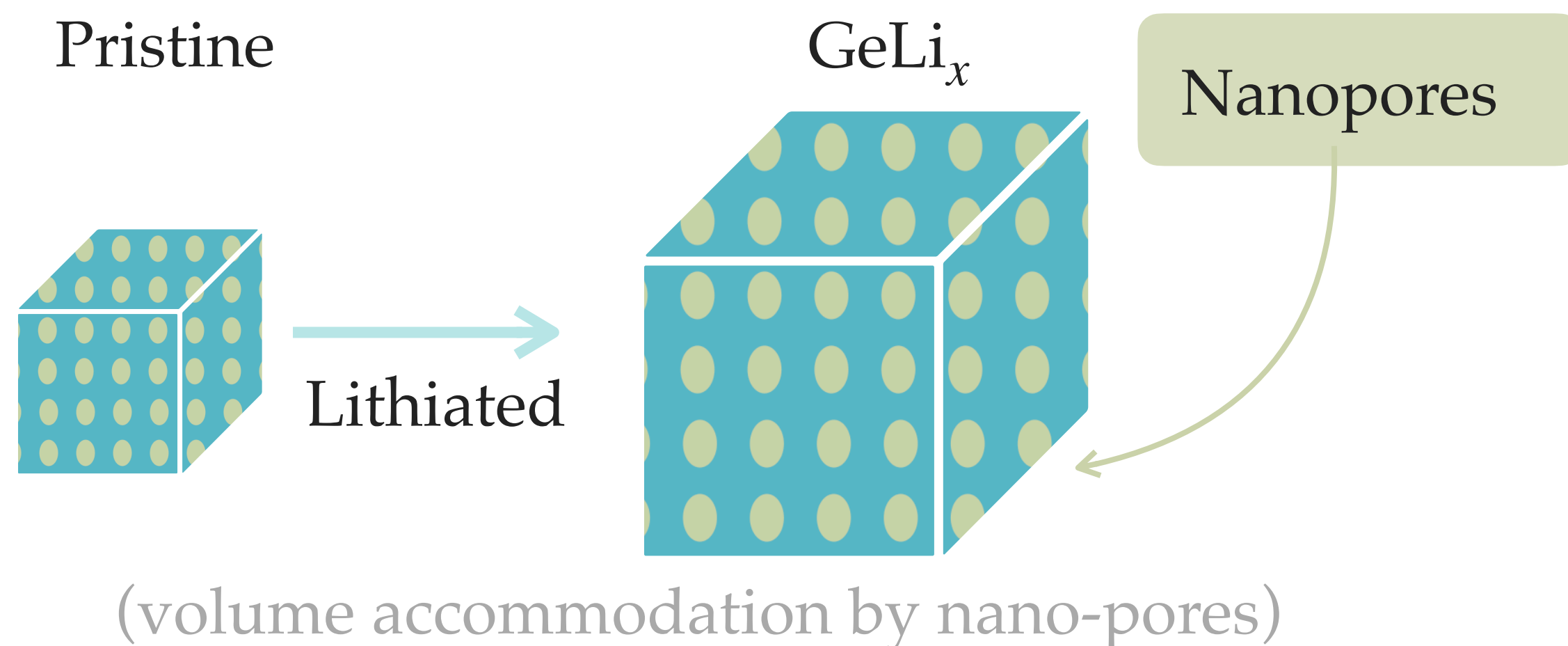
High theoretical specific capacity BUT



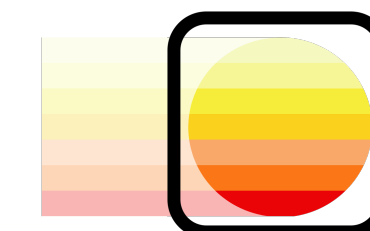
✗ Huge volumetric expansion upon lithiation

leading to

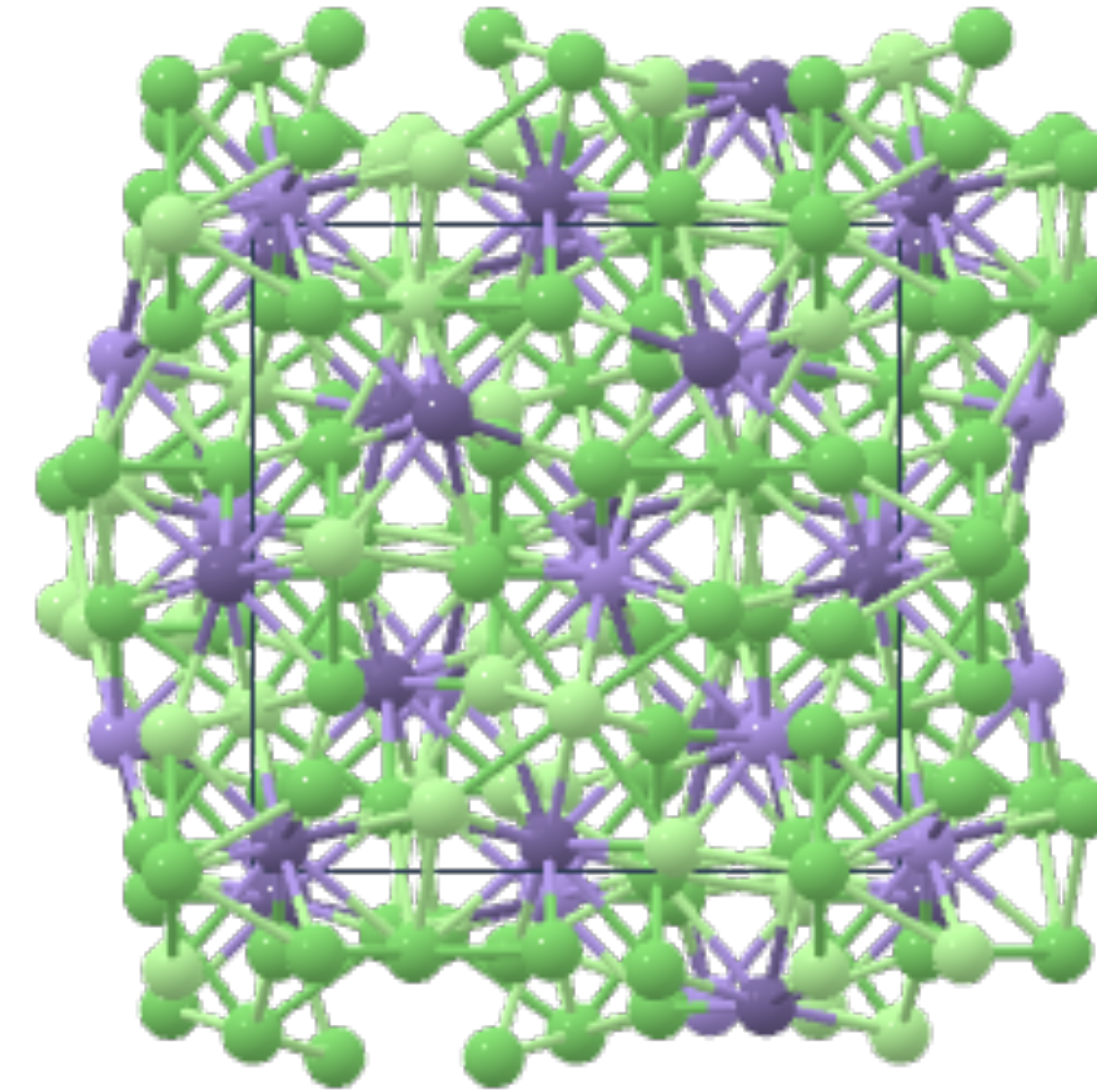
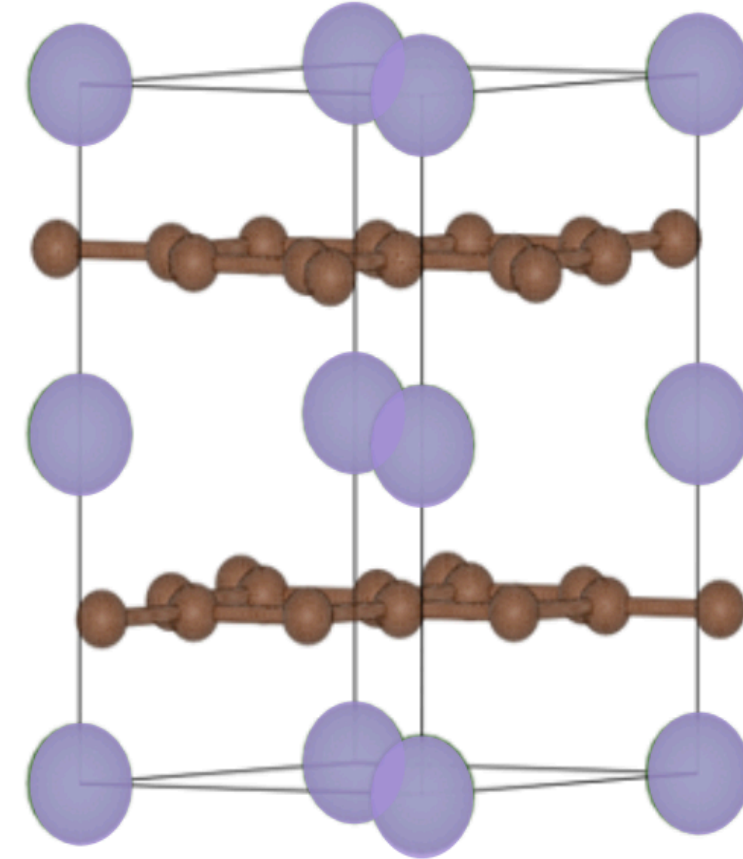
- ✗ Active material pulverisation
- ✗ Cracks formation
- ✗ Delamination from the substrate



Possible way to cope with this? **Nanostructurization**



Intercalation mechanism



Alloying mechanisms

GRAVIMETRIC CAPACITY:

the charge stored per unit mass of active material in the electrode

STANDARD TECHNOLOGY

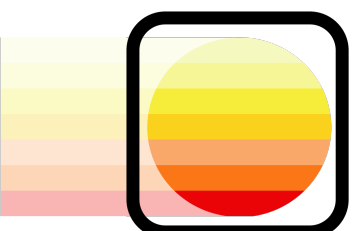


$$C_{\text{Graphite}} = \frac{1}{6} \frac{F}{\text{Carbon Molar Mass}} \approx 372 \text{ mAh g}^{-1}$$

Ge-BASED TECHNOLOGY



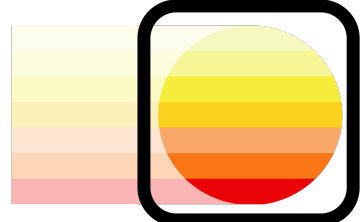
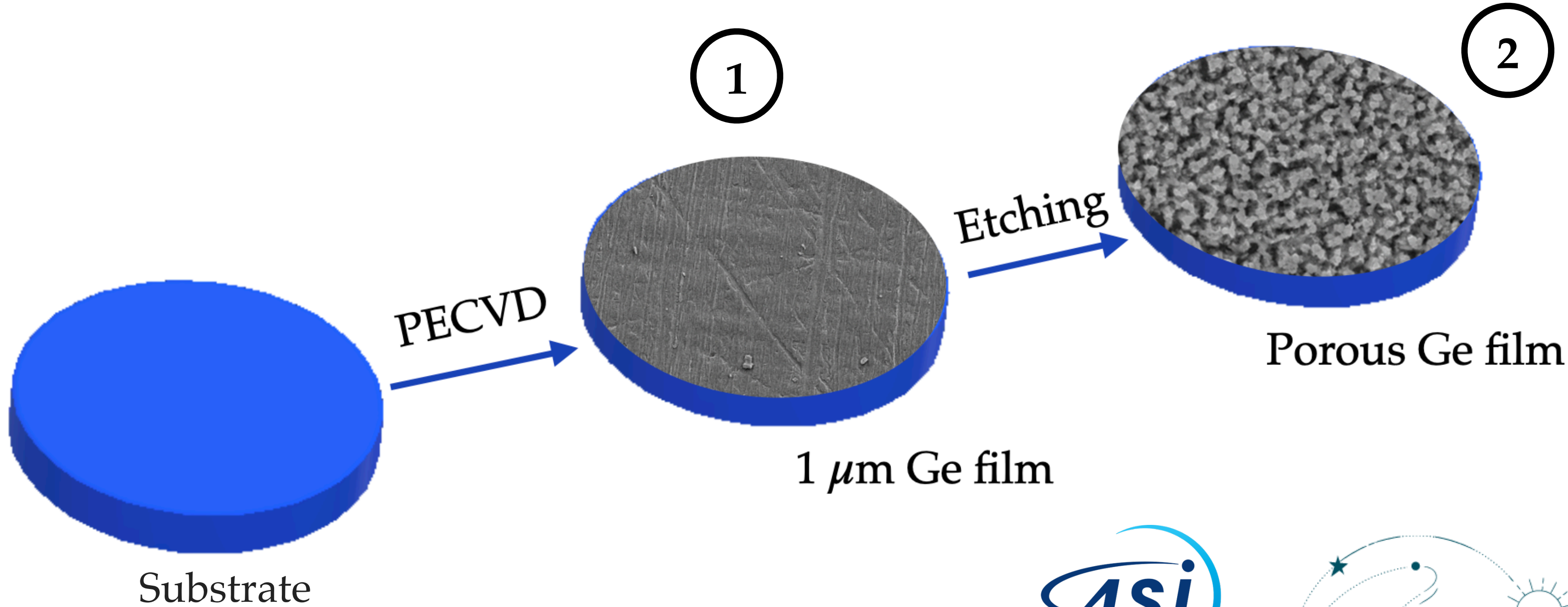
$$C_{\text{Ge}} = \frac{22}{5} \frac{F}{\text{Ge Molar Mass}} \approx 1624 \text{ mAh g}^{-1}$$



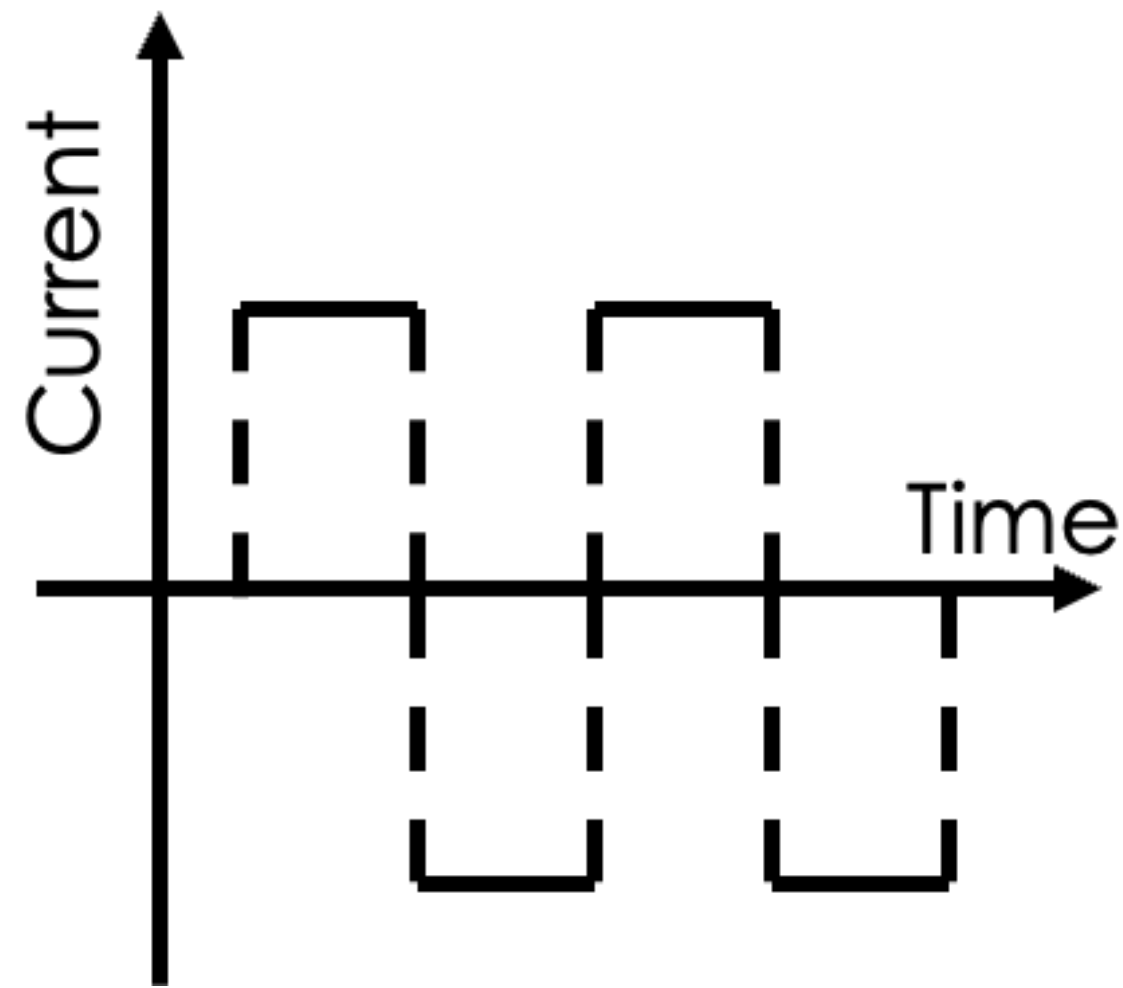


1. DEPOSITION
via Chemical Vapor Deposition

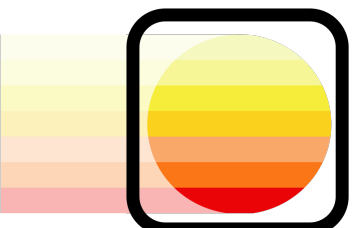
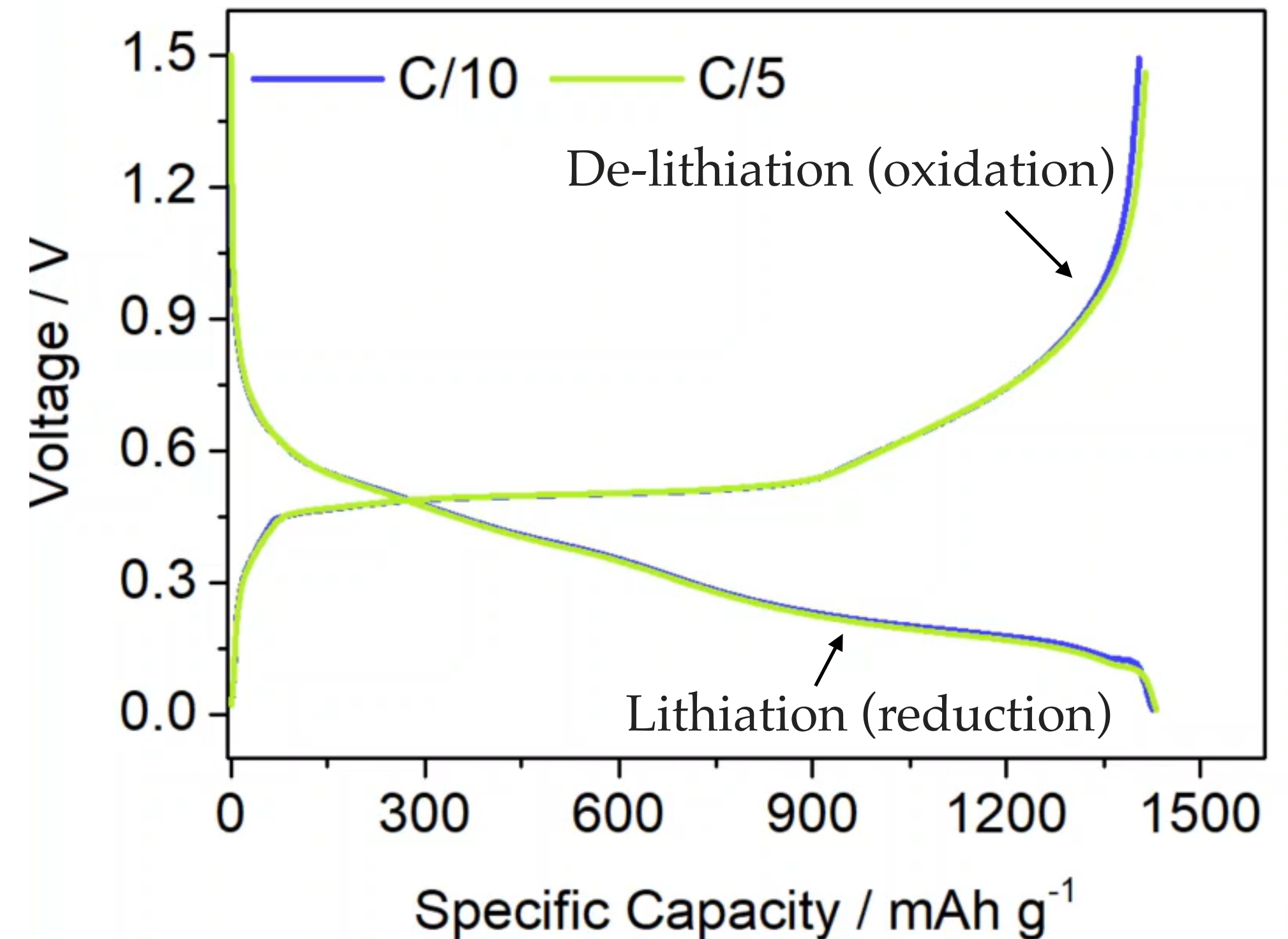
2. NANOSTRUCTURATION
via Electrochemical Etching



Galvanostatic characterisation performs one or more charge-discharge cycles at a **constant current**, while simultaneously measuring the potential difference between the two electrodes.



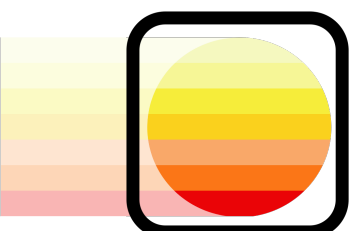
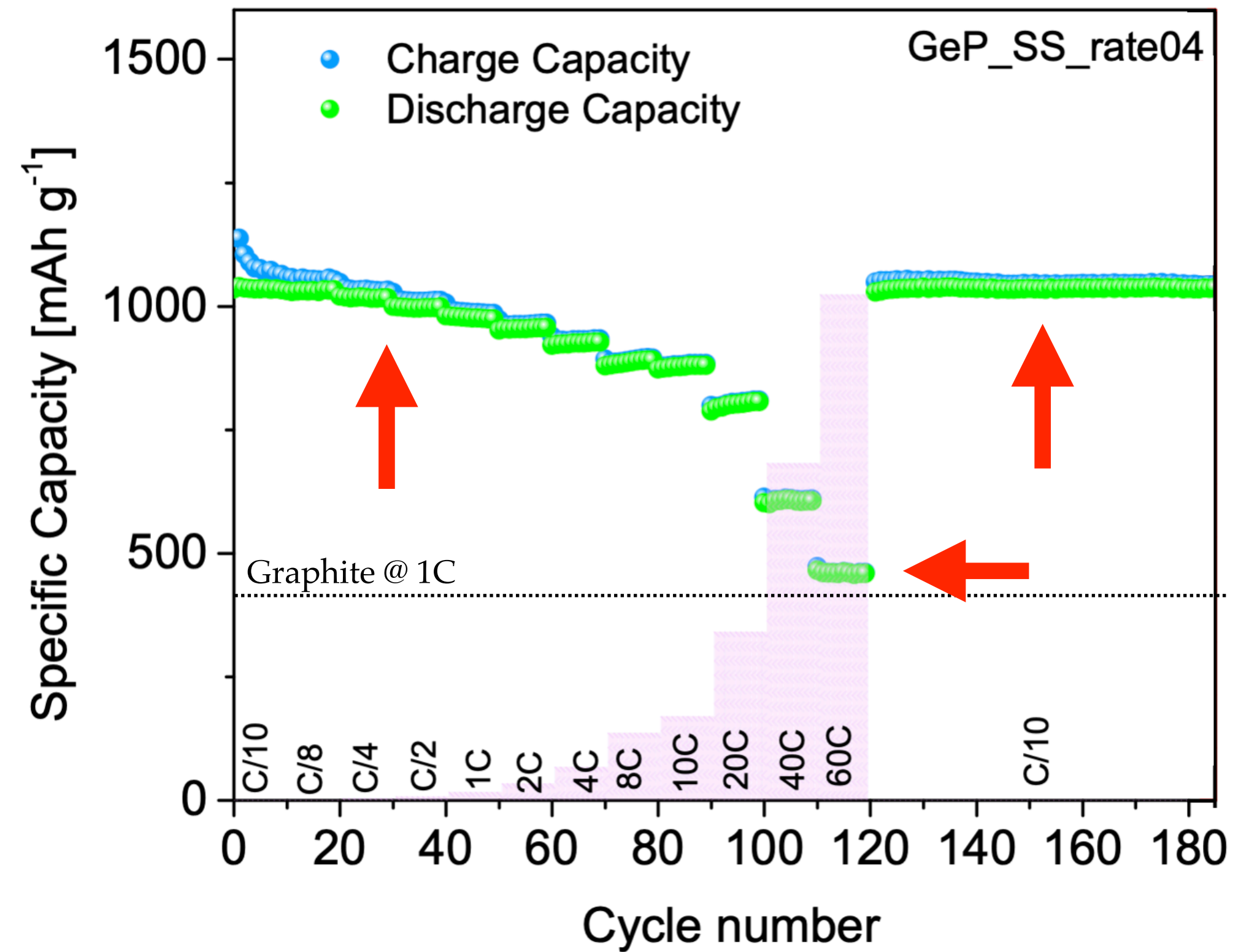
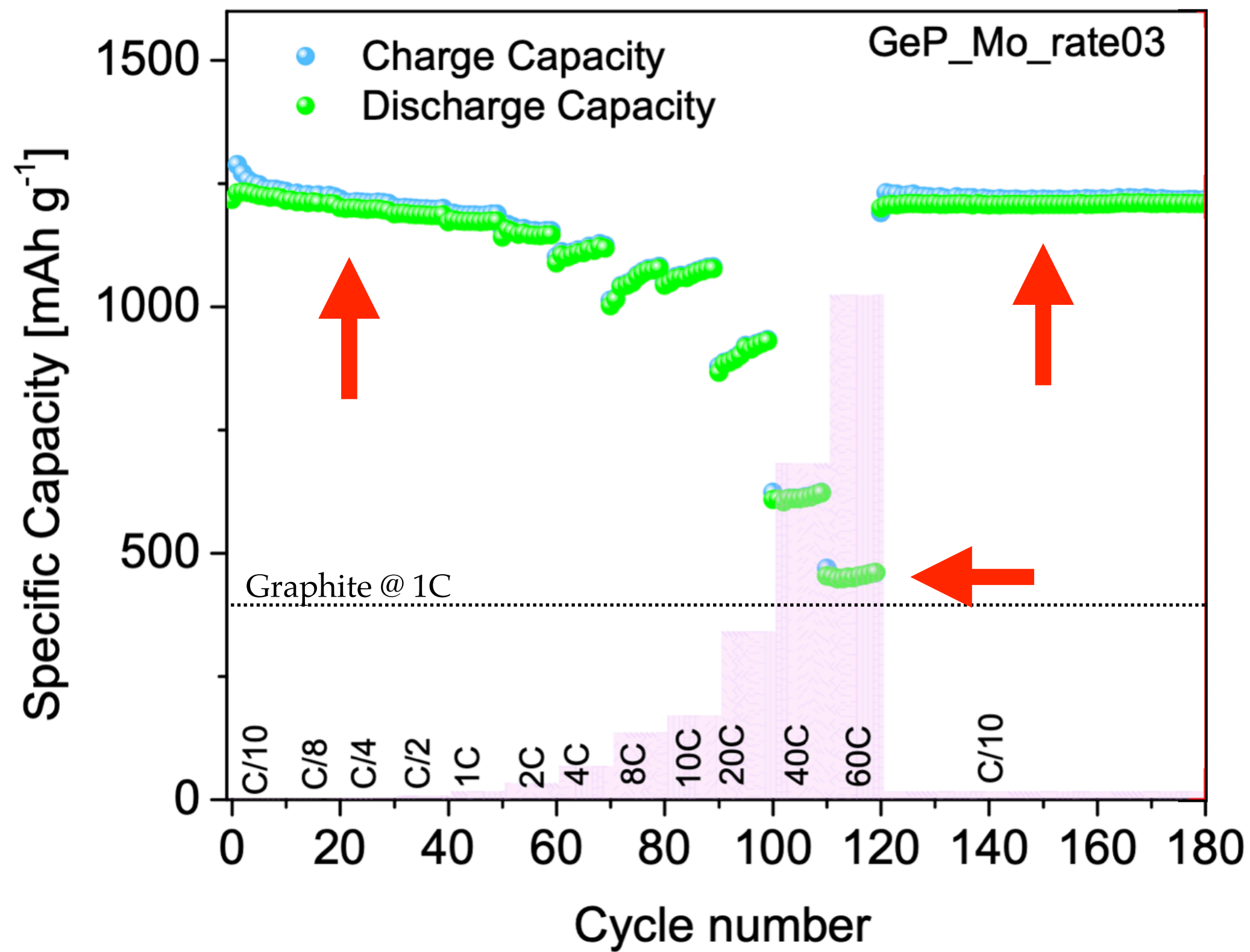
Ge-based Galvanostatic cycles between 1.5-0.01 V



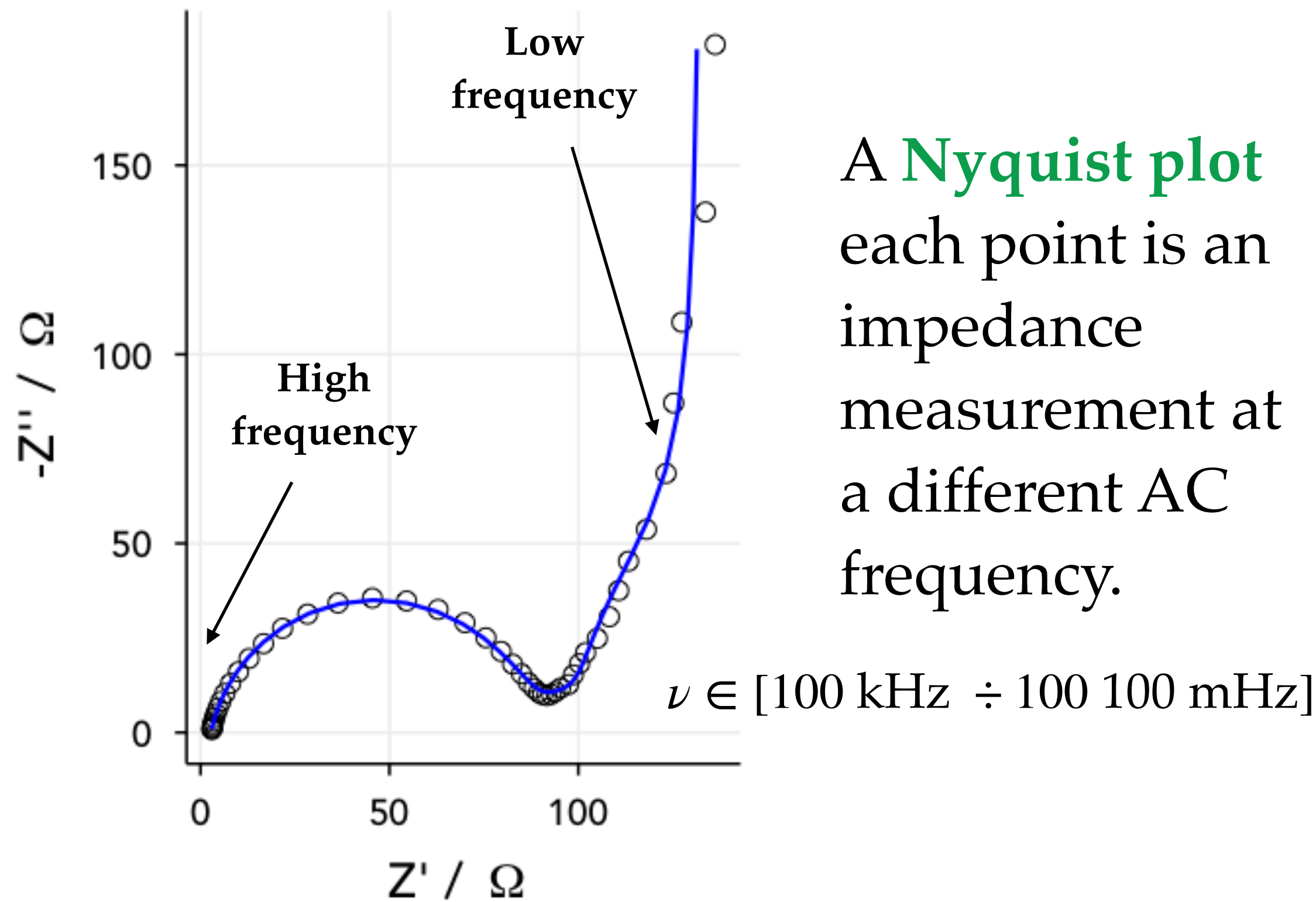
C-RATE:

$$C\text{-rate} = \frac{\text{specific capacity [mAh g}^{-1}] \cdot \text{mass loading [g]}}{\text{time [h]}}$$

1C = 1h charge/discharge
 C/2 = 2h charge/discharge
 2C = $\frac{1}{2}$ h charge/discharge



Electrochemical Impedance Spectroscopy measures **impedance** characteristics of an electrochemical system over a range of frequencies.



The measurement:

Apply oscillating voltage $V(t) = |V| \sin(\omega t)$

measure the oscillating current response

$$I(t) = |I| \sin(\omega t + \theta)$$

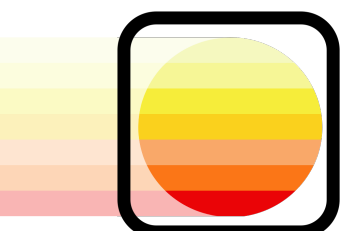
$$Z = \frac{V}{I} = \frac{|V| \sin(\omega t)}{|I| \sin(\omega t + \theta)} = |Z| \frac{\sin(\omega t)}{\sin(\omega t + \theta)} = |Z| e^{i\theta}$$

via Euler's formula

$$Z = Z' + iZ''$$

Real, "resistive part"

Imaginary, "reactive part"



Advantages:

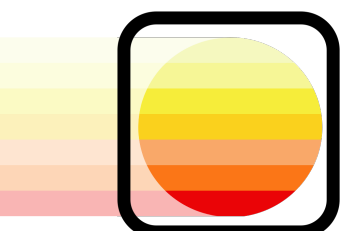
- non-destructive technique
- Quick measurements
- Can isolate conducting species and processes with different proper time

Used to study:

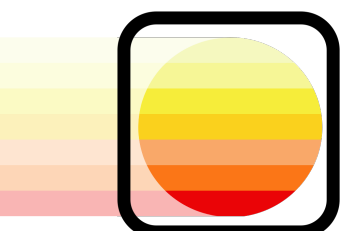
- Ionic/electronic conductivity of electrodes
- Behaviour around the electrode/electrolyte interface
- Degradation mechanism of commercial NMC/graphite cells

Case study: cycle aging of NMC/Gr pouch cell

Case study: electrode/electrolyte interface instability



- ⊙ Lithium-ion battery performance is strongly **governed by electrochemistry and interfacial phenomena**, particularly the formation of the SEI layer, critical for long term stability
- ⊙ While Graphite remains the commercial standard, its limited specific capacity and rate capability motivate the exploration of alternative materials
- ⊙ Electrochemical testing techniques at laboratory level:
 - ▶ Galvanostatic cycling provides insight into capacity, rate capability and cycling behaviour
 - ▶ EIS enables investigation of charge transport, interfacial processes and degradation mechanisms



Thank you for your attention!

CONTACT INFORMATION :

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