High-performance Lithium Battery Anodes Using Silicon Nanowires

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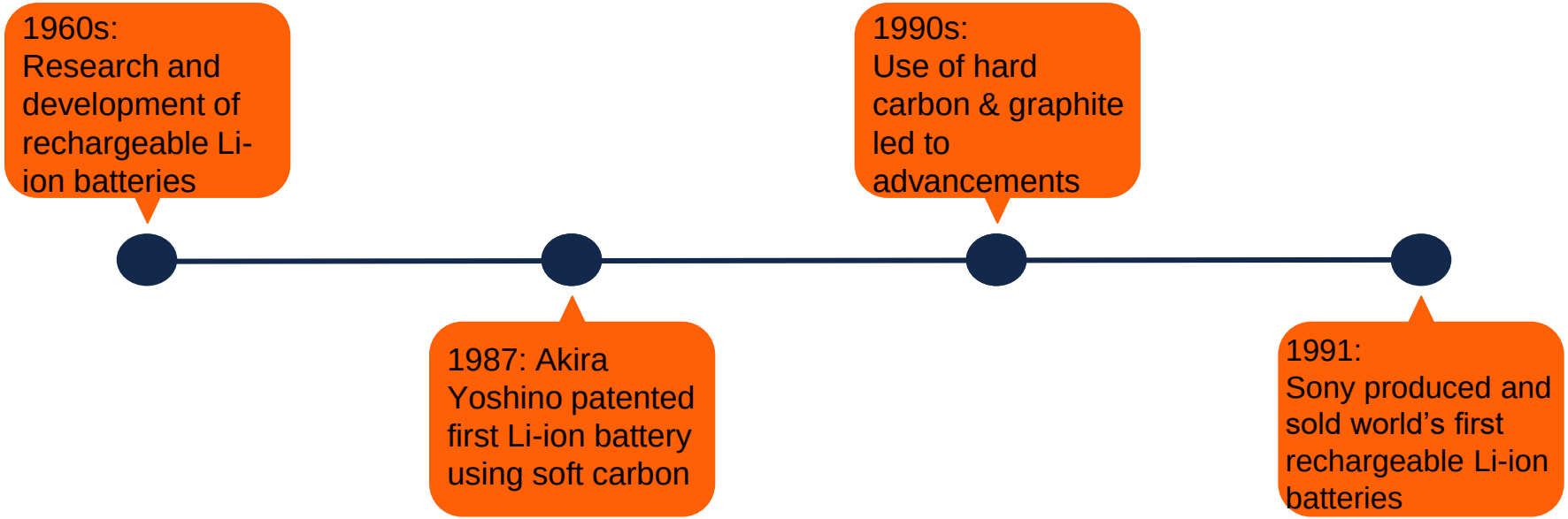
Chan, C. K., Peng, H., Liu, G., McIlwrath, K., Zhang, X. F., Huggins, R. A., & Cui, Y. *Nature Nanotechnology*, *3*(1), Article 1.

Brief History of Lithium Batteries

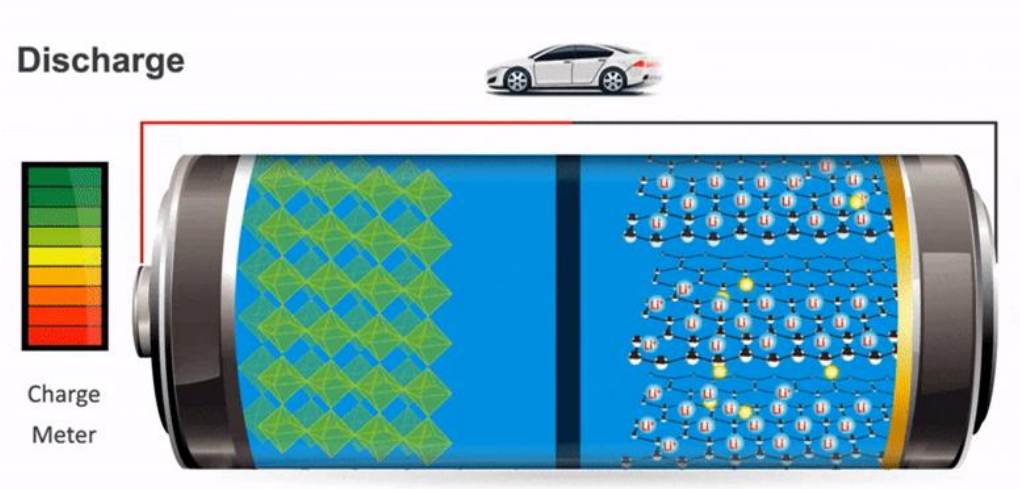


Reddy, M.V. et al, "Brief History of Early Lithium-Battery Development", *Materials 2020*

How do Lithium Batteries work?

- 4 major components:
  - Cathode
  - Anode
  - Electrolyte
  - Separator

- While charging: electrolyte carries Li-ions from cathode to anode and vice versa



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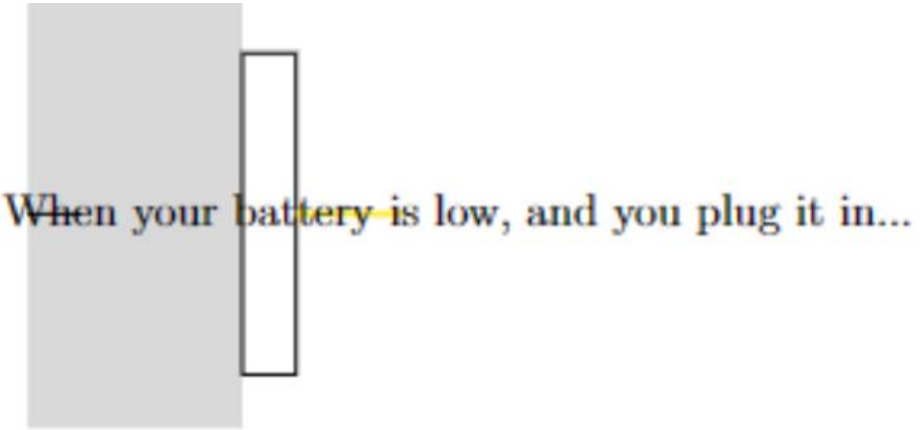
Composition of Modern Batteries

- Modern batteries are typically made with graphite anodes
  - Relatively high charge capacity
  - Cheap to produce
  - Long life cycle

- Perfect for mass production, but other materials are much more powerful.



Meme provided by ChatGPT

Advantages of Silicon Anodes

- Silicon has the highest known theoretical charge capacity
  - ~4200 compared to ~372 in graphite*

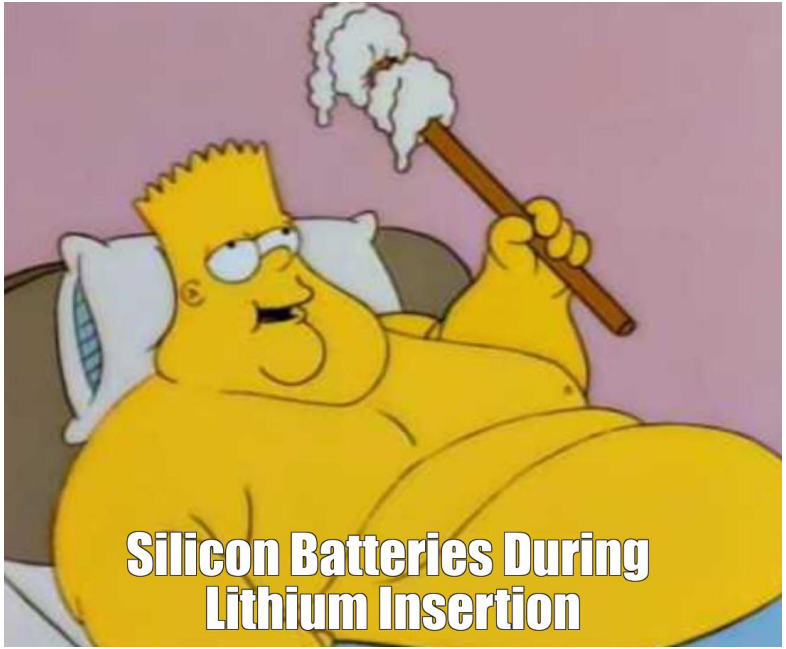
- Silicon anodes allow for batteries with much longer life cycles with many potential uses
  - Electric vehicles
  - Implantable medical devices

*using units where (1 mAh = 1 g)

Problems With Silicon Anodes

- Typically implemented as either a bulk film or nanometer-sized particles.

- Silicon anodes greatly increase in volume during lithium insertion
  - Up to 400% of their original volume



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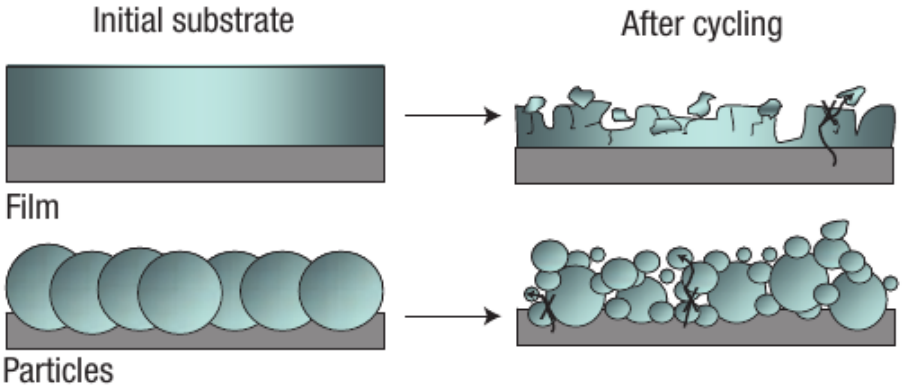
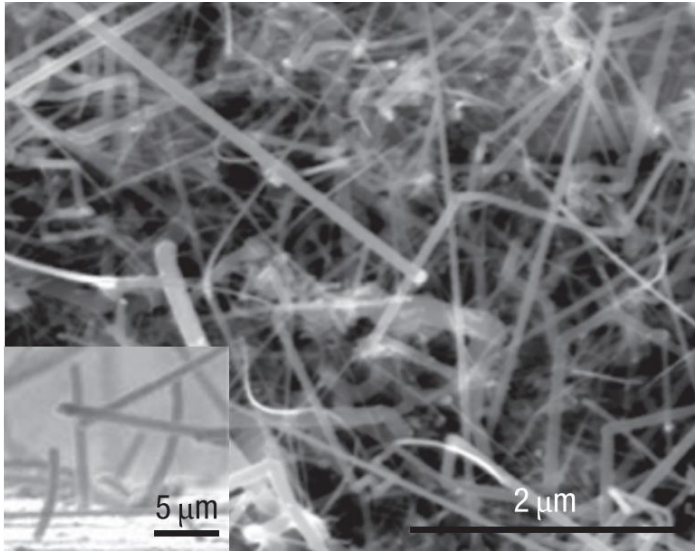
Problems With Silicon Anodes

- Contracts during lithium extraction
  - Causes much of the material to lose contact with the current collector
  - Significantly decreases charge capacity



Basics of Silicon Nanowires



- Referred to as 1-D materials due to their aspect ratios
- Function as a the building blocks for nanoscale electronics
  - Have many applications: lithium batteries and sensors
- Commonly made using VLS Method (Vapor-Liquid-Solid)

URL: https://rb.gy/mzaf2f

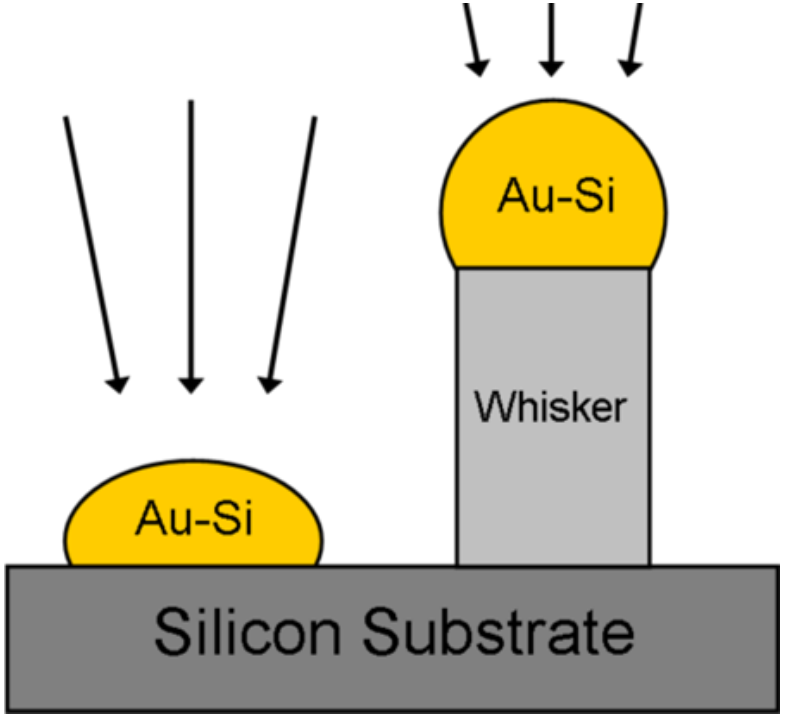
Summary of our article

- Described issues with silicon anodes in Li-ion batteries
- Showed that one solution is to introduce silicon nanowires
  - Accommodate strain on and growth of the silicon
- Achieved theoretical charge capacity of silicon anodes
  - Maintained discharge capacity close to maximum

Methods

- Single-crystalline SiNWs were grown inside a tube furnace using VLS method

- Steps of VLS Method:
  - Au catalyst was added to stainless steel substrate
  - Heated to 530°C and silane was added
  - SiNWs grown through chemical reaction



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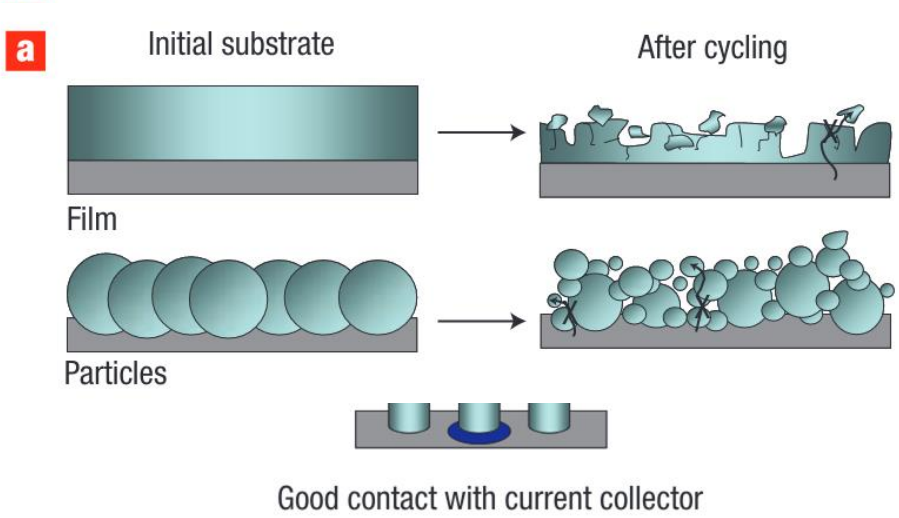
Effects of Cycling on Lithium

- Films and particles break down due to wear and tear
  - Expansion of the material
- Nanowires react to cycling by increasing
  - Diameter
  - Length



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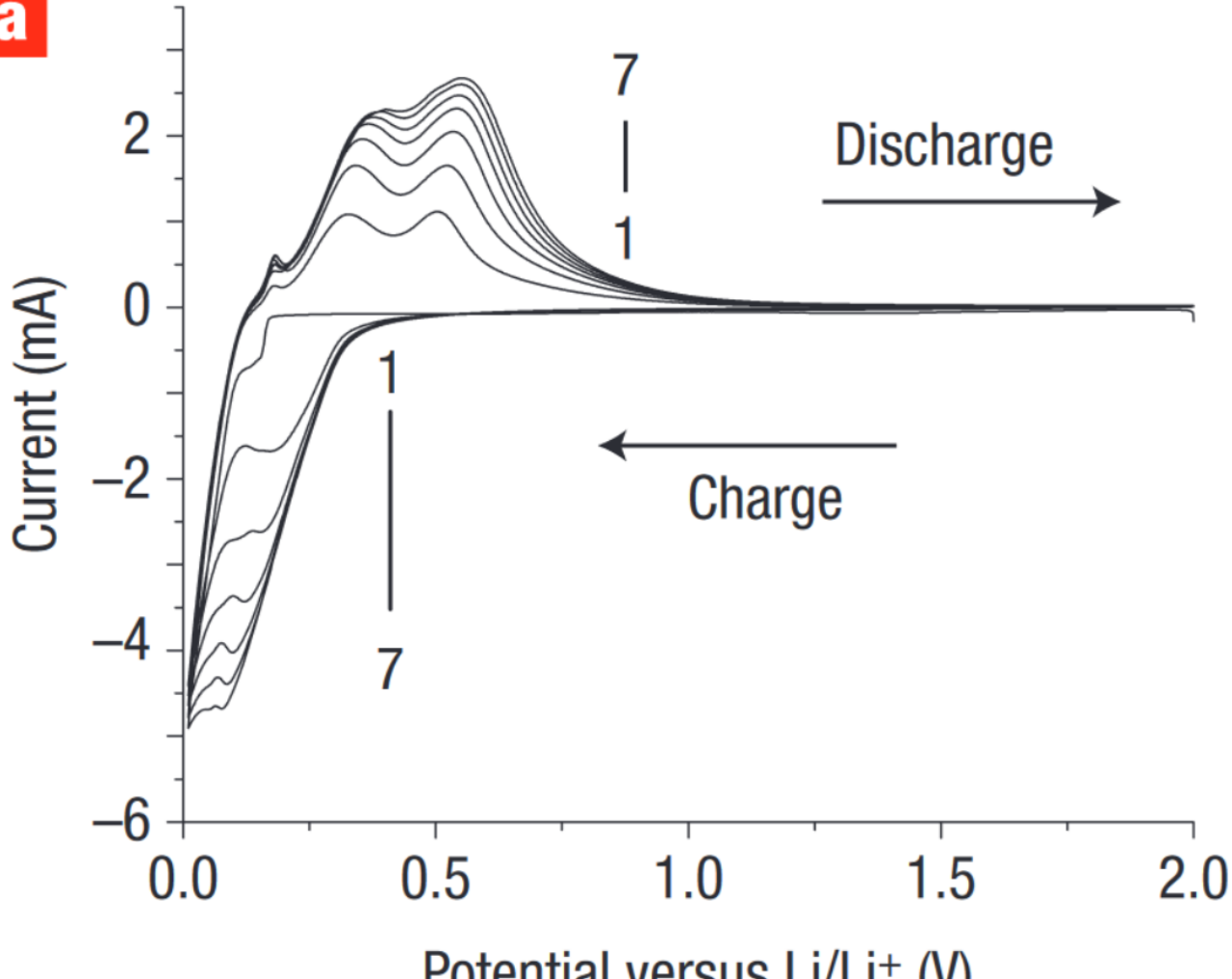
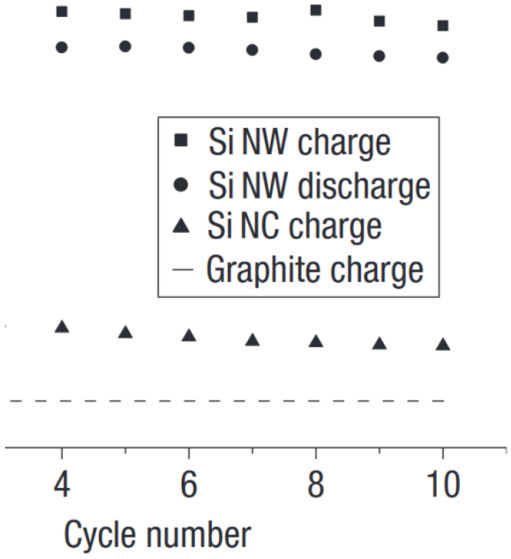
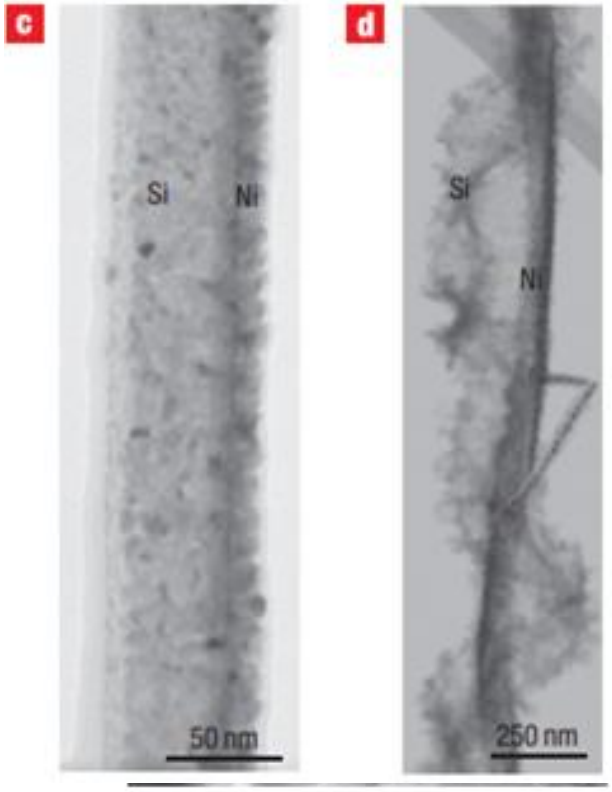

7
1
Discharge
Charge
1
7
2
0
−2
−4
−6
Current (mA)
0.0
0.5
1.0
1.5
2.0
Potential versus Li/Li+ (V)

rrent


Si NW charge
Si NW discharge
Si NC charge
Graphite charge
4
6
8
10
Cycle number

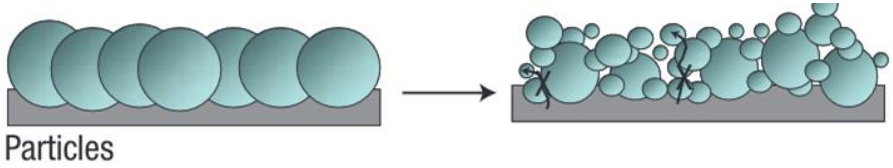
SEM Can be Used to Image the Nanowires

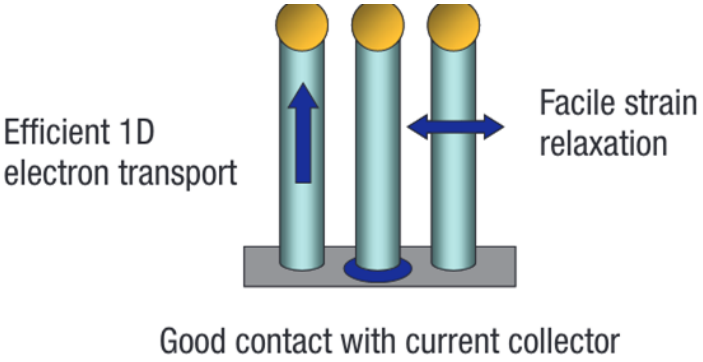
- Dimensional Increases
  - Diameter
  - Length
- Continuous after charging
- Attached to Ni backbone



Deformation adaptability of Silicon Nanowires

- Small diameter of Silicon Nanowires
  - Better accommodation of the large volume changes
  - Avoid pulverization
  - Good contact with current collector → minimal capacity fade

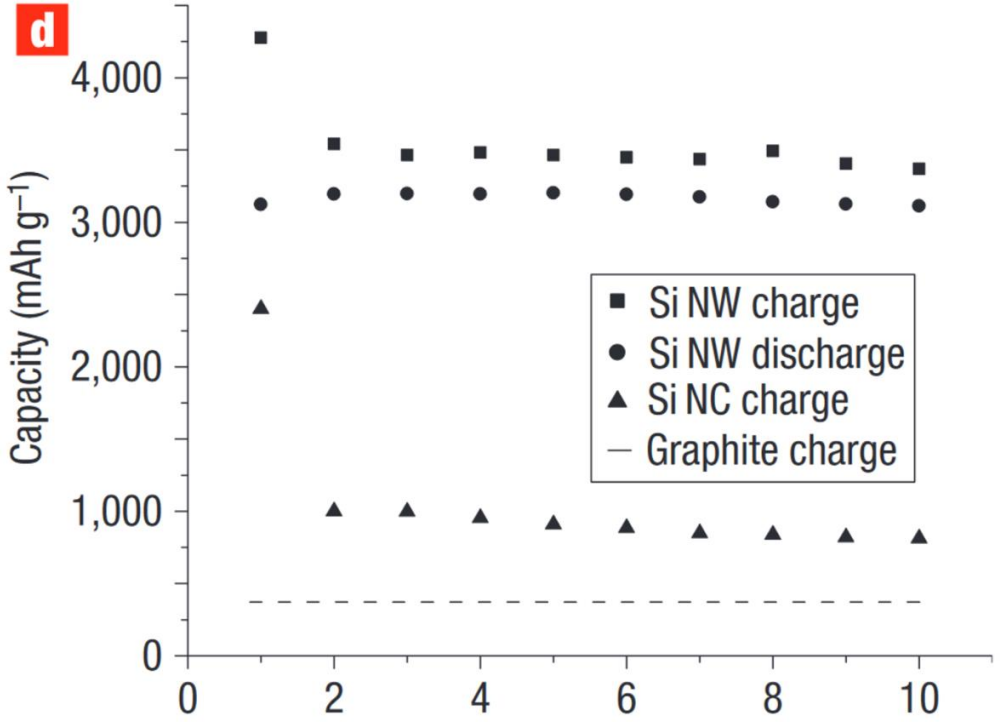




Capacity and life cycle of Silicon Nanowires

- Higher capacity
  - 4200; 3500
- Longer life cycle
  - 10 cycles

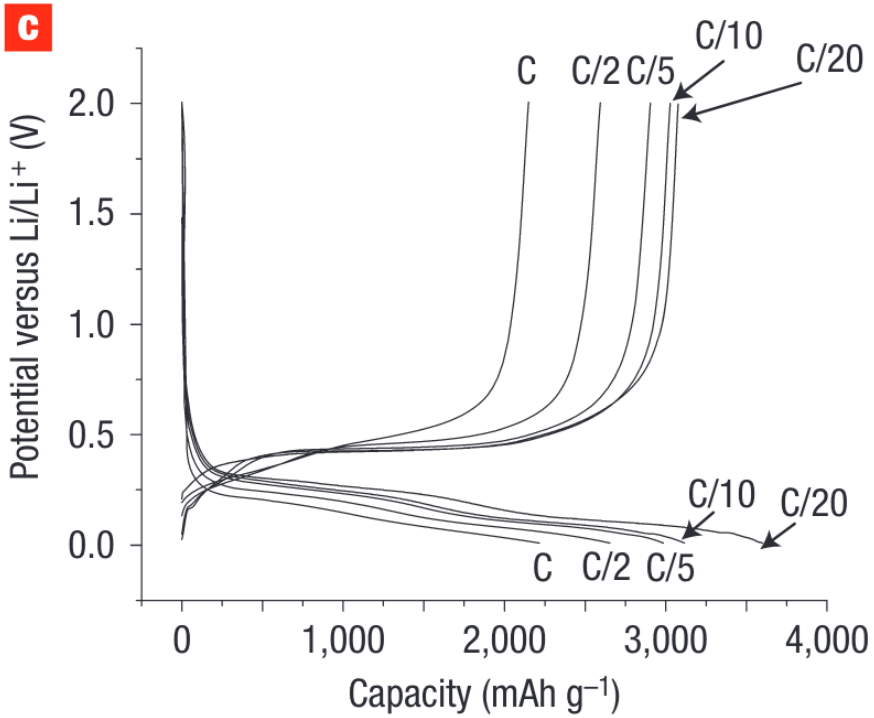
using units where (1 mAh = 1 g)



Performance under high current

- High capacities at higher currents
  - Rate: 1C (1h for per half cycle)
  - Capacity: 2100
- Great cyclability at the fast rates
  - Rate: C/5 (5h for per half cycle)
  - Capacity for 20 cycles: 3500

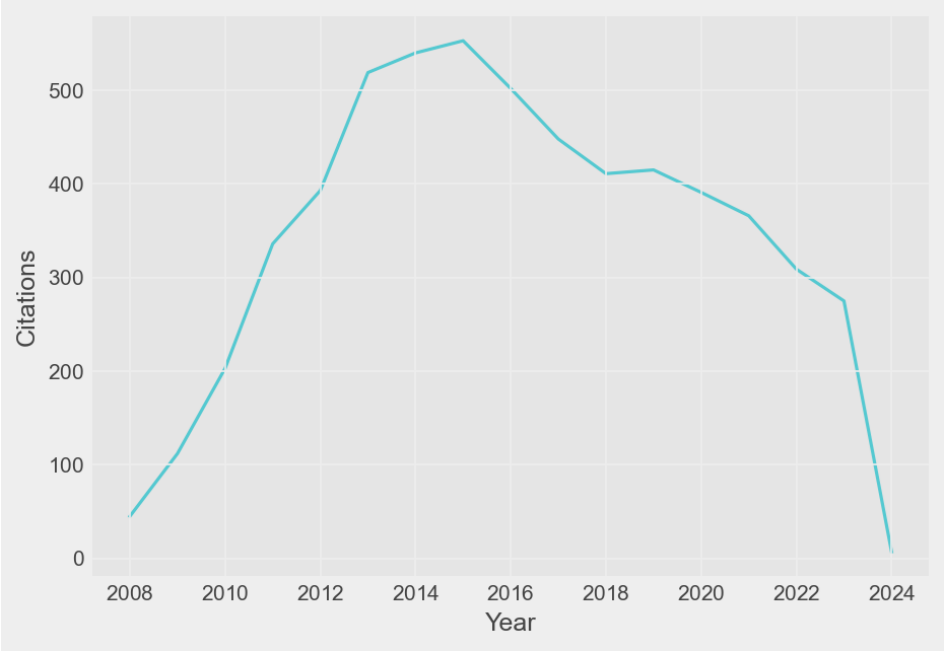
*using units where (1 mAh = 1 g)



Summary and Conclusions

- Graphite anodes are only a compromise because they don’t pulverize
- Silicon film/crystal anodes offer higher capacity, but pulverize after insertion
- Silicon nanowires can accommodate strain while retaining good transport and contact

Citation Evaluation



Citations from SCOPUS

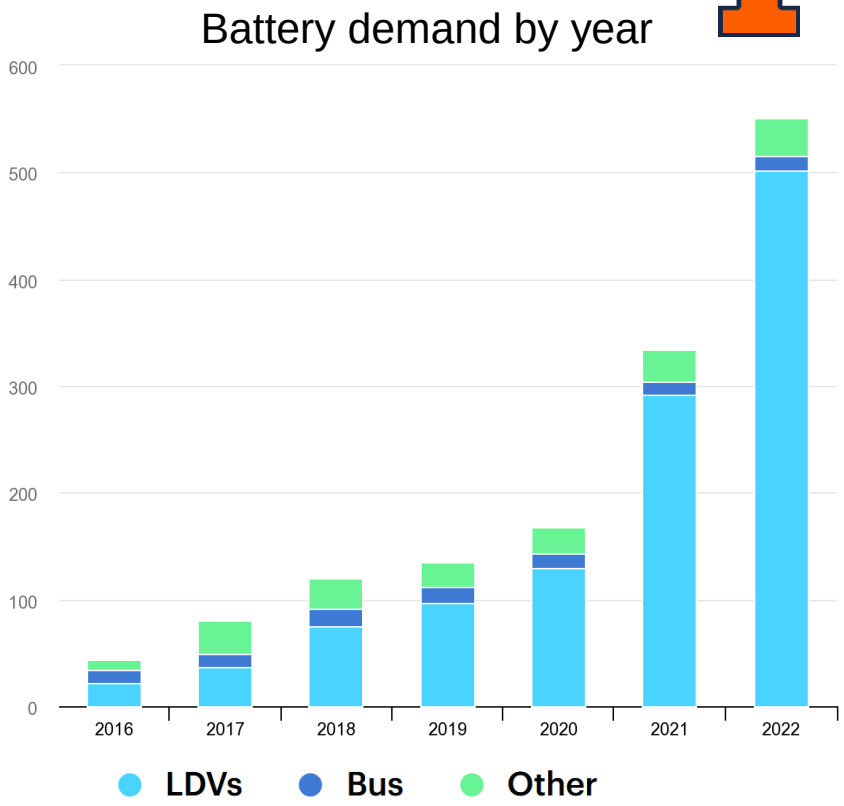
5,825 Total citations

- 99 percentile in citations
- Sustainability regulations pushed for advancements in battery technology
- Competing technologies:
  - Lithium-metal, lithium-air, and lithium-sulfur
- Cui moved on to lithium-metal

Zheng, Guangyuan et al. “Interconnected Hollow Carbon Nanospheres for Stable Lithium Metal Anodes.” *Nature nanotechnology.* 9.8 (2014): 618–623. Web.

Silicon Nanowire Anodes Today

- Demand mostly from transportation sector
- Tesla added 5 percent silicon in batteries
- One of the authors, Yi Cui cofounded Amprius in 2008
  - Pure silicon anode
  - Raised nearly half a billion dollars in 2022 with two others to commercialize



https://www.iea.org/reports/global-ev-outlook-2023/trends-in-batteries

Amprius Silicon Nanowire Batteries

Performance Metric	Graphite Anode Battery Cells[1]	amprius[3]
Anode Capacity (mAh/g)[1][2]	335-355	1,500-2,500
Specific Energy (Wh/kg)	~215-285	360-500
Energy Density (Wh/L)	~530-715	890-1,400
Charging Time to 80%	30 minutes	<6 minutes[4]
Rate Capability/Power	Up to 10C	Up to 10C
Cycle Life	500-1,000 cycles	200-1,200 cycles
Operating Temperature	-20 to 60°C	-30 to 55°C

https://amprius.com/products/

URL:https://domics.me/