## Cell formats

- We begin this lesson by considering cell structure
- Lithium-ion cells are manufactured in different form factors
  - Cylindrical cells are... err... cylindrical (round "jelly roll")
  - Prismatic cells are... prismatic (flat "jelly roll")
  - Pouch cells are also flat, but comprise stacked plates

Cylindrical cells

Prismatic cells

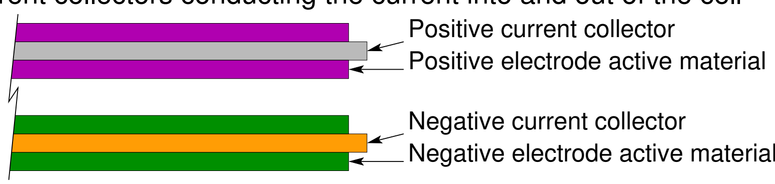
Pouch cells





## Electrode coating

- Electrodes in lithium-ion cells of any form factor are of similar structure and are made by similar processes
- The active electrode materials are coated on both sides of metallic foils which act as the current collectors conducting the current into and out of the cell



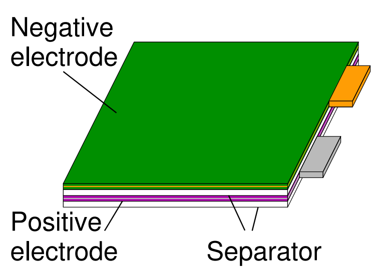

- Two basic electrode structures are used, depending on cell form factor:
  - A stacked structure for use in pouch cells, and
  - A spiral wound structure for use in cylindrical/prismatic cells





## Stacked electrode structure

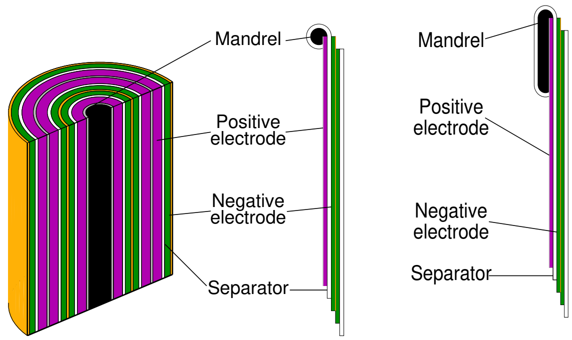
- Pouch/prismatic cells are often used for high capacity battery applications to optimize the use of space
- Pouch designs use a stacked electrode structure in which the negative- and positive-electrode foils are cut into individual electrode plates which are stacked alternately and kept apart by the separator
- Separator may be cut to the same size as electrodes but more often is a long strip wound zig-zag between alternate electrodes in the stack




- All negative-electrode tabs are welded in parallel and to the cell's negative terminal; all positive-electrode tabs are welded in parallel and to the cell's positive terminal

## Cylindrical and prismatic electrode structure

- For cylindrical cells the negative- and positive-electrode foils are cut into two long strips which are wound on a cylindrical mandrel, together with the separator to hold the electrodes apart, to form a jelly roll
- Most prismatic cells are constructed similarly, by winding electrodes on a flat mandrel

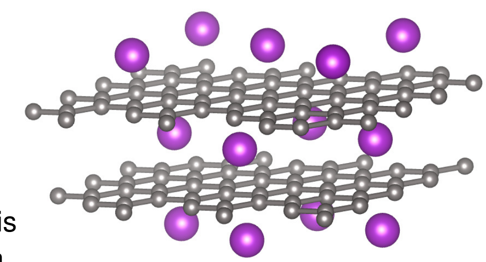







## Microscale structure of graphite

- We now start to examine the different materials used in the electrodes of lithium-ion cells, starting with negative electrode
- Presently, essentially all commercial lithium-ion cells use some form of graphite ($C_6$) for the negative-electrode material
- Graphite has graphene layers of $C_6$ structures that are tightly bonded
- These layers are loosely stacked and there is room for lithium to intercalate between them

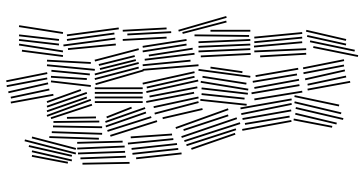




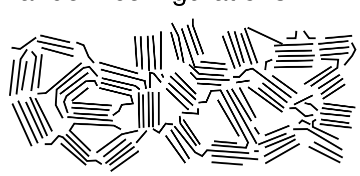


## Mesoscale structure of graphite

- Carbon used in negative electrodes can come from natural or synthetic sources (which have somewhat different layering properties), or from natural "hard" or disordered carbons, which have many small pockets of graphene layers, arranged in random configurations



Natural or synthetic graphite

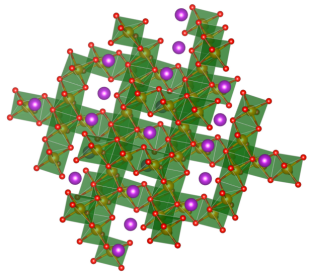


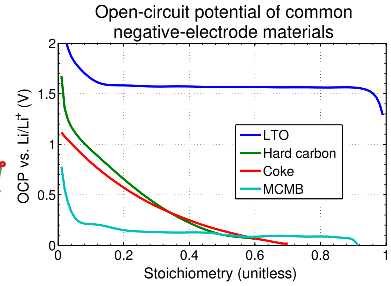
Hard carbon

- These carbons have somewhat different voltage and lifetime properties

## Alternate negative-electrode material LTO

- Lithium titanate oxide ($Li_4Ti_5O_{12}$, LTO) is an alternative negative-electrode material
- It has very different crystal structure from graphite
  - In figure, Li is purple; Ti is orange; O is red; green polyhedra show fixed crystal structure
  - Lithium diffuses through openings in crystal





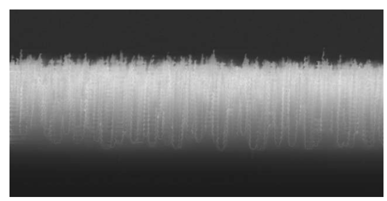

- Disadvantage: high open-circuit potential (making cell voltage low)
- Advantage: nearly indestructible — very long life





## Future negative-electrode material silicon

- Silicon is a very promising negative-electrode material
- Using graphite, one can store up to one Li per six C atoms; using silicon, one can (in principle) store four Li per every Si atom!
- Therefore, energy density using silicon electrodes can be much higher
- Unfortunately, while volume change for a charge/discharge cycle for graphite is around 10 $\%$, it is around 400 $\%$ for silicon
- Therefore, silicon electrodes tend to fracture quickly and have short lives
- Possible workarounds: mix graphite with silicon, or build small forests of silicon nanowires with space in-between to allow for expansion







## Summary

- Lithium-ion cells are manufactured in pouch, prismatic, and cylindrical form factors
- In any of these cases, current-collector metal foils are generally coated on both sides with electrode active materials
- In the negative electrode, the most common active material is some form of carbon: natural or synthetic graphite, or hard carbon
- Lithium titanate oxide (LTO) is an alternative material, which greatly increases cell longevity, but is costly and significantly lowers energy density
- Future lithium-ion cells will probably include silicon in the negative electrode to improve energy density (presently, cycle life of silicon is low)

## Credits

Credits for images in this lesson:

- Graphite structure on page 5 drawn with VESTA. See, Momma, K. and Izumi, F., "VESTA 3 for three-dimensional visualization of crystal, volumetric and morphology data," *Journal of Applied Crystallography*, 44, 1272–1276 (2011)
- LTO structure on page 7 also drawn with VESTA: See, reference above
- Silicon nanostructures on page 8, By Christoph Kubasch (2005) [CC BY-SA 3.0 (`http://creativecommons.org/licenses/by-sa/3.0`)], via Wikimedia Commons, `https://commons.wikimedia.org/wiki/File:Black_Silicon_-_ASE.jpg`