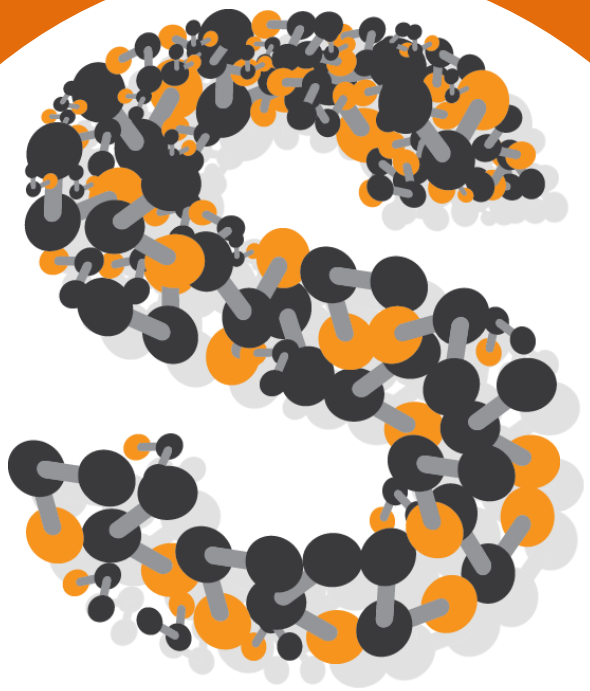
Silicon Friendly Materials and Device Solutions for Microenergy Applications



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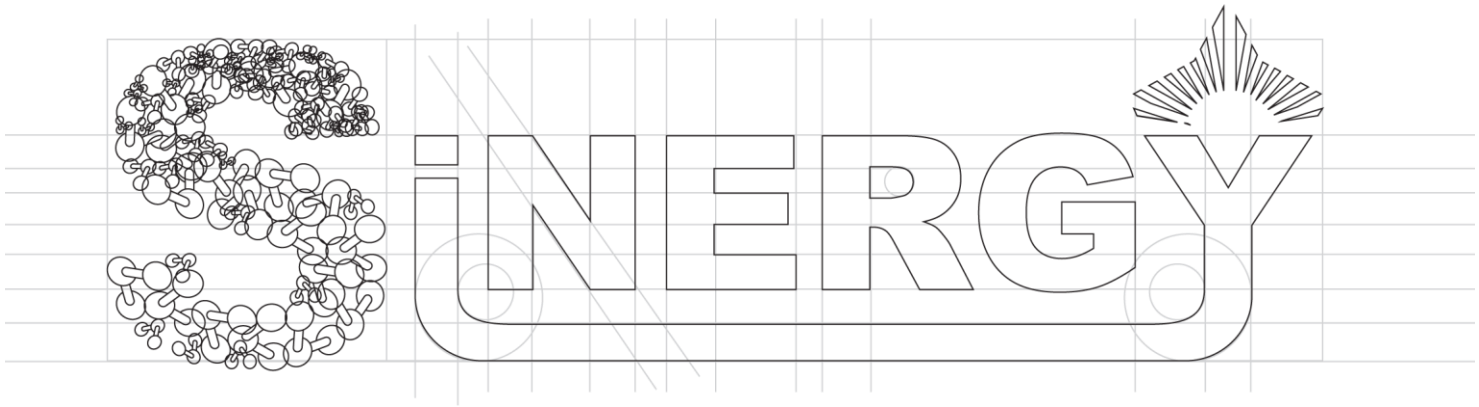
SILICON FRIENDLY MATERIALS AND DEVICE SOLUTIONS FOR MICROENERGY APPLICATIONS

SOLID-STATE MICRO-BATTERIES



Thin film/3D approaches for on-chip batteries

State-of-art: Li+ batteries

Li-ion chemistry has highest energy density of all rechargeable battery technologies

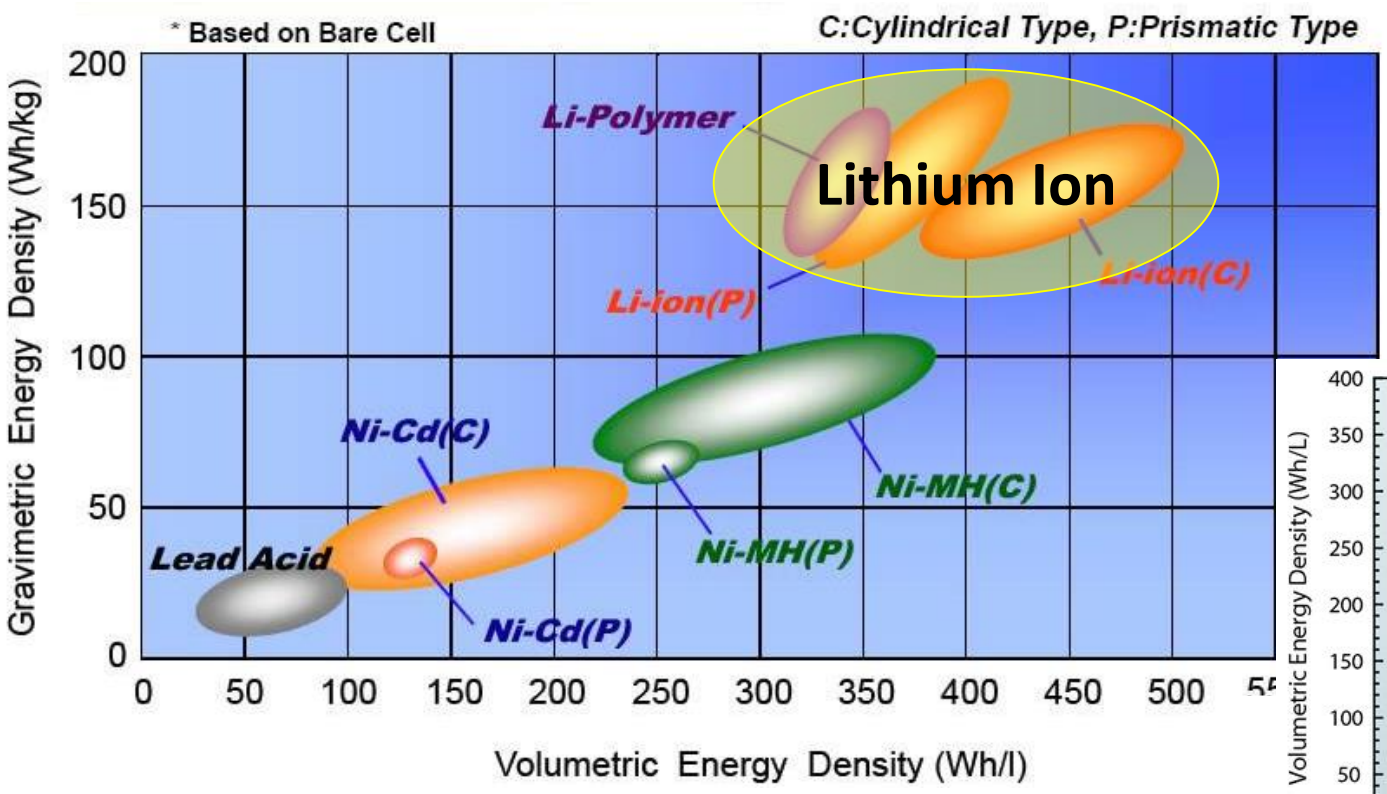
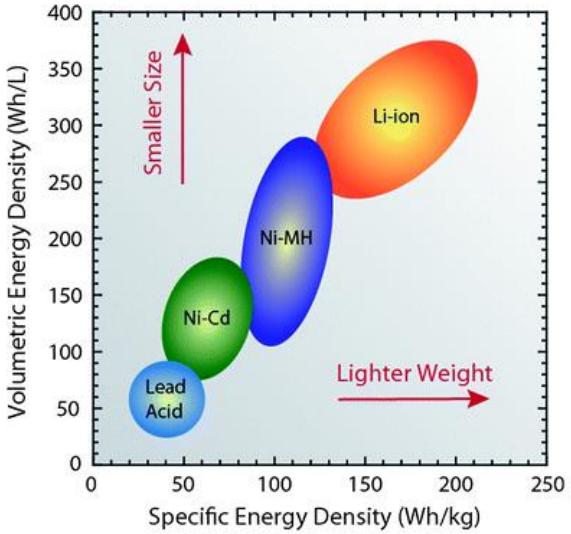


Photo Credit: NASA - National Aeronautics and Space Administration



Lithium-ion thin film batteries

Insertion materials

Cathode

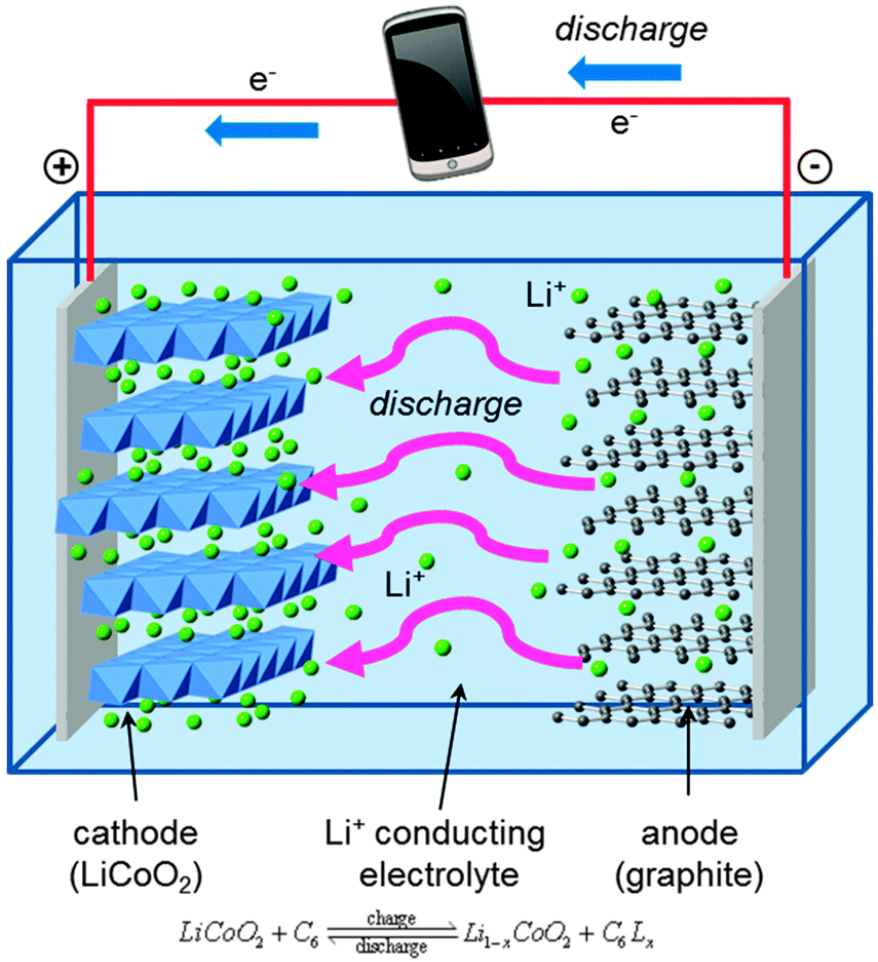
LCO ($LiCoO_2$)

LMO ($LiMn_2O_4$)

NCA ($LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$)

LFP ($LiFePO_4$)

NMC ($LiCo_{1/3}Ni_{1/3}Mn_{1/3}O_2$)



Anode

Graphite (LiC_6)

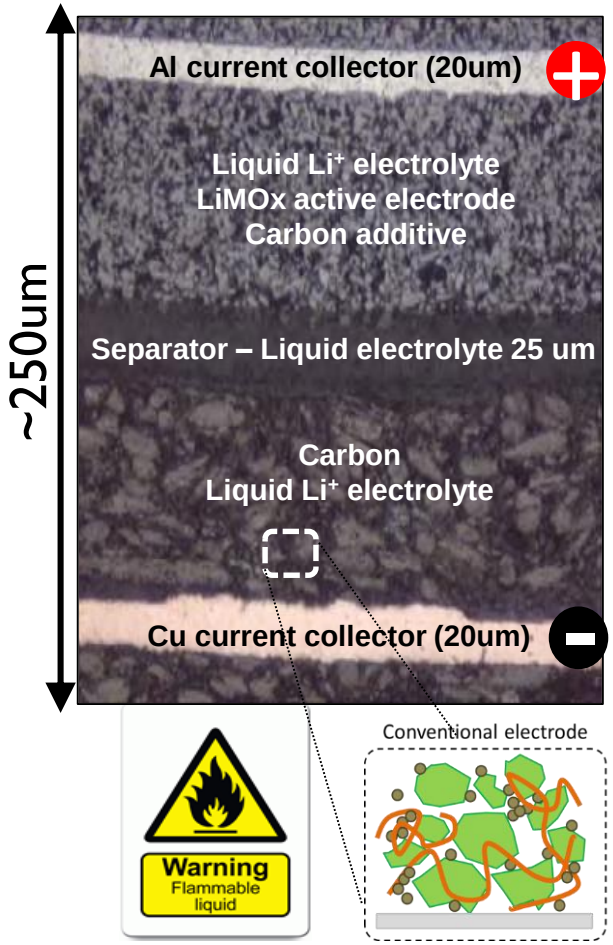
LTO ($Li_4Ti_5O_{12}$)

Lithium

Shuttling of Li^+ ions between anode and cathode

Moving towards all-solid state batteries

Wet Li-ion battery with porous particle composite electrodes



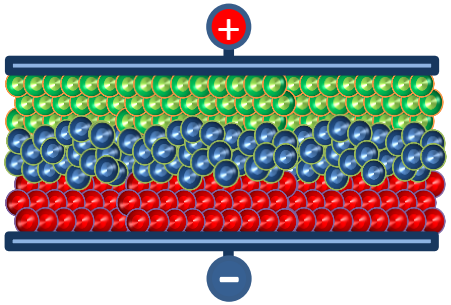
Conventional wet Li-ion battery

Limited Energy Density: small active volume fraction due to **inactive components and porosity**
Limited Power Capability: has **poor conductivity** through electrodes due to inefficient percolation mechanism. Large **I-R drop** over electrodes (over-charging)
Limited Cycle Life Time: Chemical degradation and mechanical dislodging
Unsafe: contains **flammable** solvent

Introduction of solid-state ionic and electronic conductors

Makes devices more **efficient** due to the use of the available cell volume
Increases performance through device architecture
It is **Safer** and has **no leakage**

All-solid stat thin film battery



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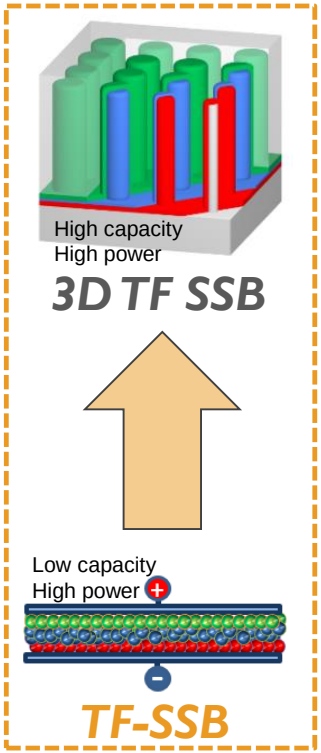
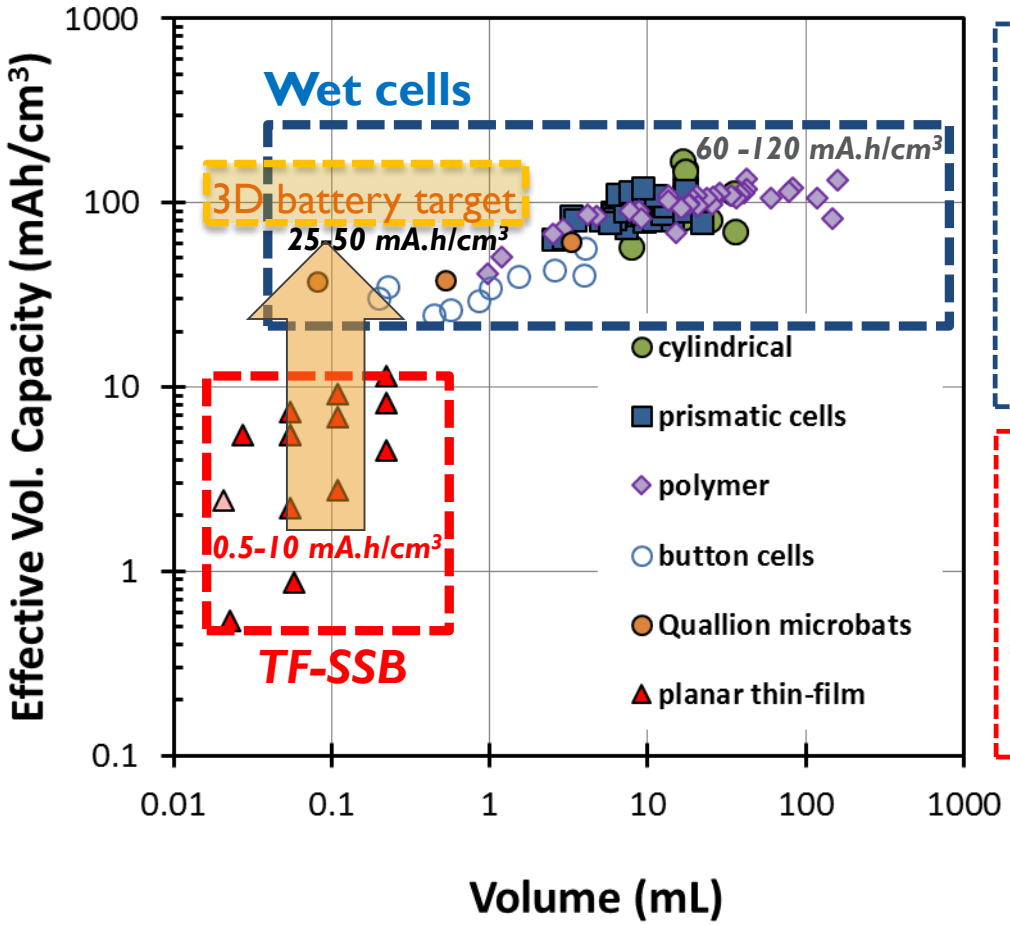
Moving towards all-solid state batteries

Solid-State batteries have limited capacity compared to wet cells





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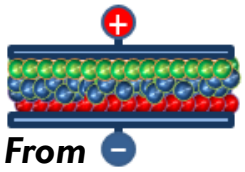
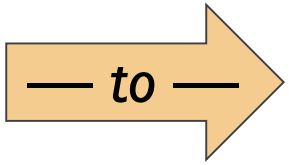
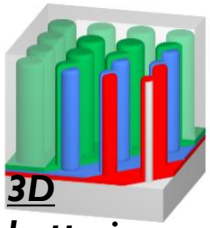
Moving towards all-solid state batteries

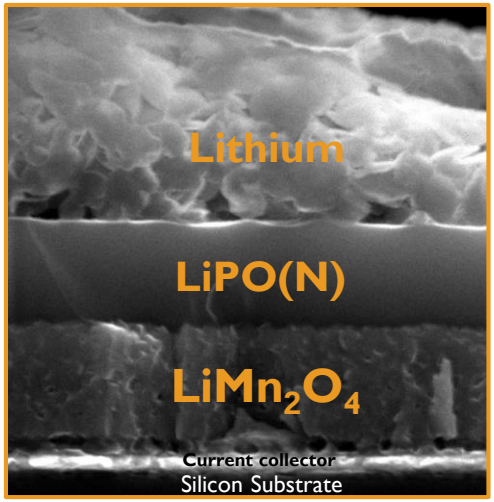
WP4

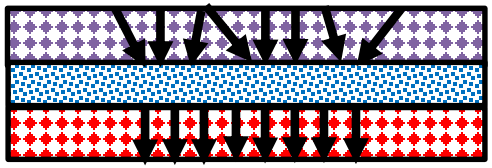






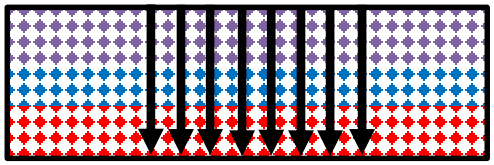
Thin film stacks





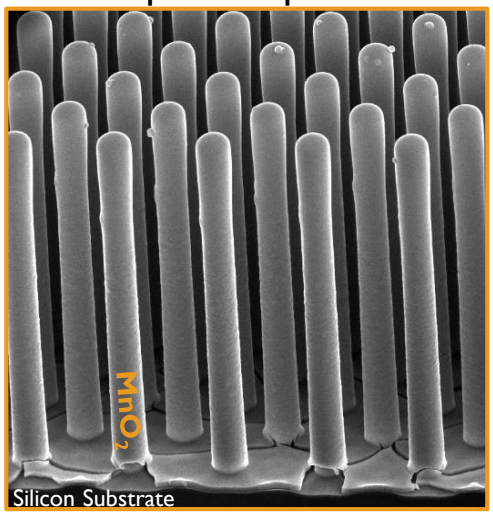
Thin film battery stack

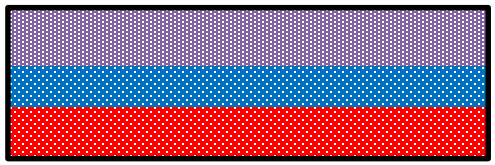
Lattice match interfaces



Transparent interfaces *all-spinel* battery stack

Si compatible processes





***Post-lithiation* schemes of CMOS compatible stacks**

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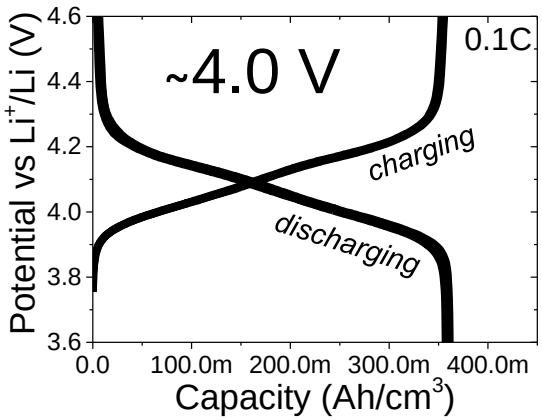
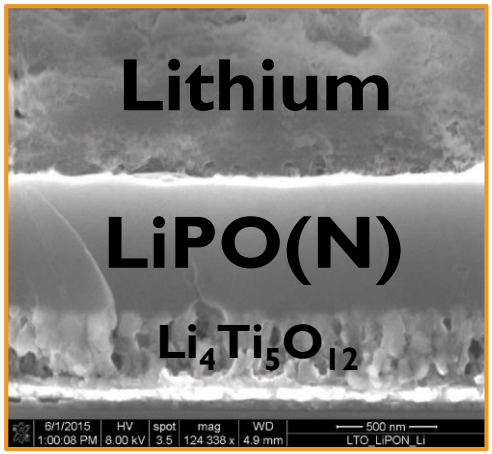
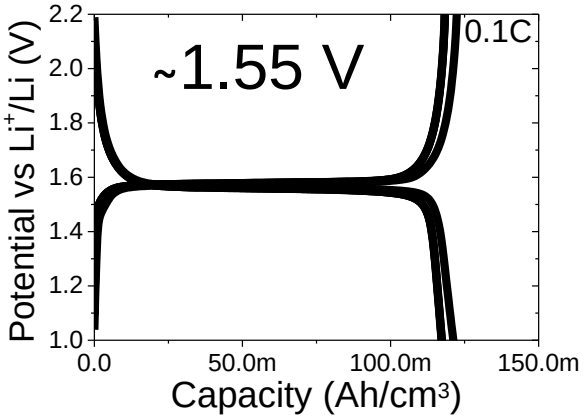
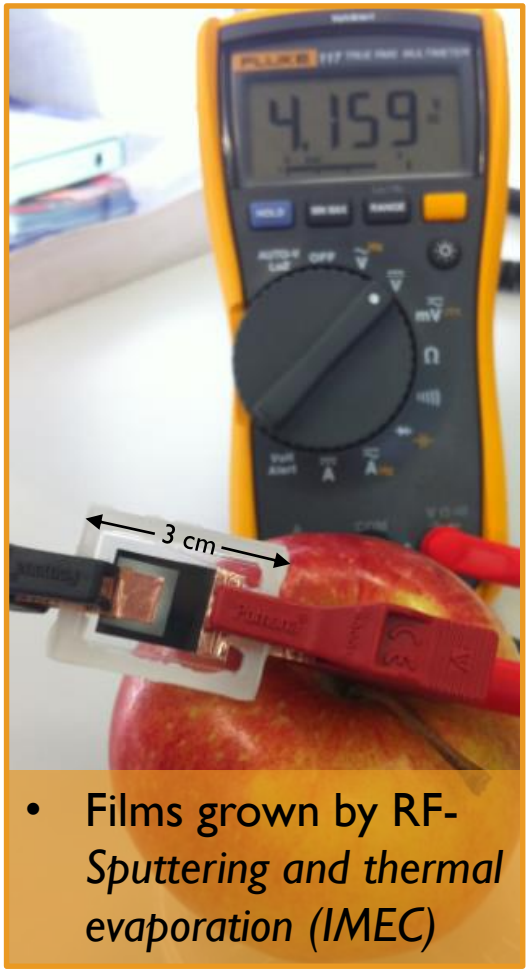
Thin film all-solid state battery stacks

Thin film stacks as model systems





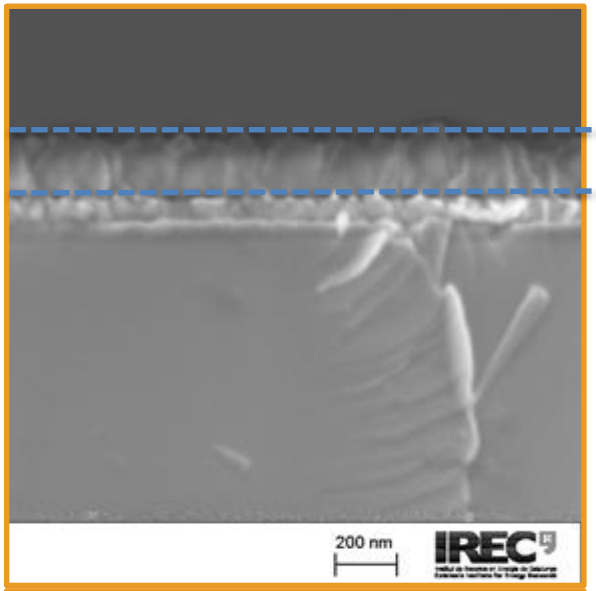


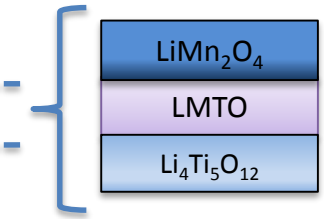


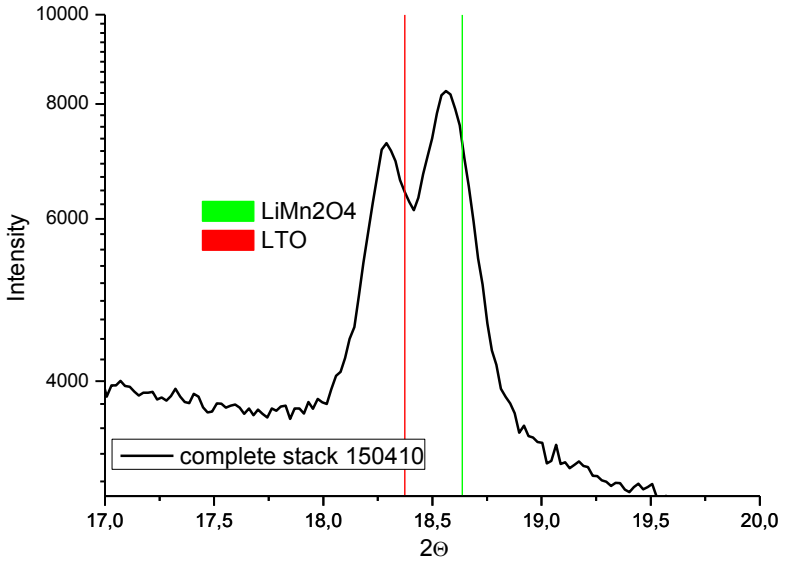
- Films grown by RF-*Sputtering and thermal evaporation (IMEC)*

All-spinel thin film battery

Transparent interfaces all-spinel thin film stacks



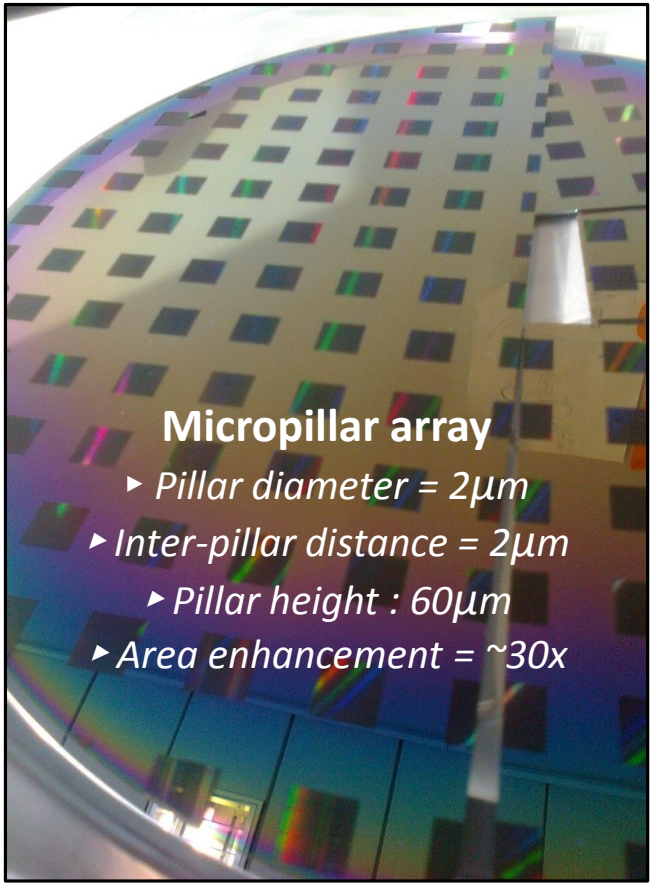


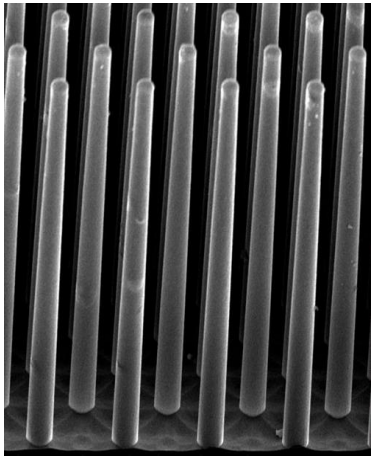


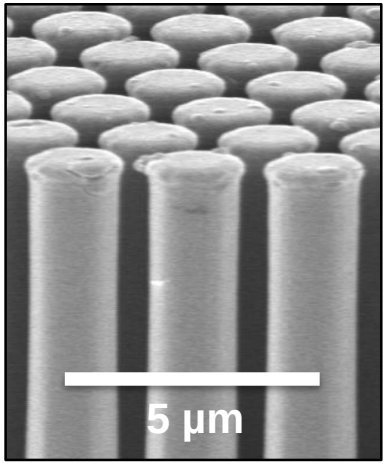
- Films grown by *Pulse Laser Deposition (IREC)*
- Entire device has spinel structure, no segregation
- Continuous microstructure, no interface and layers
- LMO and LTO diffraction peaks detected

3D thin film all-solid state battery

Si pillar arrays are developed in IMEC's 300mm Pilot Line

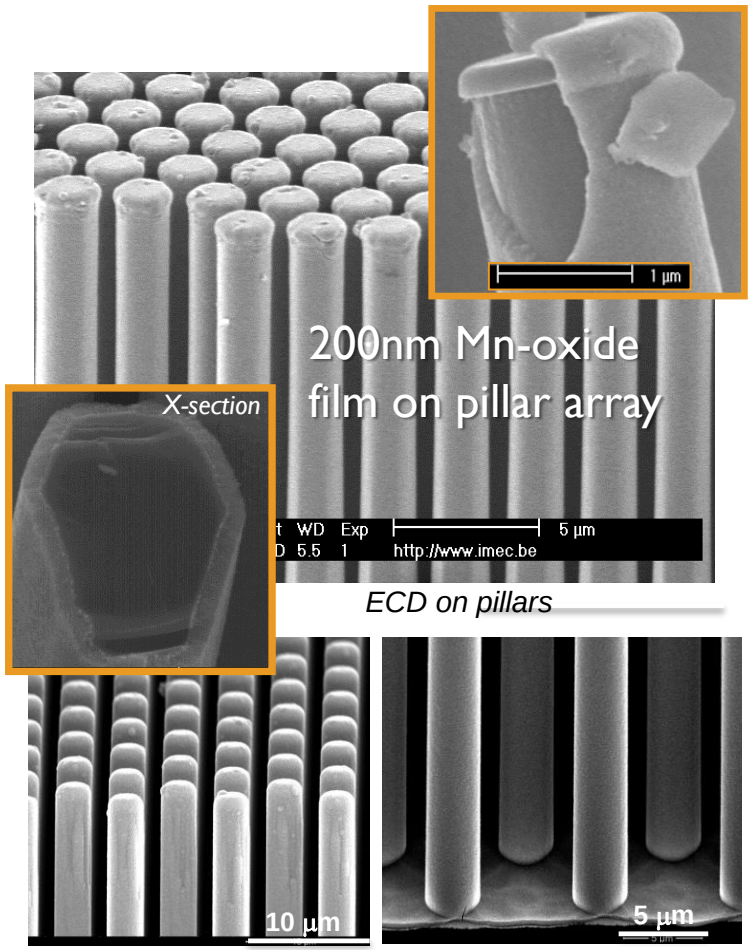


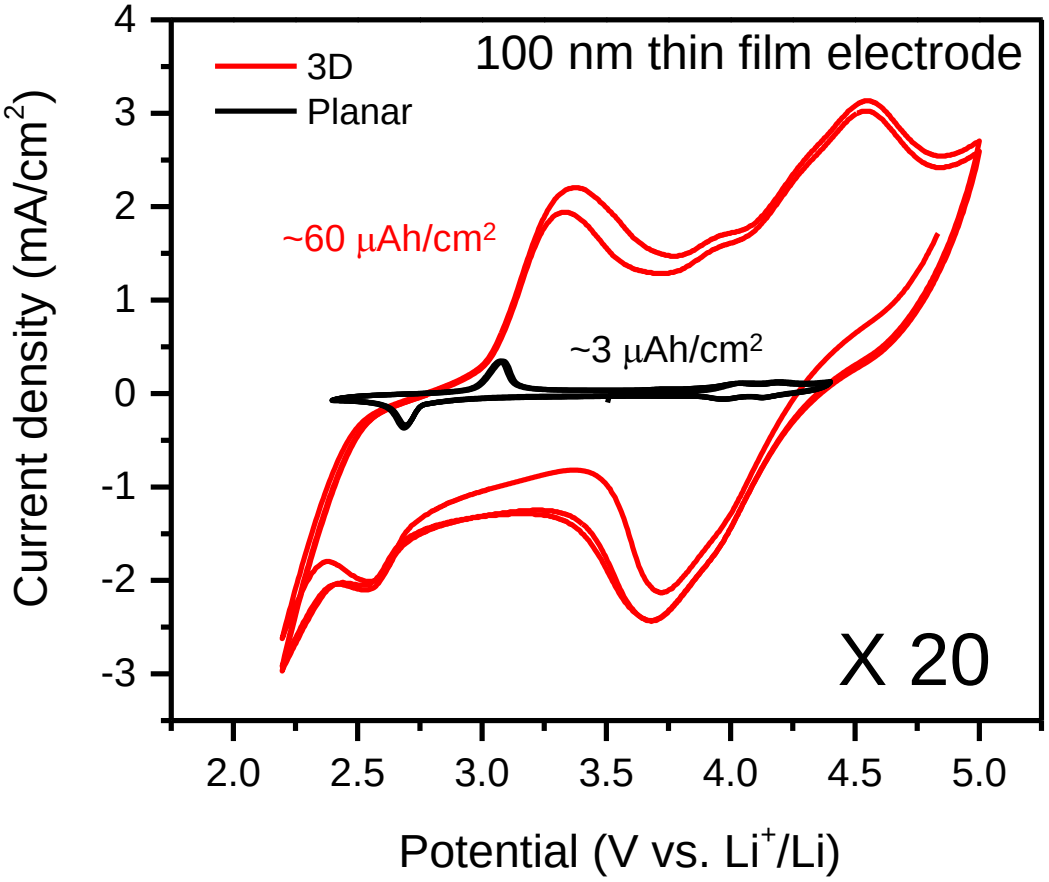




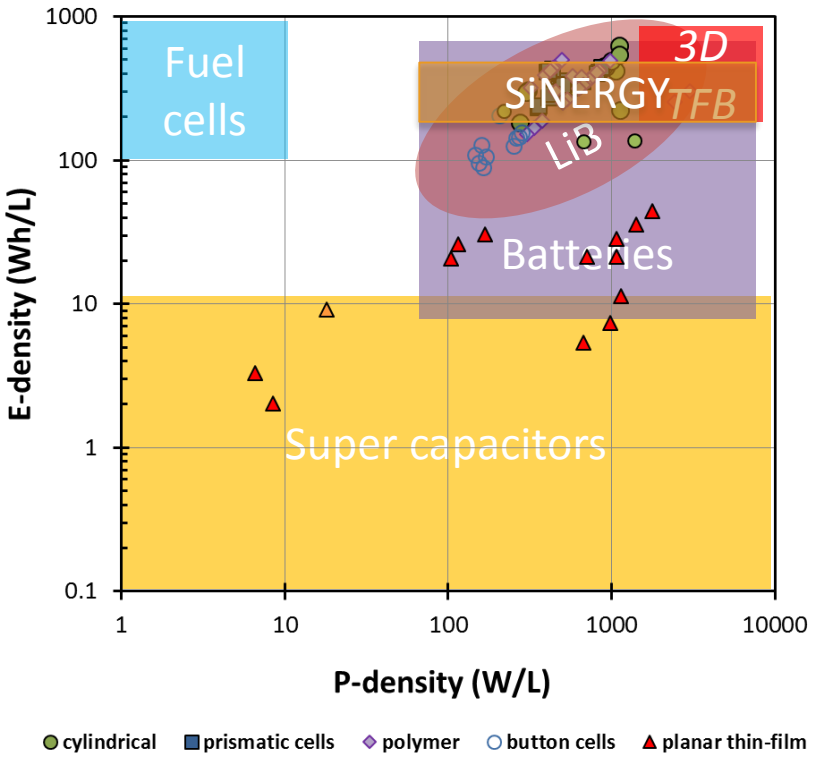
3D thin film all-solid state battery

3D compatible thin film materials: $LiMn_2O_4$





Benchmarking and targets



High speed charging *is set as target for 3D thin-film batteries*

High cell capacity *is set as main target for thin film planar batteries*

- *Safe to operate*
- *Cycle-life time*

10.000 cycles (i.e. 10 year life-time with 3 recharge cycles a day)

Full all-spinel stack (LMO/LMTO/LTO) *~1.5V* -> IREC
Full battery stack (LMO/LiPO(N)/Li) *~4.2V* -> IMEC
Full battery stack (LTO/LiPO(N)/Li) *~1.5V* -> IMEC
Full battery stack (LMO/LiPO(N)/LTO) *~2.5V* -> IMEC

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