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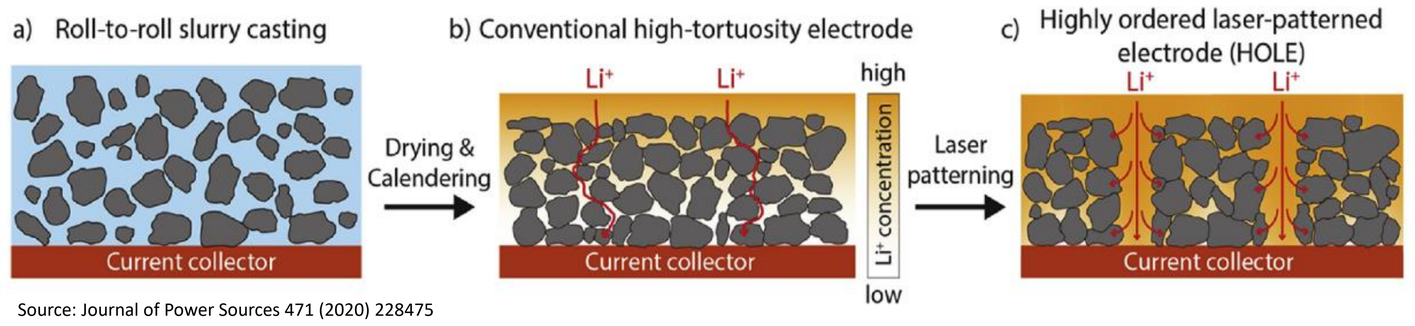
Superior battery manufacturing solution through 3 dimensional pore array diagram (3D PAD) electrode

Motivation:

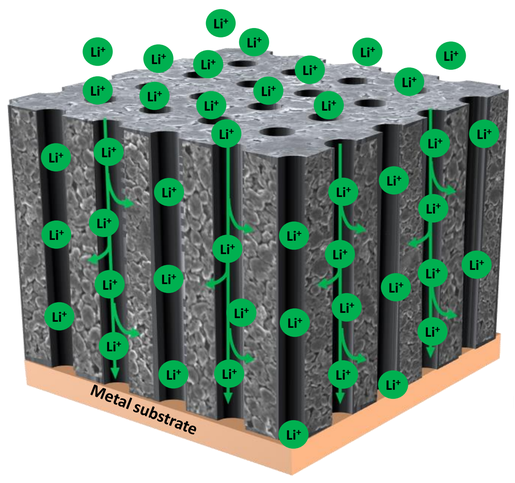
- There are good high-energy lithium-ion battery cells on the market, and there are also high-power lithium-ion battery cells.
- However, there are no proper battery cells that simultaneously deliver high power (> 4C) and high energy (>350Wh/kg). When such battery cells are offered, they often have a short lifespan or a safety issue due to dendrite formation.
- Yet there are many applications that only function well with these or better properties (heavy-duty drones, electric flight, humanoid robots, professional tools, etc.).

The path to solving the problem

- It has already been described and proven in many scientific publications that pores in anodes and cathodes significantly improve ionic conductivity.
- Various methods for creating the structure were investigated. All methods used so far work, but only one is economical and scalable: **screen-printing**.



Source: Journal of Power Sources 471 (2020) 228475



Fast transportation of Li+ ions in patterned electrode

General description of 3 dimensional pore array diagram electrode (3D PAD)

1. Electrodes (anode & cathode) aligned pore channels (3D PAD) provide fast channels for ion transportation
2. Enables the use of **thick electrodes** with **high energy and power density**
3. Prevent Li-dendrites to improve density, safety, cycle life and charge & discharge rate.
4. Significantly increases the lifetime of silicon-doped anodes.
5. Wet and dry screen-printing processes reduce mass manufacturing costs and enhance environmental sustainability AND applicable for SSB.

Advantages of screen-Printing Process

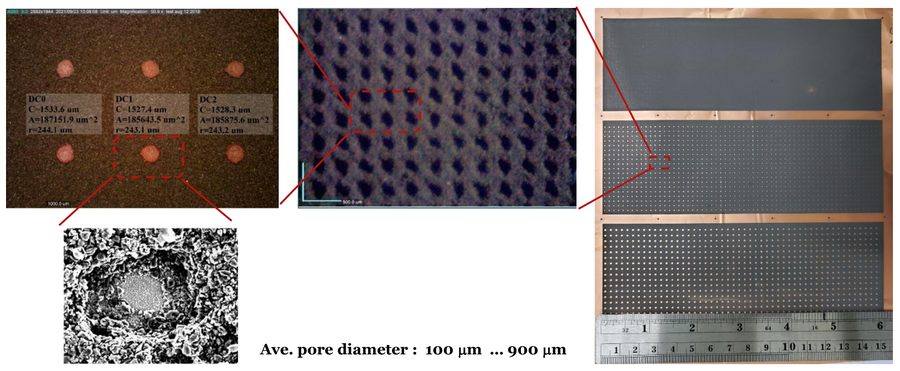
- High throughput, scalability and transferability
- Lower cost
- High precision in structure control
- Multiple printing of thin layers in one machine (gradient formation)
- Pastes with low solvent content and fast drying time
- No subsequent removal of material from the pores is necessary

Printed graphite anodes and cathodes (printed area: 15 cm×4 cm)

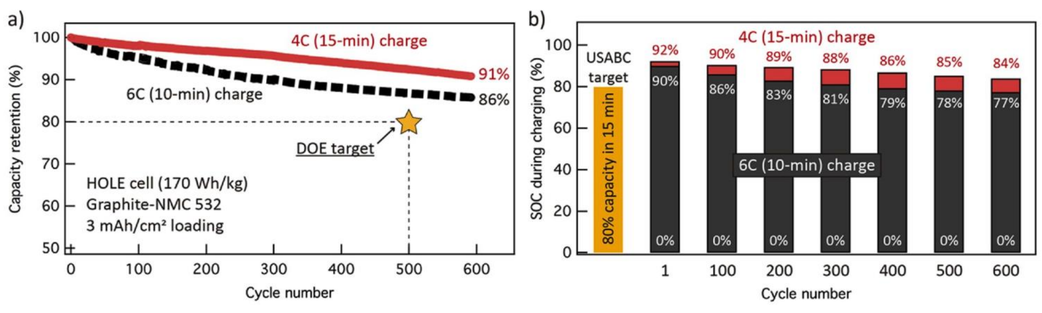
Machine set-up:

Industrial Roll-to-Roll Screen Printing Line

- Print Size: 600 x 600 mm (W x L)
- Printing Speed: 16.7 m/m
- Dryer: 6 m length, 150 °C maximal
- Automatic camera system registration



Ave. pore diameter : 100 µm ... 900 µm



Test Results

We tested button cells (~3 mAh) with single-layer electrodes and pouch cells (~100 mAh) with multi-layer electrodes. The capacity, charge/discharge capability, and cycle stability of the button cells were tested at both Western Michigan University (WMU) and Argonne National Laboratory (ANL). The capacity of the pouch cells was tested only at WMU.

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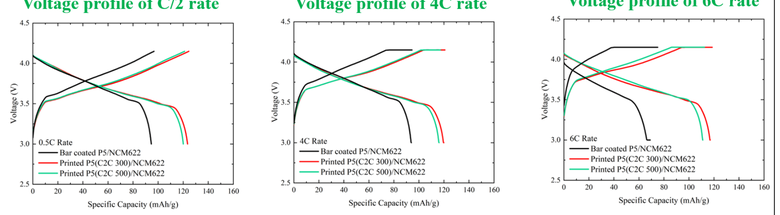
Test condition:

- Charge: Constant current @**C/10, C/2, 4C, 6C** to 4.2V, voltage hold @4.2V till 10, 2, 1/4, and 1/6 hours or current < C/20
- Discharge: Constant current @C/3 to 3.0V

Voltage profile of C/2 rate | **Voltage profile of 4C rate** | **Voltage profile of 6C rate**

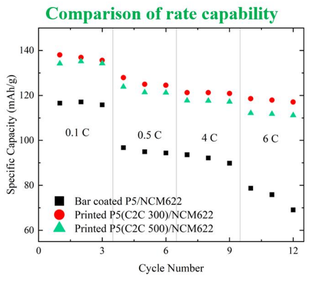


- **Printed electrode deliver the significant higher capacity with a lower over potential**
- **The shorter C2C distance delivers the higher capacity**
- **As the charging rate increases, the advantages of the printed electrodes become more obvious**

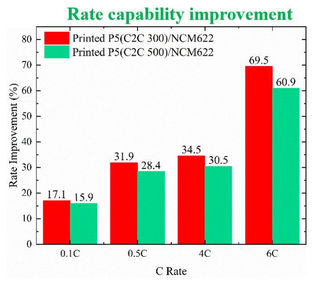
Test condition:

- Charge: Constant current @**C/10, C/2, 4C, 6C** to 4.2V, voltage hold @4.2V till 10, 2, 1/4, and 1/6 hours or current < C/20
- Discharge: Constant current @C/3 to 3.0V

Comparison of rate capability



Rate capability improvement

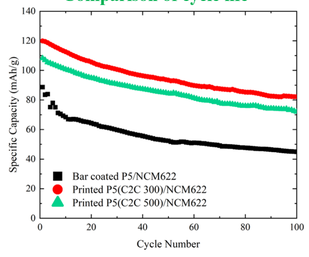


- **Printed electrode indicates the significant improvement on rate capability at high C rate**

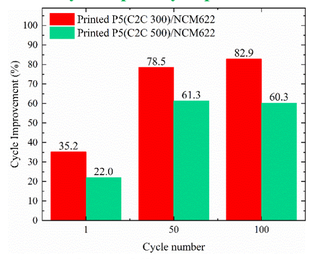
Test condition:

- Charge: Constant current @**6C** to 4.2V, voltage hold @4.2V till 1/6 hour or current < C/20
- Discharge: Constant current @C/3 to 3.0V

Comparison of cycle life



Cycle capability improvement



- **Printed electrode indicates the significant improvement on cycle capability**
- **The shorter C2C distance delivers the higher cycle performance**

Summary:

The structuring of thick electrodes and its advantages have been extensively described and demonstrated in the literature. Various methods for creating the structure have been investigated. All existing methods are functional, but only one is economical and scalable: **screen-printing**.

XRBT and XCellBT holds the patents and know-how for this process. It is now time to build a pilot plant with rotary **screen-printing 3D PAD technology** in Germany. The right mechanical engineering companies and the necessary technical expertise are available in Europe.