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Ultrasonic characterisation of Li-ion battery layer properties

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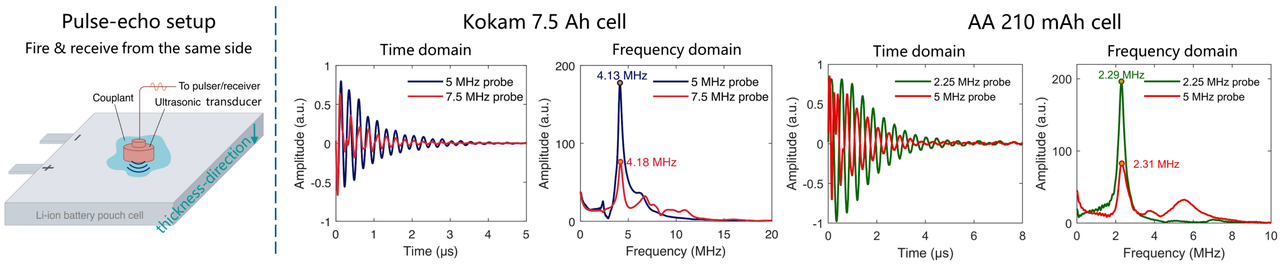
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Introduction

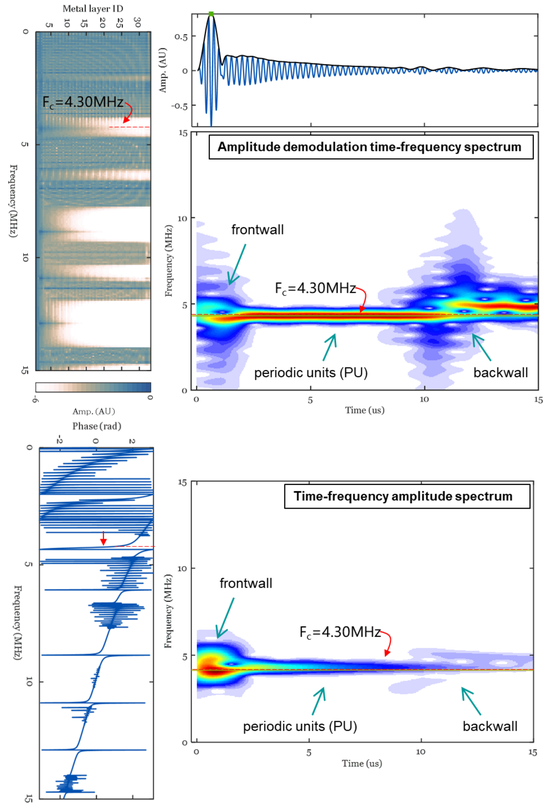
We report (1) a holistic ultrasonic resonance method for rapid, cheap and non-invasive characterisation of battery's inner structures and states, and (2) an ultrasonic method for quantifying the porosity, tortuosity and permeability of battery electrodes during production. Both methods are promising tools for quality control and health monitoring.

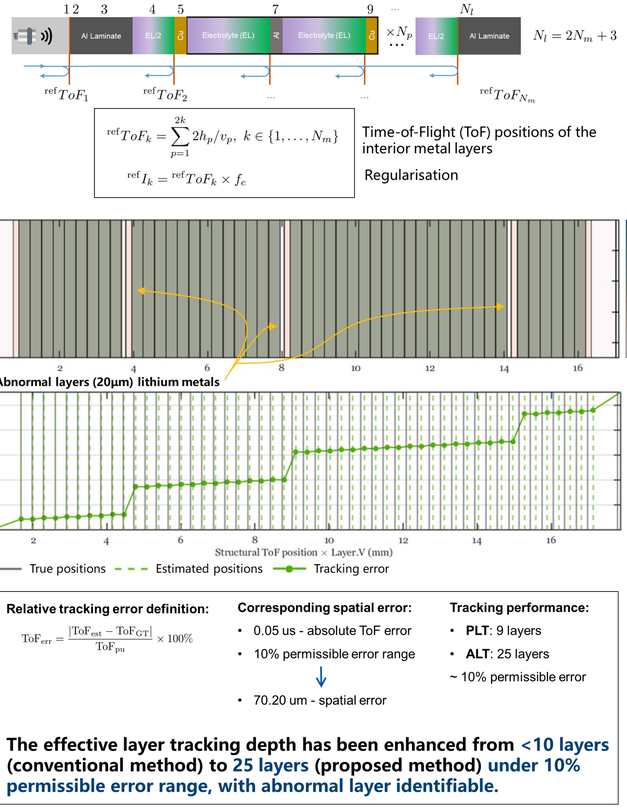
Characterisation of multi-layer stacking structure inside pouch cells

Ultrasonic resonance of multi-layer LIBs: With a simple ultrasonic setup on a Li-ion pouch cell (left), acoustic resonance of layered LIBs is captured as an *intrinsic* characteristics for different cells (right).



Optimal procedure - physics-guided layer tracking: By modelling band and time-frequency structure of the cell (left), optimal excitation protocol and adaptive tracking approaches are proposed to estimate interior cell structure.





Relative tracking error definition:

$$\mathrm{ToF_{err}} = \frac{|\mathrm{ToF_{est}} - \mathrm{ToF_{GT}}|}{\mathrm{ToF_{pu}}} \times 100\%$$

Corresponding spatial error:

- 0.05 us - absolute ToF error
- 10% permissible error range
- 70.20 um - spatial error

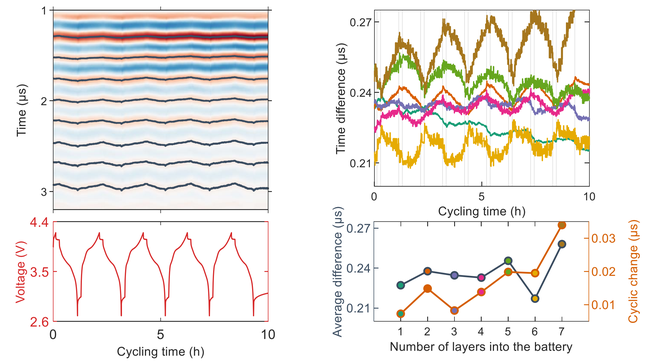
Tracking performance:

- **PLT**: 9 layers
- **ALT**: 25 layers

~ 10% permissible error

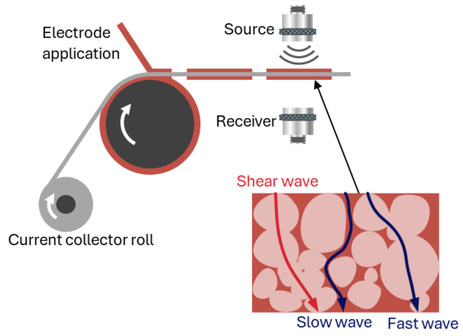
The effective layer tracking depth has been enhanced from <10 layers (conventional method) to 25 layers (proposed method) under 10% permissible error range, with abnormal layer identifiable.

Layer-resolved state of charge monitoring: Resonant signal changes with battery state of charge (left) and allows for layer-by-layer monitoring (right).

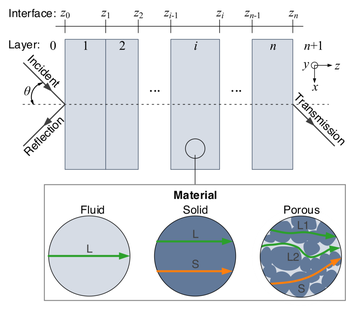


Characterisation of dry electrode porosity and tortuosity

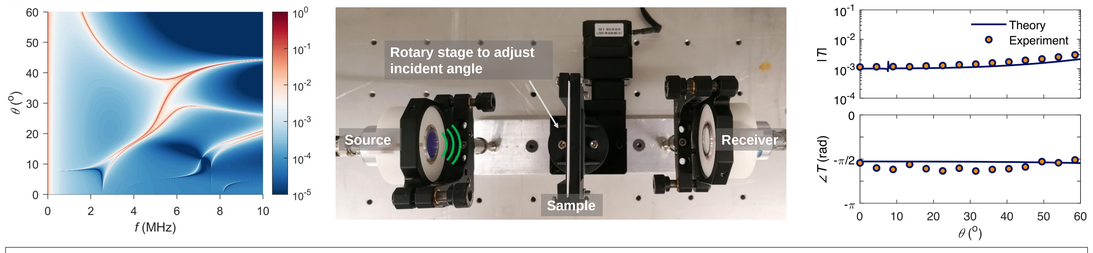
Concept: Use non-contact, air-coupled ultrasound to quantify electrode properties during production.



Theory: Developed a stiffness matrix method to describe ultrasound in multi-layered, porous battery electrodes.



Experimental validation: Verified the theory (result on the left) using experimental measurements (setup in the middle), demonstrating good agreement (right) and suitability for electrode characterisation applications.



Publications

- Huang, Kirkaldy, Zhao, Patel, Cegla, Lan, Quantitative characterisation of the layered structure within lithium-ion batteries using ultrasonic resonance, J. Energy Storage 50, 104585 (2022).
- Ren, Huang, Cegla, Patel, Lan, Error-aware layer-resolved characterisation of lithium-ion battery based on ultrasonic resonance and parametric analysis, 244th ECS Meeting, Gothenburg, Sweden (2023),
- Huang, Cegla, Lan, Stiffness matrix method for modelling wave propagation in arbitrary multilayers, Int. J. Eng. Sci. 190, 103888 (2023).