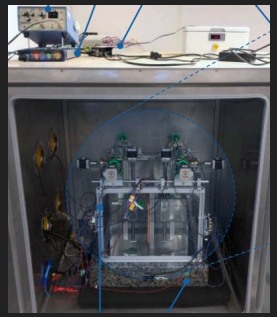
Ultrasound on Li batteries

A physics 536a work by Bubba

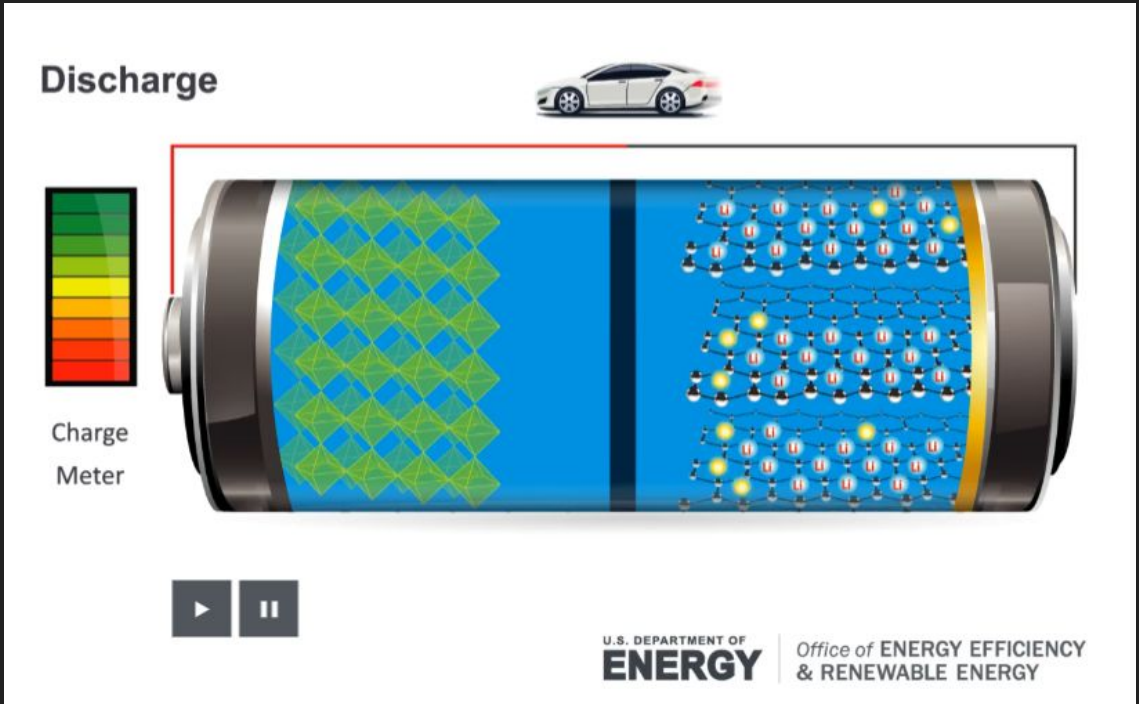
Battery degradation can be imaged by several technologies



But they are all very expensive, in space and money.

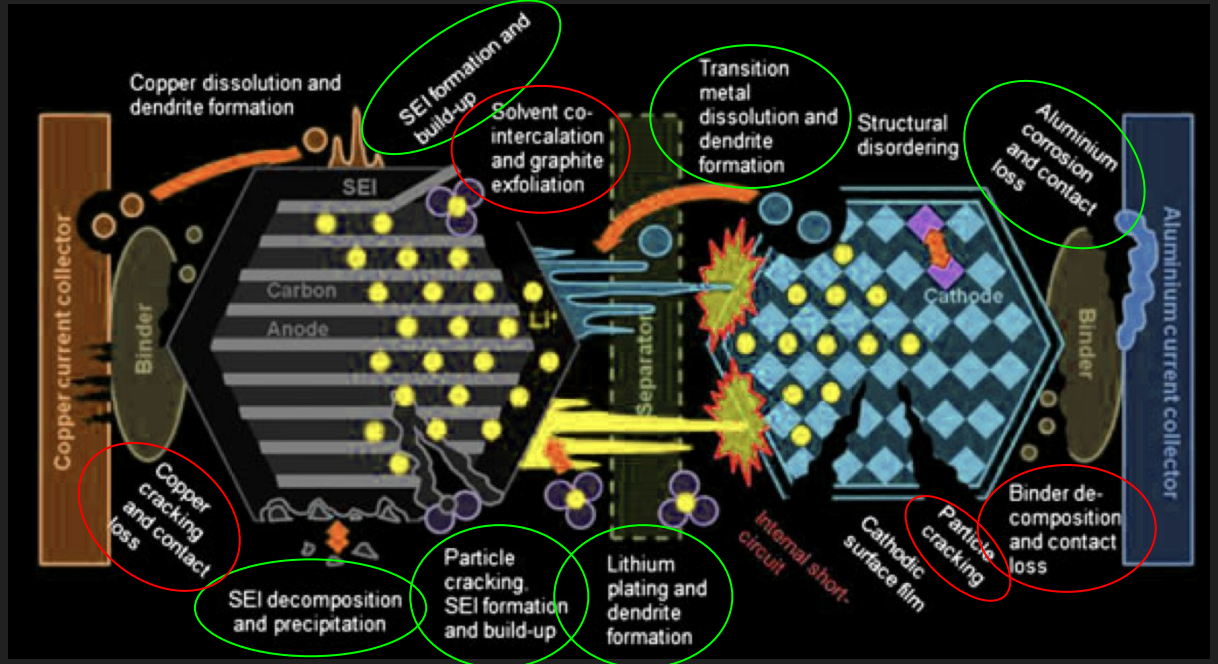
That’s why US may be a sound alternative.

Lithium ion batteries move lithium ions from a high energy location to a low energy location, and back again.



https://www.energy.gov/eere/articles/how-does-lithium-ion-battery-work

Lithium ion batteries degrade by these methods



A gas-forming process

A gas-trapping process

Intra-cell accumulation of gas is easily and cheaply visible via US imaging.

Reflection and transmissions depend on material properties

$$A_r = \left(\frac{Z_2 - Z_1}{Z_1 + Z_2} \right) A_i$$

$$A_t = \left(\frac{2Z_2}{Z_1 + Z_2} \right) A_i,$$

with

$$Z_i = \rho_i \left(K_i + \frac{4}{3} G_i \right) \qquad \text{with } i = 1, 2.$$

A_r reflected amplitude

A_t transmitted amplitude

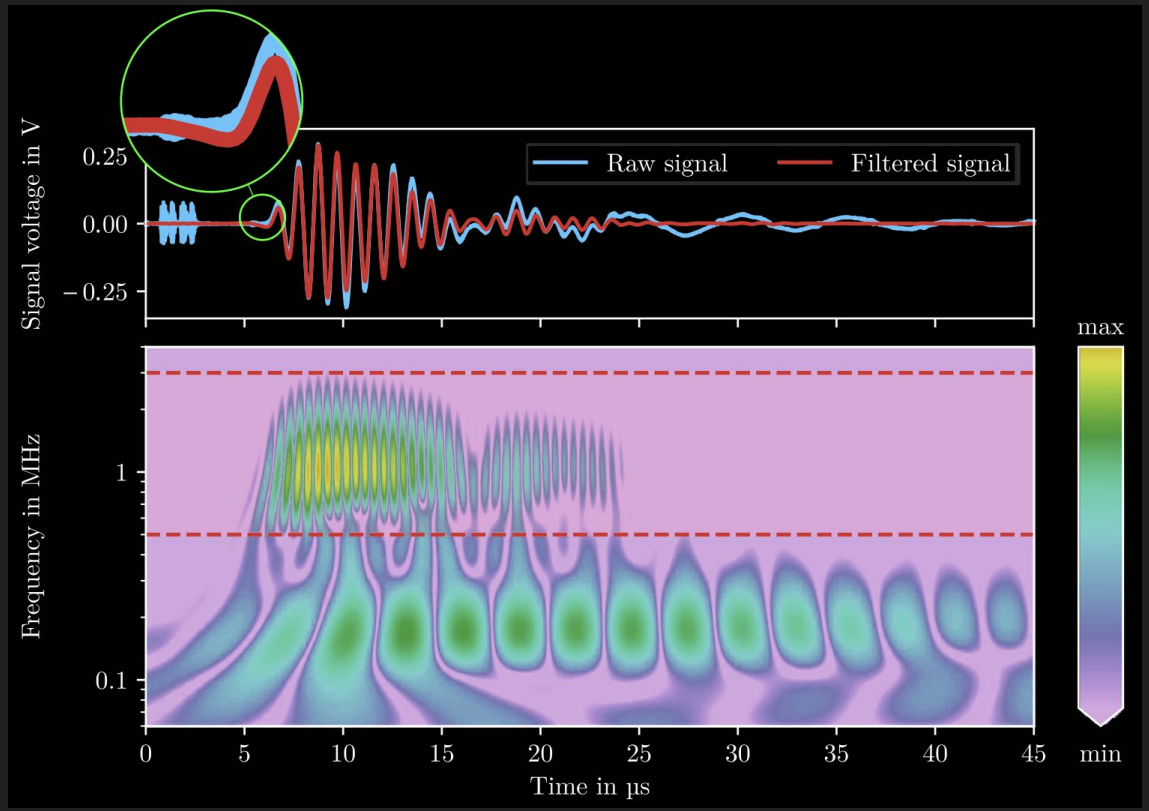
Z mechanical impedance

ρ density

K compression modulus

G shear modulus

A band-pass filter cuts out noise that has moved laterally through a battery cell



Without filtering, images are unrecognizably noisy.

In this study, US amplitude is measured in volts, and intensity is proportional to amplitude squared.

$$\mathrm{SI} = \int_0^{t_N} f_{filt}^2(t)\,\mathrm{d}t$$

What the heck was that, a frequency versus time plot?

$$\Psi_{a,b} = \Psi(\frac{t-b}{a})$$

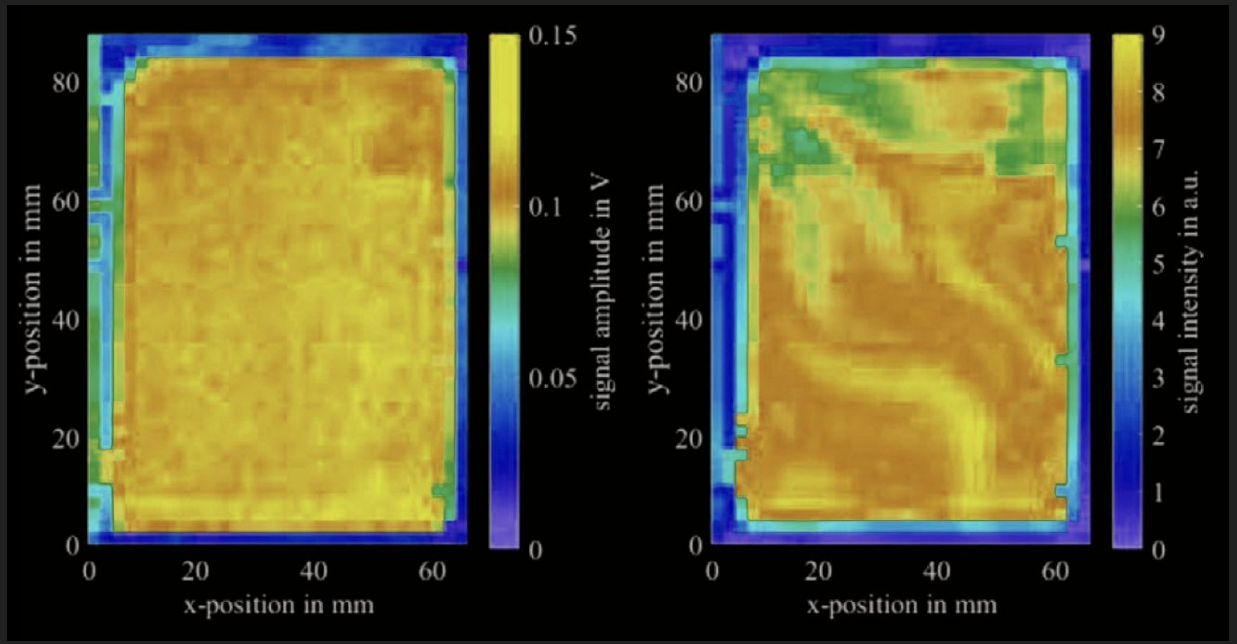
Yes: CWT instead of FT → see frequency evolving through time

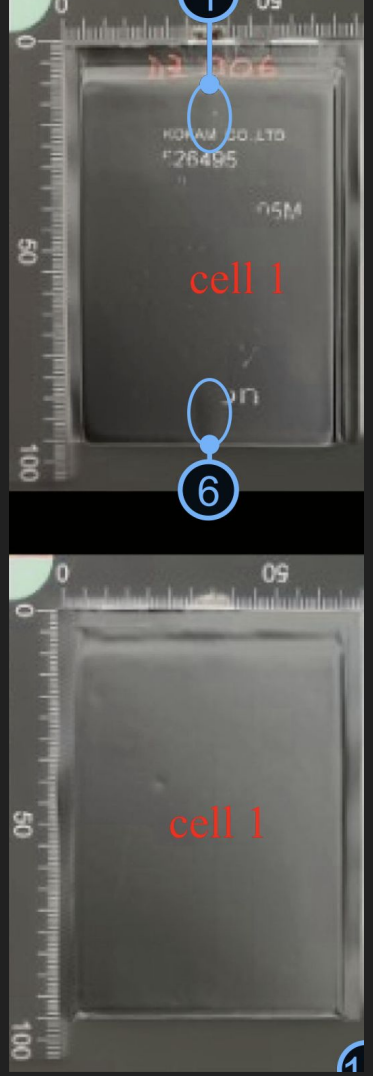
Like FT, a convolution.

Unlike FT, a convolution of three functions: integral of ultrasound * e^{ix} * $e^{-x^2/2}$

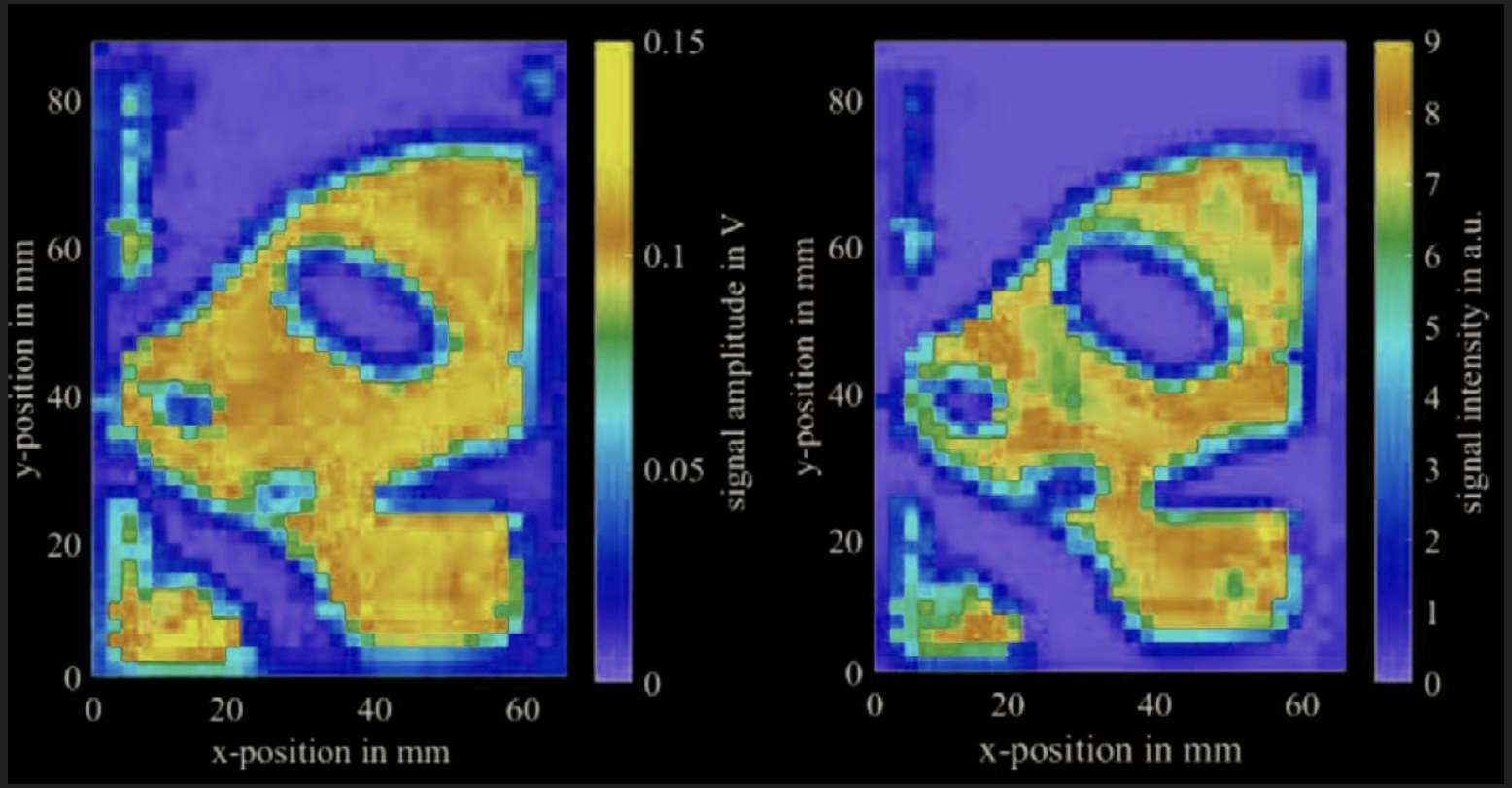
$$\Psi(t) = k\ e^{i\omega_0 t} \cdot e^{-\frac{t^2}{2}}$$

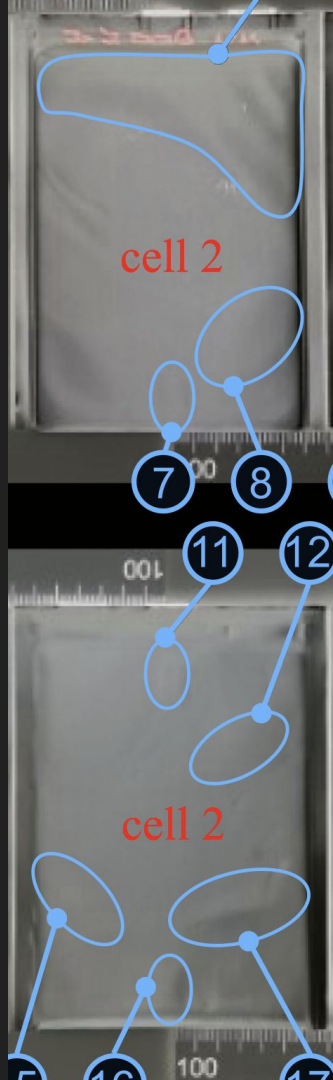
US reveals SEI formation (green)



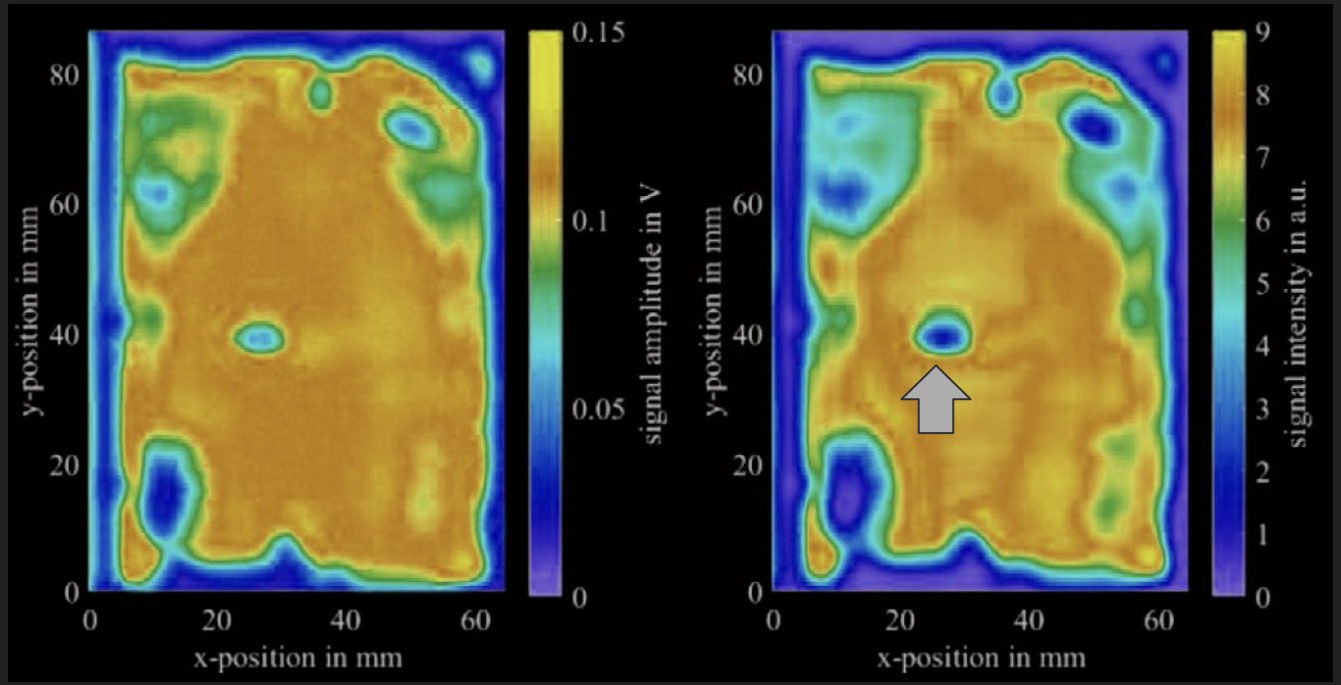


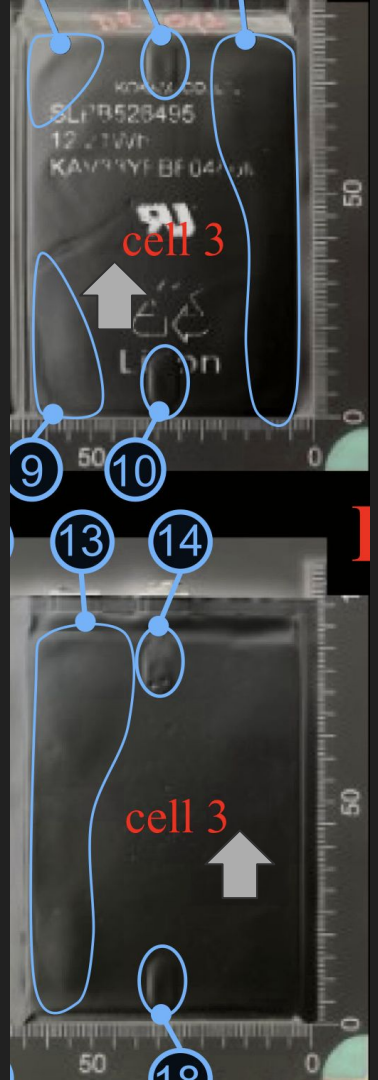
US reveals gas formation (blue)



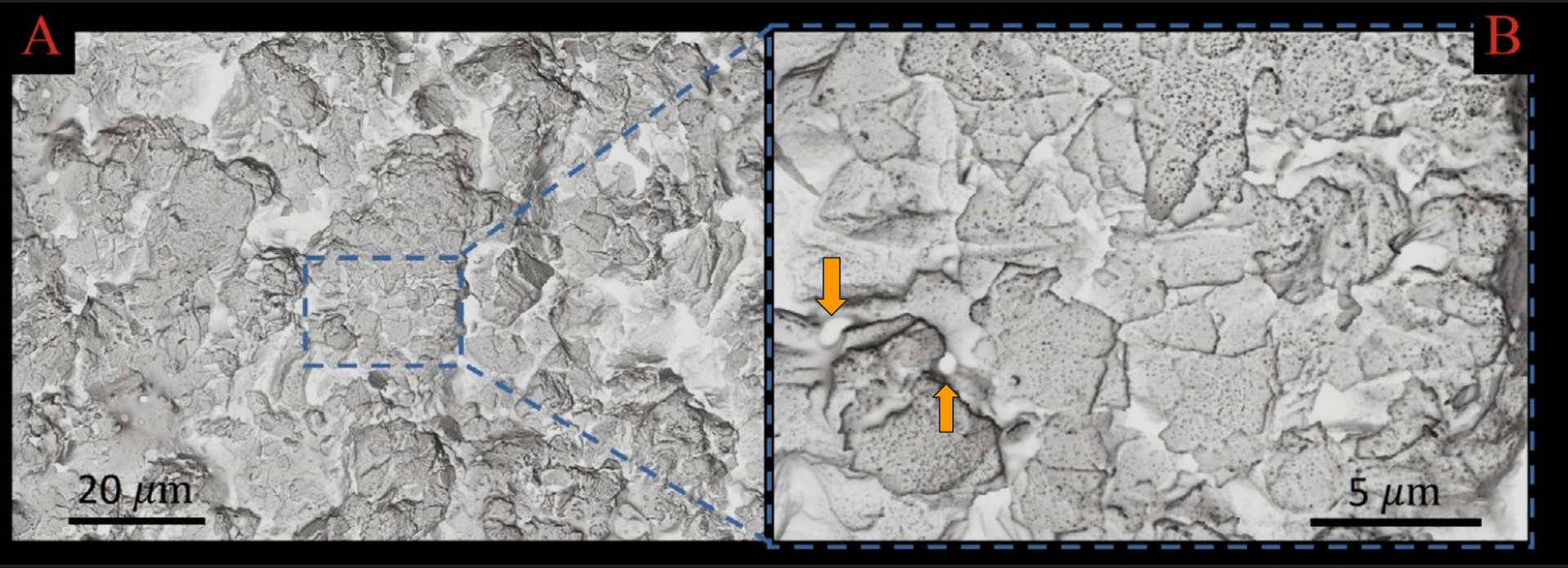


US reveals otherwise unseen gas formation





SEM confirms the conclusions drawn from US imaging



Sources, with links (Dropbox, YouTube, or website)

Wasylowski et al's 2022 article on their invention of the scanning acousic imager.

Rowden and Garcia-Araez' 2020 review of gas evolution in Li ion batteries.

Artem Kirasonov's 2022 video "Wavelets: a Mathematical Microscope."

Kabir and Demirocak's 2017 review of Li ion battery degradation mechanisms.