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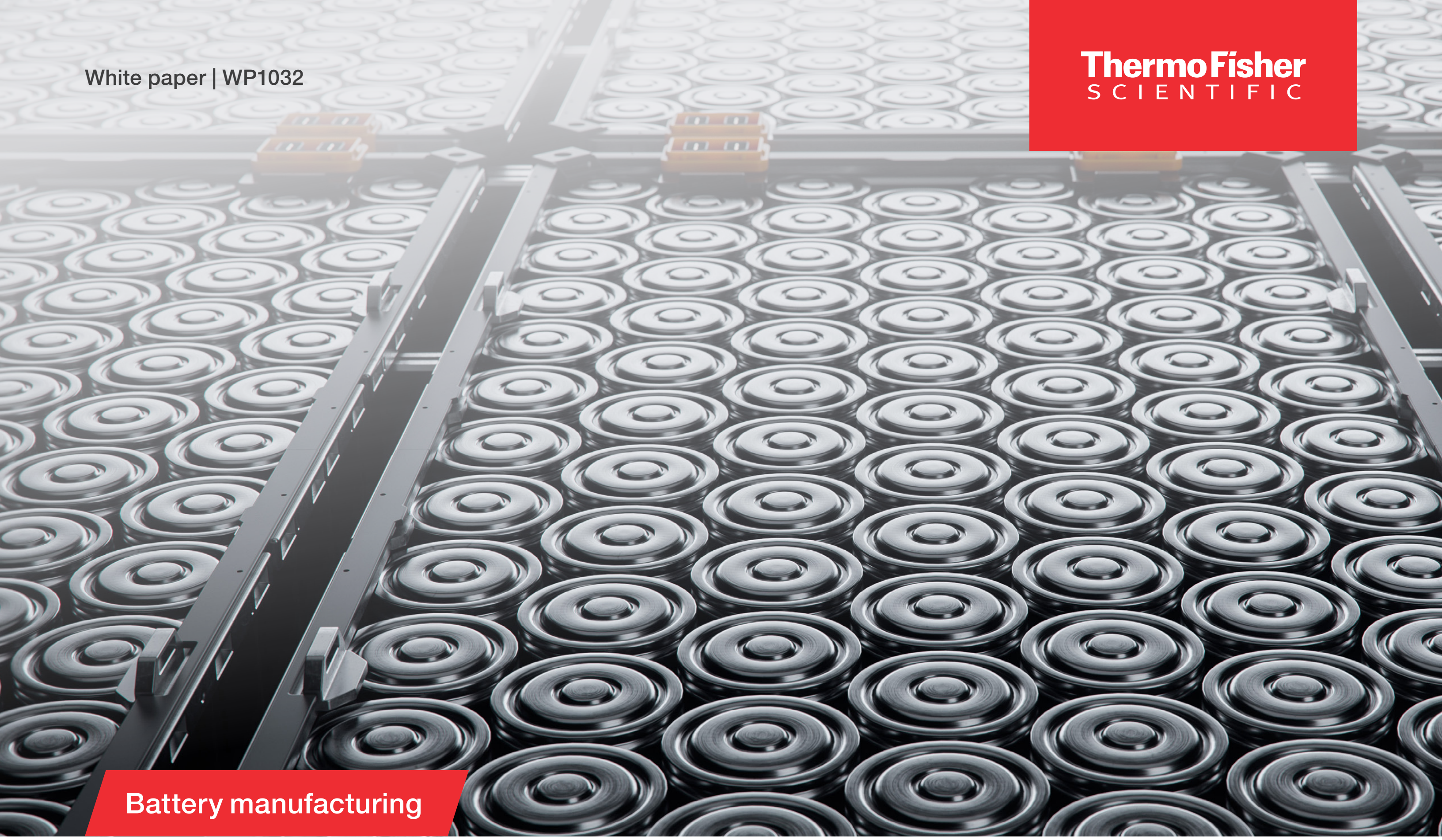

Battery manufacturing

Mass profilometry: a new paradigm for in-line metrology on battery electrode production lines

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Introduction

To meet the growing demand for batteries in electric vehicles, early leaders in electrode and cell manufacturing have scaled up their volume through duplication of existing production lines. In cases, yield has been sacrificed in the name of reducing time to market or increased numerical volume of battery cells delivered. End-of-line electrical cycle testing of the completed cells provides a partial backstop for assurance of the safety and performance of the final product, but this is not a perfect solution. The number of product recalls resulting from battery failures has grown as more electric vehicles enter the global market. As cost competition in the market accelerates, maximizing yield becomes critical for long term profitability, but failure rates between 5% and 30% have been observed, especially in early stages of production scale-up. The electrode coating process is particularly challenging to master and is often the area where most significant yield losses occur. This paper will introduce a new metrology technique, in-line mass profilometry, that offers potential to dramatically improve electrode coating quality and process yield.

Industrial metrology

Prior to the mid-1900s, the thickness or basis weight (mass per unit area) of flat sheet materials produced on an industrial scale could only be determined through destructive contact measurements taken post-production. As physicists explored new applications for the use of x-ray, radioisotope, and other electromagnetic energy-based sensors, manufacturers across a diverse set of industries have benefited from a variety of non-contact, non-destructive measurement instruments. (See Figure 1)

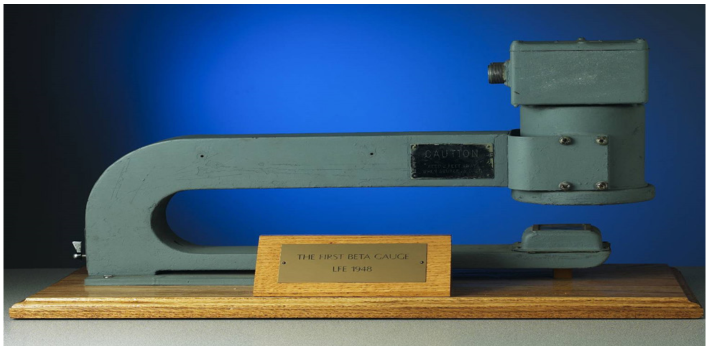

Figure 1: Early beta-ray basis weight gauge

The functions and features of these early instruments evolved as process engineers sought more real-time data on the mass profile and dimensional properties of the material produced. Where thickness data across the sheet was required, a sensor was mounted to a frame on a motor that drives the measurement head from one edge of the strip to the other (see Figure 2). This basic concept is still employed on manufacturing lines for every type of material produced in a flat sheet, including battery electrodes.

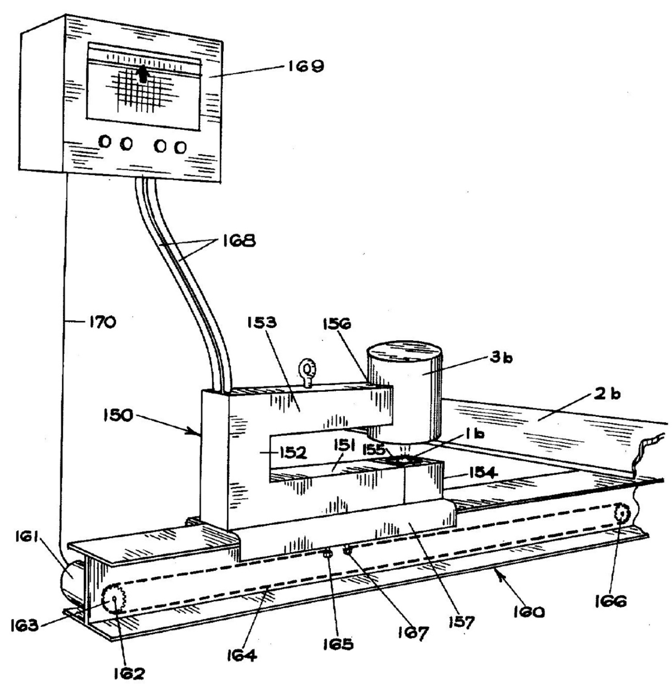

Figure 2: 1952 patent for profile thickness gauge

Battery electrode production

Electrode manufacturing lines within a modern gigafactory have been optimized in their design for continuous mass production. Ideally, slot die coaters running at well-controlled flow rates deposit precise amounts of active electrode material suspended in a slurry onto metal foil substrates. The wet coating then enters a long oven to dry out the slurry. The top side coated sheet is then directed back through a second coating station where the same application process is carried out on the bottom side. (See Figure 3)

The end result is a coated electrode "mother roll" that can be slit into narrower format to be combined with its opposite electrode and separator film to be stacked or rolled into the final cell. Traditionally, during the electrode coating process, the mass per unit area of active material, often called mass loading, is monitored via a multi-frame gauging system, where each frame has a single point sensor that traverses across the sheet, in a synchronized motion, over the measurement path of the previous sensor.

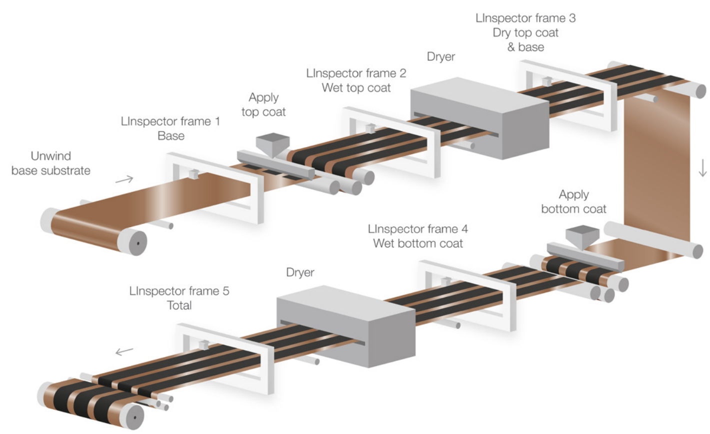

Figure 3: Typical double-sided electrode coating line

This coordinated motion allows the system software to calculate a differential measurement of the top or bottom layer independently. This data is certainly helpful to line operators for monitoring the slot die gap and slurry pump flow, but from a quality perspective, it only provides measurement data on 2% to 4% of the electrode material. (see Figure 4)

While scaling high volume production has led the way for reducing the cost per kilowatt-hour (kWh), there is now a growing need to improve yield while maintaining an uncompromising level of battery cell quality, safety and performance. Innovation in in-line metrology now offers the manufacturers and cell development teams an opportunity to gain a greater insight into the electrode coating process. Instantaneous analysis of mass loading on the entire electrode at full production speeds is paving the way towards a new level

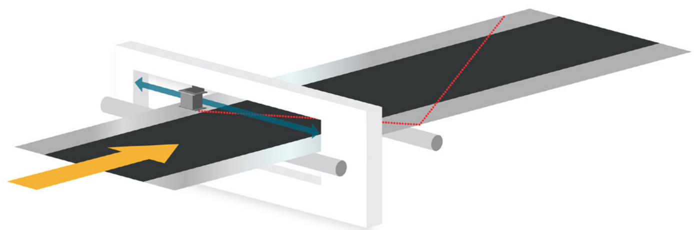

Figure 4: Traversing single point sensors only measure 2% to 4% of the electrode material (note red trace of measurement spot)

of quality assurance and enables faster process qualification and development.

Mass profilometry

The term ‘mass profilometry’ describes a new paradigm in in-line metrology. It accurately conveys the ability of an innovative analyzer to provide mass loading data across the full width of the electrode sheet in real-time. With a measurement profile available instantaneously, 100% of the electrode material is measured. Line operators are provided with a complete data set for controlling their coating stations, and process engineers are provided with rich data for optimization of process parameters and design studies.

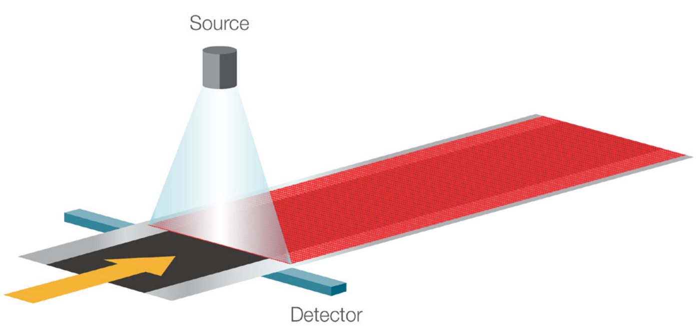

Figure: 5 Mass profilometry measurement

From a quality and traceability perspective, the mass profilometer is not only able to see loading defects missed by single point sensors, but with its high-resolution, high-speed capability, it can identify defects in-line that could only previously be determined through time consuming offline destructive analysis. High frequency oscillations in the coating application, excess coating, scratches and high edges can all impact the localized loading of the active electrode materials, potentially impacting the localized anode-to-cathode balance.

The example of visualized mass profilometry data in Figure 6 shows a full mapping of an electrode patch that makes high

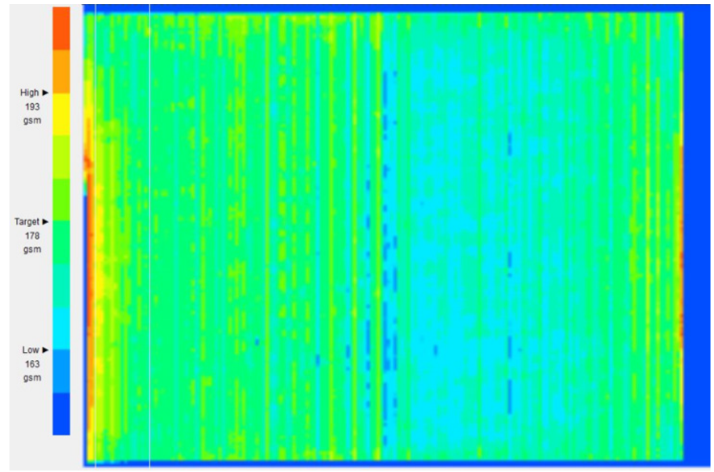

Figure 6: Mass loading heatmap of a cathode patch

edge defects (orange and red of left and right edges) and coating steaks clearly visible. Pass/fail thresholds and alarm parameters can be configured to alert the operator of changes in process conditions.

Through the ability to display the loading uniformity, or lack thereof, the mass profilometer allows for segregation of out-of-tolerance material or sections of the coating that include high or low spots. Identifying these defects early in the cell production process enables cost savings associated with downstream processes such as slitting, stacking and electrical testing. Additionally, sections of the electrode that are slightly high or low relative to target loading can be paired with similarly loaded areas of the opposite electrode material, thereby maintaining the ideal anode/cathode ratio for optimum battery cell performance.

When compared to the tens of seconds, and tens of meters of material that pass under a traversing scanner before a complete edge-to-edge profile measurement is available, the instantaneous profile data from the mass profilometer allows operators to dramatically reduce the time to target when starting up a new production run.

Summary

Current single point gauges used for electrode mass loading measurement only measure between 2% and 4% of the electrode material. In use for many decades, this technology has reached its peak and will struggle to deliver meaningful improvements required by the rapidly developing battery manufacturing industry to improve overall yield and achieve levels of reliability and performance demanded by the consumer.

The new technology of in-line mass profilometry provides effective, real-time quality assurance allowing for improvement in the areas of:

- Detecting increasingly small non-uniformities and dimensional errors
- Allowing battery manufacturers to reliably balance anode and cathode mass loadings
- Identifying problems more quickly to reduce scrap and minimize downtime
- Providing complete data for traceability and failure analysis
- Enabling responsive, advanced process control.

With volumes of loading data available, pilot plants and gigafactories can now achieve their production targets while assuring optimum cell quality and safety.

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