Exploring Porosity in Battery Electrodes: Terahertz Technology Unveiling Remote Sensing

Faezeh Zarrinkhat
TeraView Ltd
Cambridge, UK
faeze.zarinkhat@teraview.com

Arturo I Hernandez-Serrano
TeraView Ltd
Cambridge, UK
a.serrano@teraview.com

Alasdair Pentland
TeraView Ltd
Cambridge, UK
alasdair.pentland@teraview.com

Philip F. Taday
TeraView Ltd
Cambridge, UK
phil.taday@teraview.com

Donald D. Arnone
TeraView Ltd
Cambridge, UK
don@teraview.com

Michael Pepper
TeraView Ltd
Cambridge, UK
Mike.Pepper@teraview.com

***Abstract*—Porosity significantly influences lithium-ion battery performance, impacting cell capacity, voltage, and specific power- critical to designers. Terahertz technology enables non-destructive, remote porosity assessment, addressing limitations in current measurement methods.**

Keywords—Porosity assessment, Battery electrodes, Terahertz Technology

I. Introduction

Lithium-ion batteries have become crucial components in the automotive industry, large-scale utility storage, and various advanced technologies due to their beneficial traits. They boast higher energy and power densities, along with remarkable cycle durability, rendering them highly desirable for diverse applications. Additionally, their reduced environmental impact and enhanced safety unquestionably demonstrate their superiority as alternatives to conventional fossil fuels.

Within this context, understanding the characteristics of battery electrodes—porosity, thickness, density, and conductivity—is of paramount importance. Ensuring the homogeneity of coating thickness prevents uneven responses across electrodes and reduces degradation rates. Coating density must strike a balance between energy density and the necessary power requirements for the intended application. Moreover, coating conductivity enhances capacity at high discharge rates, essential for rapid energy release. Coating porosity directly influences the efficiency, performance, and longevity of lithium-ion batteries. Traditional methods for measuring these quantities often involve destructive techniques, limiting their applicability, especially in understanding real-time performance or in-operando behaviour. Porosity assessment traditionally involves destructive methods like Mercury Intrusion, Gas Adsorption, and Liquid Extrusion. X-Ray scanning, while effective, raises safety concerns due to its use of radiation. Additionally, electrochemical impedance spectroscopy offers indirect porosity measurement, but its complexity may limit its application.

Terahertz technology is the sole technique enabling the direct, simultaneous in-line measurement of coating density, thickness, and conductivity [1-4]. For instance, while laser triangulation [5] can estimate thickness, its implementation with opaque coatings is challenging and frequently requires calibration. Other sensors exist for measuring coating weight, but techniques such as X-Ray, beta, and gamma radiation raise safety concerns and, in the case of beta sensors, necessitate long integration times for accurate signals. Ultrasound can gauge the weight of coated material but relies on stable and precise calibrations.

In this paper, we present the recent advancement in analysis that enables the terahertz assessment of battery porosity. This remote sensing technique provides a unique opportunity to delve into electrode structures without altering them, offering detailed insights into their internal architecture. Terahertz technology stands at the forefront of revolutionizing our understanding of battery porosity, paving the way for advancements in battery design and performance optimization without compromising electrode integrity..

II. Result and Discussion

It's been previously shown that terahertz technology can be applied to measure the porosity of tablets in pharmaceutical industry [6]. Terahertz time-domain spectroscopy was employed to assess porosity of tablets through the application of effective medium approximations, specifically utilizing Bruggeman models [7]. That indicates the porosity of a material is related to the density of the material.

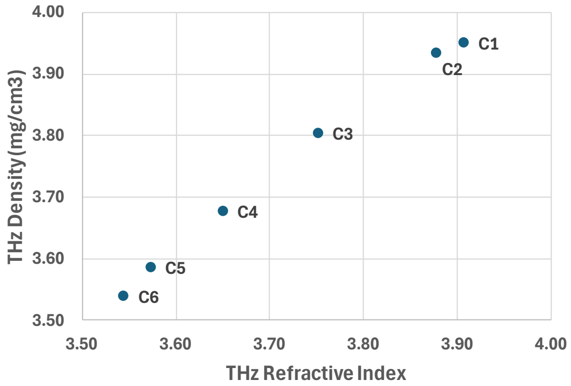

Figure 1: Illustrating the relationship between refractive index and coating density across five battery electrodes, providing insights into coating porosity interpretation. The thicknesses of electrodes C1 to C6 range from 150 to 180 μm.

Similar findings have been demonstrated previously concerning tablet density, where the real part of the material's index of refraction in terahertz is proportionate to its bulk density [8]. This relationship allows direct density measurement with calibrated terahertz technology. So, interpreting the refractive index measurement can provide insights into density and consequently to porosity. Density and porosity are inversely correlated, meaning higher density implies a lower level of porosity.

Five calendared electrodes, featuring varying density levels (with thicknesses ranging from 150-180 µm, C1-C6), underwent assessment using the TeraView terahertz sensor, revealing the correlation between the measured terahertz signal and density in Figure 1. As expected, the application of stronger calendaring to lower thicknesses (C1) resulted in higher density. The graph demonstrates that an increase in refractive index aligns with higher density. At TeraView lab, an empirical factor was derived to assist establishing a relationship between terahertz refractive index and porosity, based on the coating properties such as density. Figure 2 shows an example of correlation between the THz porosity and THz refractive index. As expected, C1 electrode with

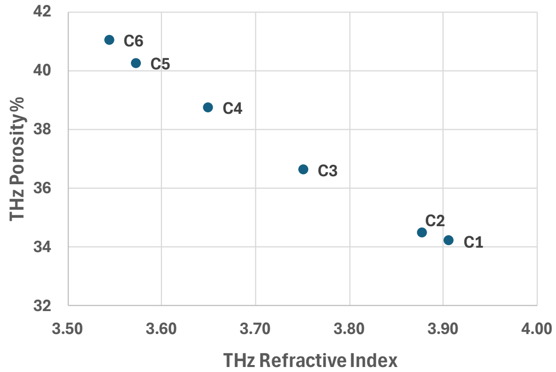

Figure 2: Illustrating the relationship between refractive index and coating porosity across five battery electrodes. The thicknesses of electrodes C1 to C6 range from 150 to 180 µm.

highest density, owns lowest level of porosity. Our ongoing research aims to investigate the adaptability of this factor across diverse materials and a broader spectrum of coating porosity levels, paving the way for future advancements.

III. Conclusion

In summary, our study identified a relationship between the real refractive index and coating porosity, utilizing an empirical factor. It demonstrates that an increase in porosity corresponds to a decrease in refractive index, indicating an decrease in density. This finding highlights that terahertz sensors can remotely measure porosity alongside conductivity, coating density, and thickness, showcasing the expanding versatility of terahertz technology in non-invasive characterization of battery electrodes.

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