Anisotropy - Thermal Conductivity Tests of Batteries

Modern batteries (Li-ion) have drastically different thermal -conductivity in different directions. Using a Hot Disk instrument makes it easy and accurate to -measure these properties, in one single transient.

Since the first discovery of the Lithium-ion (Li-ion) battery in the early 1970s, hardly anyone could have imagined that such a rechargeable battery would undergo a tremendous evolution over the following decades. Today Lithium-ion batteries are employed throughout human society, and power everything from portable electronics such as laptops and mobile phones to heavy electric vehicles. The 2019 Nobel Prize in Chemistry was accordingly awarded to three scientists, John B. Goodenough, M. Stanley Whittingham, and Akira Yoshino, for their work in developing the influential and very useful Li-ion battery (1).

Li-ion batteries are under the spotlight because they have higher specific energy densities and longer life cycles (charge and discharge) than conventional battery models, not merely because they come in such diverse forms and shapes adapted for various applications, as shown in Figure 1. However, an important factor to consider regarding Li-ion batteries is that they self-produce heat when operating, and a high operational temperature (in excess of 55 °C) can accelerate battery aging and shorten its lifespan. It is therefore imperative to seek an effective thermal management system (TMS) to guarantee that the battery can operate in the desired temperature range and also to maintain as little temperature difference from cell to cell as possible.

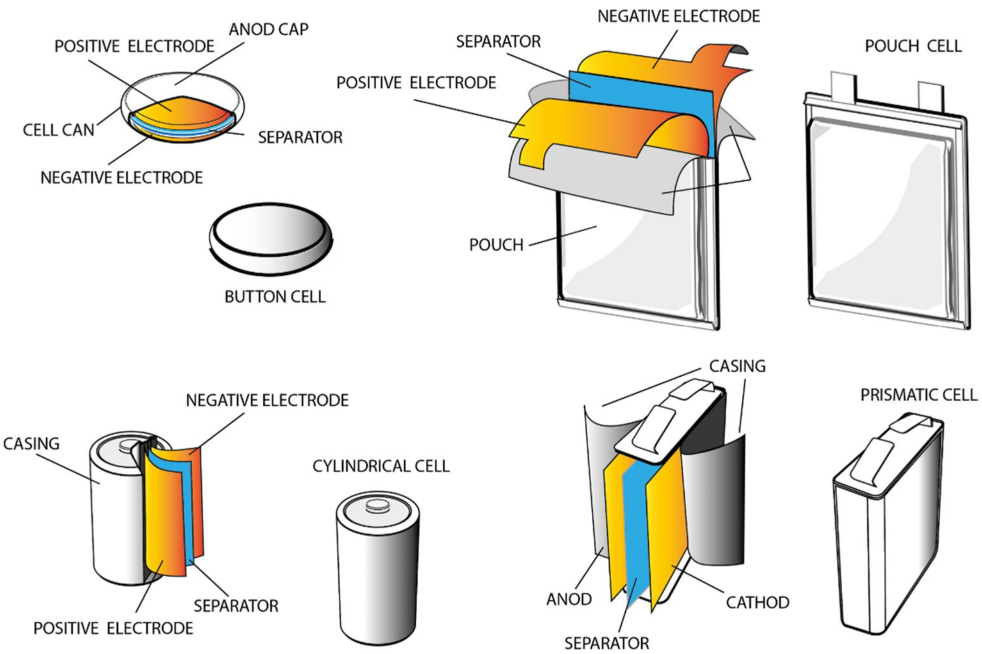

Figure 1. Examples of 4 different shapes of Li-ion batteries

To engineer a suitable TMS, acknowledgment of the directional dependent thermal conductivity and thermal diffusivity of the battery cell due to its internal stack structure is of great importance. Hot Disk instruments provide a unique approach using the anisotropic module to swiftly and accurately measure these properties, which other techniques are unable to quantify with a single transient.

Since 1998, Hot Disk AB has delivered a large number of TPS units for the application of testing Li-ion batteries. In the early years of 1998 – 2005, most of the samples consisted of dry layers (electrodes and membranes) which were then stacked into a setup that resembled the final structure in the Li- ion battery, as sketched in Figure 2. From a stack setup that often displays an in-plane shape, our instruments and sensors could obtain both the in-plane (in parallel with the stack layers) and through-plane (across the stack layers) thermal conductivity results. On occasion, we were also able to test a rolled stack structure for customers who produced cylindrical battery cells, where the high- conducting component was in the battery axial direction, while the low-conducting component was in the battery radial-direction. Typically the stack structure provided results approx. 10 – 50 W/m K in- plane, and through-plane of approx. 0.3 – 0.5 W/m K.

For more recent tests conducted since 2006, most of our cases have been in relevance to the final-assembles of Li-ion batteries arranged in pouch cells. With this assembly, we have regularly observed much higher thermal conductivity in both in-plane and through-plane directions. During demonstration tests at customers' facilities, we recorded values of up to 160 W/m K in-plane, and up to 8 W/m K through-plane. Current trends clearly show that manufacturers have worked substantially on improving the thermal conductivity of the structure of Li-ion batteries. A number of research projects have been conducted recently where scientists have used the Hot Disk technique to analyze the thermal properties of these enhanced batteries (2, 3, 4).

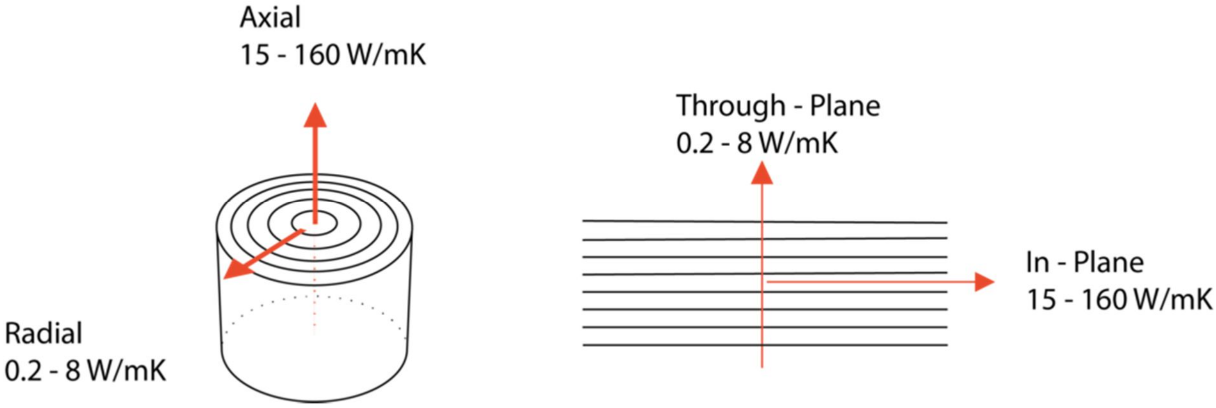

Figure 2. Anisotropic structures inside the battery cells.

In Table 1, we have listed a few examples of the measurements on pouch cells that are today produced by different manufacturers in China for use in electric vehicles. The measurements were performed by our colleagues KAITS who have established a routine to test the anisotropic thermal properties of the pouch cell. We hope one may receive a general picture of the thermal properties as well as the related measurements of modern Li-ion batteries from the table below. Nevertheless, it is noted that for the through-plane, mechanical pressure, surface roughness, and/or other chemical solutions, will strongly influence the thermal contact resistance between the layers. This will in turn directly influence the effective thermal conductivity in the through-plane direction.

Table 1. Results of the thermal transport properties of different pouch cells measured by the Hot Disk anisotropic module, using Hot Disk sensor 4922, heating power 1 W, measurement time 10 – 20 s.

Dimension [l x w x h, mm^3]	ρCp [MJ/m^{3}K]	Through-plane λ [W/mK]	Through-plane κ [mm^2/s]	In-plane λ [W/mK]	In-plane κ [mm^2/s]
212 x 113 x 9	2.36	1.0279	0.4356	16.394	6.9468
69 x 47 x 4.65	2.71	1.4794	0.5465	17.844	6.5918
325 x 100 x 12	2.55	1.5142	0.5938	17.826	6.9905
273 x 97 x 11	2.61	1.0186	0.3903	21.710	8.3189
144 x 80 x 12	2.51	0.8857	0.3529	18.889	7.5253
120 x 105 x 11	2.54	1.4467	0.5696	20.060	7.8976
120 x 105 x 9.4	2.68	1.3121	0.4896	18.386	6.8313
270 x 97 9.4	2.44	1.5852	0.6497	16.837	6.9003
313 x 101 x 7.3	2.41	0.6615	0.2745	40.685	16.882

At times customers had a special interest in the measurements of pouch cells at different temperature intervals. Figure 3 and 4 reveal the relationship of the thermal transport properties of the particular pouch cell as a function of the elevated temperatures from RT to 80°C measured by the Hot Disk anisotropic module.

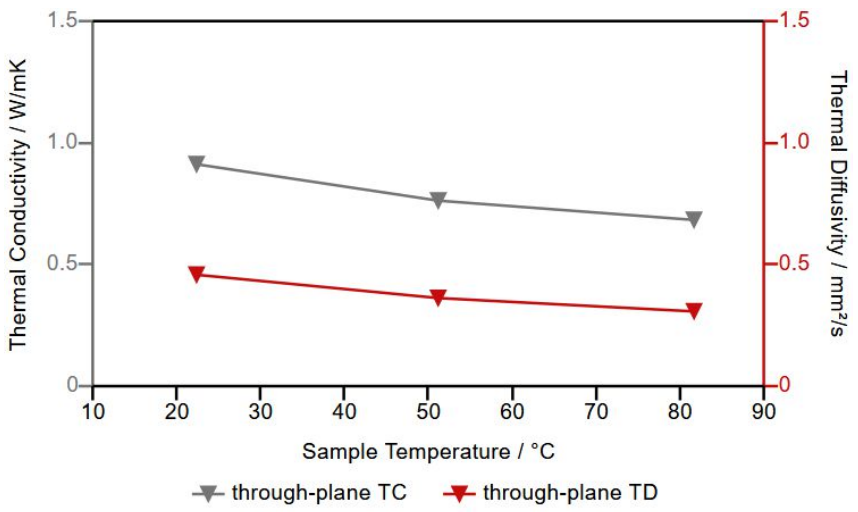

Figure 3. Through-plane thermal conductivity (left y-axis, in grey) and thermal diffusivity (right y-axis, in red) of the particular pouch cell under test as a function of the sample temperature.

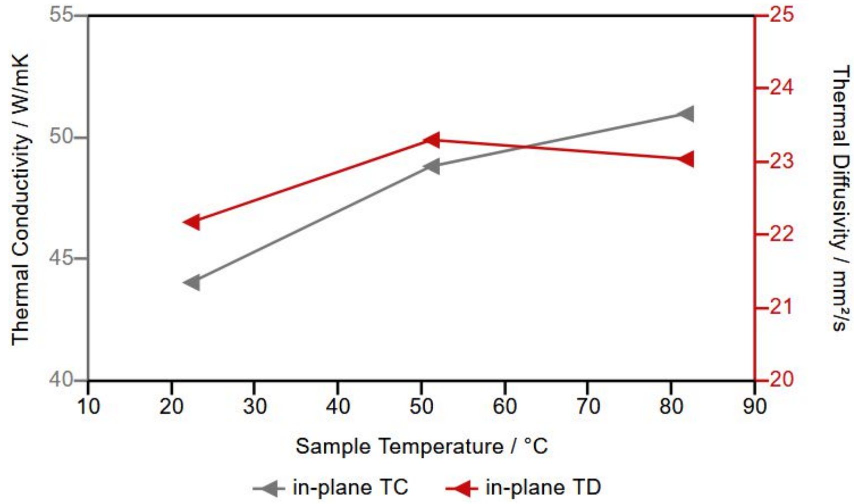

Figure 4. In-plane thermal conductivity (left y-axis, in grey) and thermal diffusivity (right y-axis, in red) of the particular pouch cell under test as a function of the sample temperature.

All in all, Hot Disk instruments with anisotropic module provide an excellent tool for R&D of modern batteries – and especially pouch cells – at present, provided that the volumetric heat capacity of the battery under test is known or can be determined elsewhere. As a part of our commitment to our customers, Hot Disk AB is constantly making extensive efforts to develop a large Cp setup to measure the heat capacity of batteries with different dimensions, and also to devise a suitable approach to measure the prismatic batteries which have a metal casing. Stay tuned!

For more information on our instruments and contract testing, please contact: info@hotdisk.se or info@c3-analysentechnik.de.

References:

(1) https://www.nobelprize.org/prizes/chemistry/2019/summary/

(2) B. Koo, P. Goli, A. Sumant, P. Ceilia, T. Rajh, C. S. Johnson, A. A. Balandin, E. V. Shevchenko, Toward Lithium Ion Batteries with Enhanced Thermal Conductivity. American Chemistry Society (ACS) Nano. 8(7): 7202–7207.

(3) P. Goli, S. Legedza, A. Dhar, R. Salgado, J. Renteria, A. A. Balandin, Graphene-enhanced hybrid phase change materials for thermal management of Li-ion batteries. Journal of Power Sources 248 (2014) 37-43.

(4) Y. Xie, J. Tang, S. Shi, Y. Xing, H. Wu, Z. Hu, D. Wen, Experimental and numerical investigation on integrated thermal management for lithium-ion battery pack with composite phase change materials, Energy Conversion and Management 154 (2017) 562-575.