CHADA

Characterisation Data and description of a characterisation experiment

For [*Electrochemical Impedance Spectroscopy for low impedance battery full cells*]

Used in [*NanoBat (H2020)*]

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Overview of EIS Characterisation

1	**Sample**	Half-cell, full-cell, commercial batteries, modules and packs. Samples are tested in specifically prepared fixtures. EIS on Battery modules and packs need to be done in a safe environment using safety chambers.
2	**Method**	Electrochemical impedance spectroscopy (EIS) method consists of applying an alternating current signal (galvanostatic mode) or voltage signal (potentiostatic mode) to the battery under test (BUT) and records the system response, which is the voltage drop across the BUT terminals or the resulting current through the BUT, respectively. The frequency of the excitation signal is swept within a defined frequency window. The response of the BUT is a complex function that results in the characteristic amplitude and phase shift of the flowing current with respect to the voltage signal. The frequency dependence of the BUT is used to separate the different electrochemical and physical contributions from the total response, such as observing different electrochemical reactions happening, physical phenomena (e.g. diffusion, electrode kinetics), or the capacitive and inductive properties of the system.
3	**Data publication**	Working title of planned publication: “Calibrated battery impedance at micro-Ohm”. Target Journal: IEEE MTT IEEE Trans. on Microwave Theory and Techniques.
4	**Access conditions**	The data will be made available under license type **CC BY**.
5	**Workflow of the characterisation**	Electrochemical impedance spectroscopy method for characterization of batteries and consists of: Installing the battery under test in a fixture that is prepared for different battery form factors, using 4-wire kelvin connection, then a sinusoidal current is fed into the battery terminals while sensing the voltage across the terminals to measure the battery impedance over a frequency range. The current i(t) and voltage v(t) across the terminals are digitized and transformed into the frequency domain, where the actual impedance Z(ω)=V(ω)/I(ω) is computed. In this process frequency sweeping is used for the excitation signal to cover the whole spectrum e.g. mHz to kHz+. The resulting data is stored, analysed and visualized by complex impedance plots.

EIS Workflow Picture

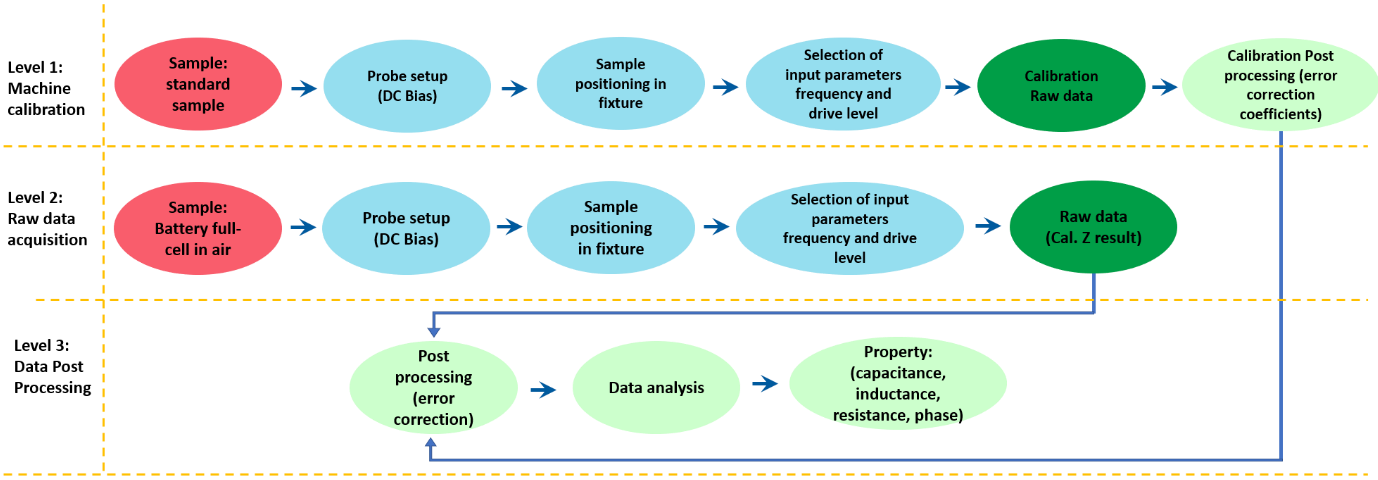

Figure 1 CHADA workflow for EIS

1. Sample		
1.1	**USER**	Human operator. Typically, EIS characterization measurements are done by electrical engineers, electro-chemists, or practical physicist. The level of automation is partial.
1.2	**User case (sample specifications)**	Samples under test consist of battery full-cells: types 18650 (18mm by 65mm), 21700 (21mm by 70mm); pouch cells (with dimensions from a few cm^2 to about 30 cm^2). Sample attachment to sample holder (a fixture) is done typically with spring connectors, or different types of alligator or insulated ring connectors.
1.3	**Specimen**	Battery heterogeneous material containing solid electrodes and liquid electrolyte.
1.4	**Testing environment**	Temperature-controlled chamber or specific battery safety chambers are used, characterization is done in air.
1.5	**Material**	Commercial battery cells (e.g. Samsung, Panasonic, LG, Sony), or pouch cells from pilot lines. Battery chemistries are typically (Lithium manganese nickel, Lithium nickel cobalt aluminium oxide, Lithium manganese oxide), battery have a metallic outer case that contains the electrodes (cathode, anode), the separator and the electrolyte materials.

2. Method		
2.1	**Sample/probe physics of interaction**	Sample is attached to the probe via 4-wire Kelvin connection directly contacting the battery terminals. A stimulus signal current/voltage is applied to the battery and the response to this stimulus is detected. The physics of interaction is based on Ohm's law $V(\omega) = I(\omega)\ Z(\omega)$.
2.2	**Volume of interaction**	Full volume of sample.
2.3	**Equipment setup**	Both the instrument Source Measure Unit (SMU) force and sense terminals are connected through coaxial wiring to the battery test fixture to remove any voltage drop effects. The coaxial wiring is separated in the test fixture.
2.4	**Calibration**	Standards short" and various "shunt" standards are used for calibration. The shunt standard contains a precisely characterized resistor prepared in a fixture design similar to the BUT.
2.5	**Probe**	Arbitrary wave generator in the SMU is used to drive the output amplifier which is used in constant current (CC) mode.
2.6	**Detector**	After DC component of the battery voltage is removed the remaining AC component is sensed by SMU and digitized coherently with the current signal.
2.7	**Signal**	Sinusoidal current signal
2.8	**Time lapse**	Depending on the resolution, number of points and frequency range the acquisition time can vary. Low frequency points require more time (e.g. at 1 mHz about 17min are needed to get the data at that point).
2.9	**Testing Input parameters**	Frequency start and stop, frequency points, excitation current and drive level, integration time.
2.10	**Main acquired channels**	Two channels force and sense are used to transmit the current signal and sense the voltage across the DUT terminals.

3. Raw data		
3.1	**Raw Data**	Raw impedance as a function of frequency is computed, containing information on amplitude and phase, inductance, capacitance, resistance. This results from digitizing the current and voltage across the battery terminals and transforming them into the frequency domain where the actual impedance is computed.
3.2	**Data acquisition rate**	100k samples/sec – 100 samples/sec

4. Data processing		
4.1	**Main data filtering processes**	Down-sampling + FIR filtering is done depending on the EIS frequency and speed settings
4.2	**Main data analysis procedures**	Frequency sweep for input signal, pre-processing (filtering and windowing), applying Discrete Fourier Transform DFT for both current and voltage signals, then analytic calculation of impedance $Z(\omega)=V(\omega)/I(\omega)$, followed by error correction based on the extracted calibration coefficients.
4.3	**Main processed channels**	One channel is used to source the current through the DUT terminals while sensing the voltage between the terminals.
4.4	**Data processing through calibrations**	The systematic error correction is processed by defining an appropriate error model and measuring certain calibration standards in order to solve for the error coefficients.
4.5	**Properties (elaborated data)**	The complex calibrated impedance results are separated into magnitude and phase results or real and imaginary values, the latter representing resistance for the real part and the imaginary (reactive impedance) representing the inductance and capacitance extracted data.