Experimental study on half-cell impedance of lithium-ion battery considering various alternating current amplitudes

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Outline

I. Background

II. Experiment design

III. Results

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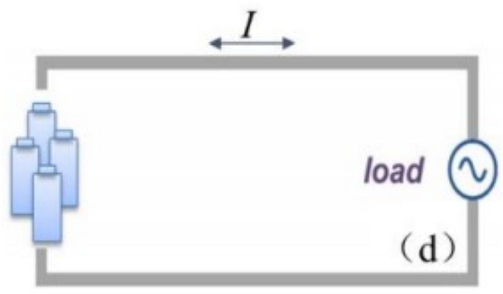
I. Background

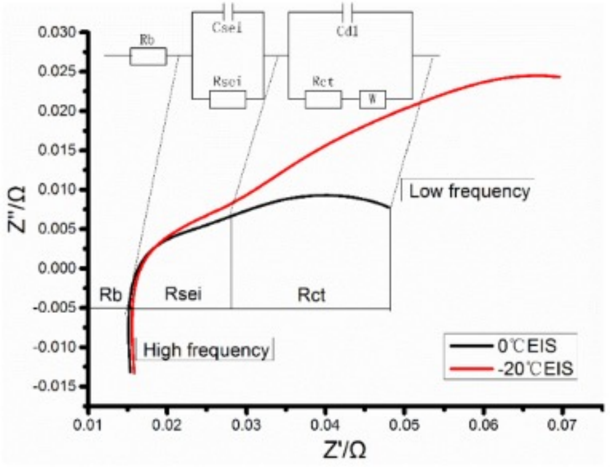


Alternating current (AC) heating

Find

Frequency

Amplitude



The amplitude is small!

In fact, although the influence of different impedance amplitudes on the impedance of the full cell has been studied, there has been little research on the positive and negative half cells.

SOC

Temperature

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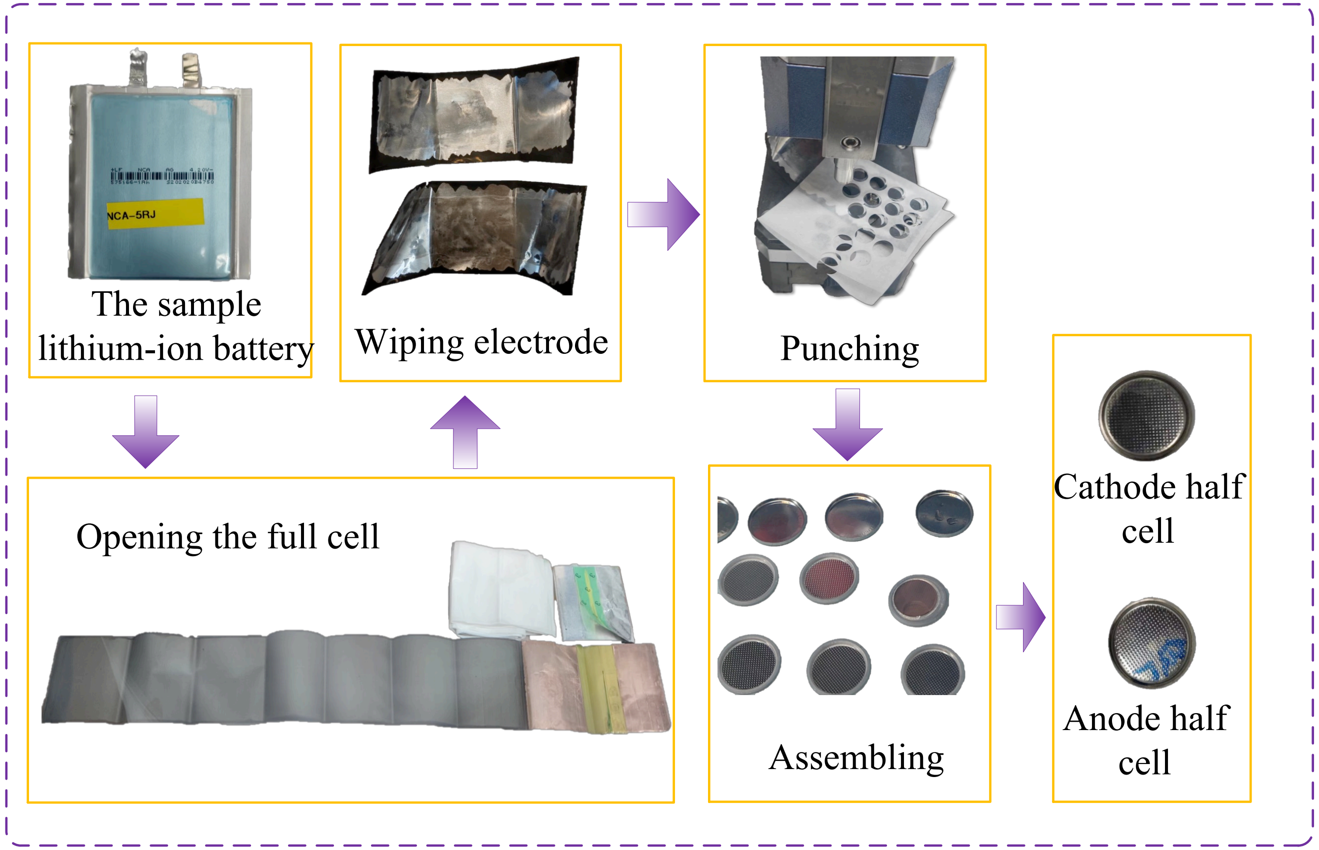
II. Experiment design

2.1 Making half-cells

Basic parameters
NCA/Graphite
1Ah
3V~4.2V



Basic parameters
CR2016
NCA/Li Graphite/Li
3.69mAh

II. Experiment design

2.2 The relation of OCV among the full cell and half-cells

$$OCV(SOC) = U_c\left(\left(x_{c,100\%} - x_{c,0\%}\right)SOC + x_{c,0\%}\right) - U_a\left(\left(x_{a,100\%} - x_{a,0\%}\right)SOC + x_{a,0\%}\right)$$

Cathode half-cell

Anode half-cell

70μA CC charge&discharge

2.8V~4.3V

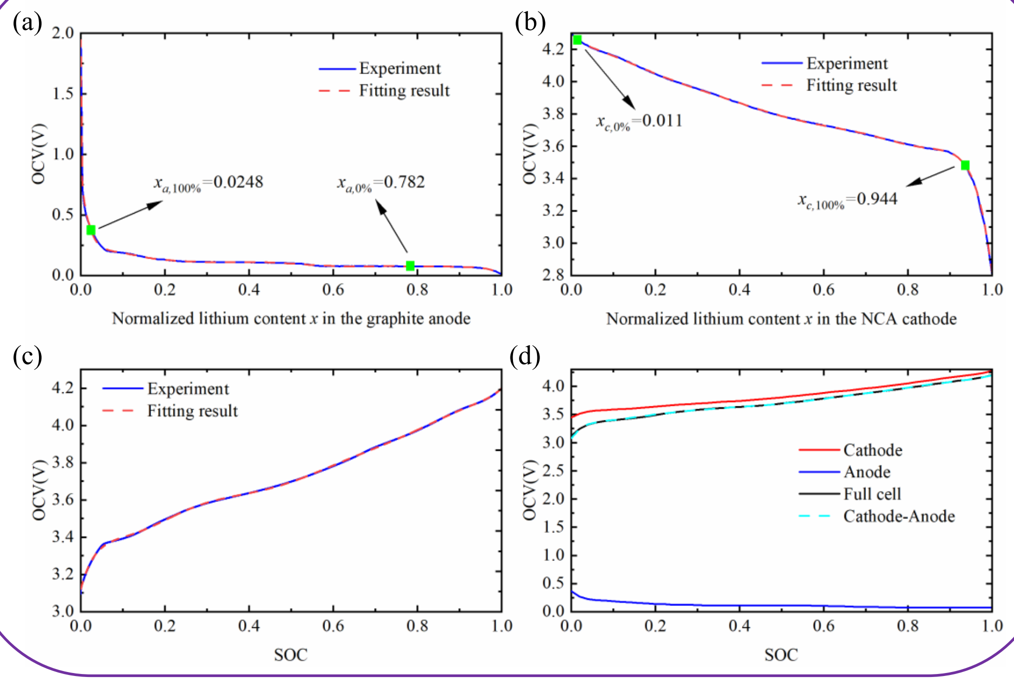
0.01V~2V

The full cell

50mA(0.05C) CC charge&discharge

3V~4.2V

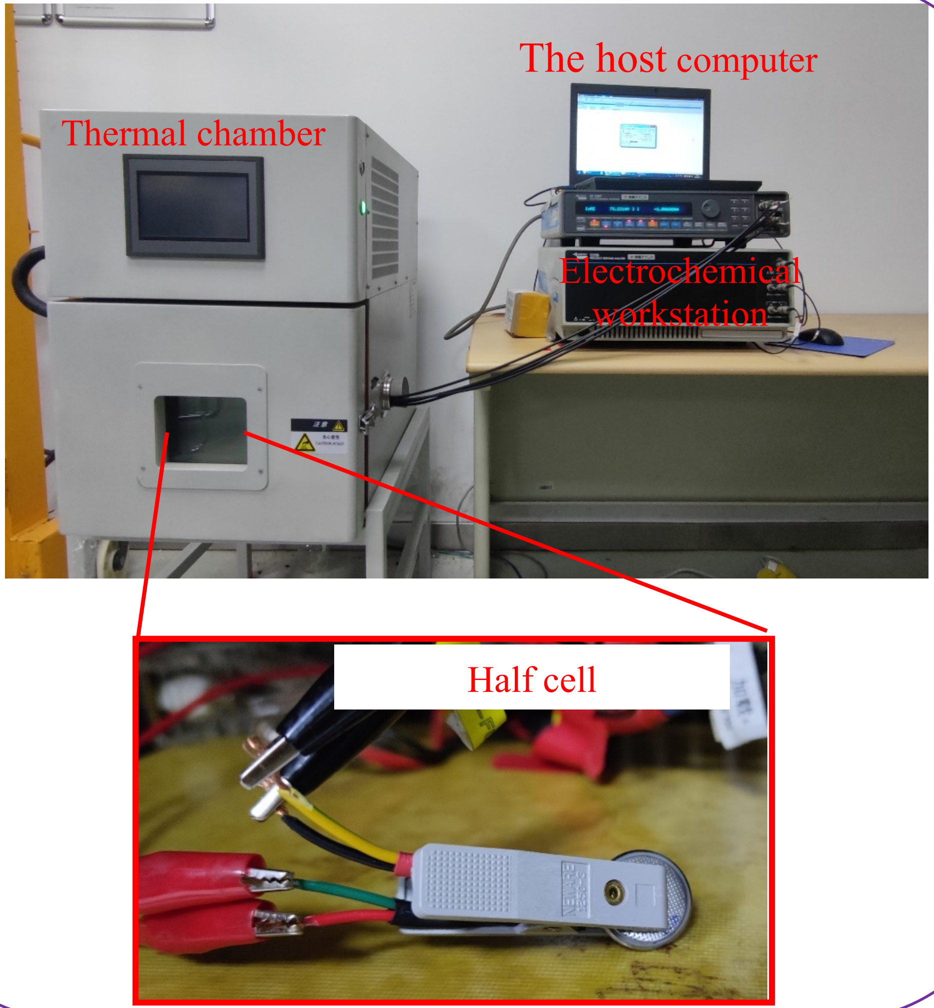
The genetic algorithm



Full cell SOC	0.2	0.5	0.8
Anode OCV	0.137V	0.109V	0.076V
Cathode OCV	3.638V	3.805V	4.054V

II. Experiment design

2.3 The anode impedance under different AC amplitudes



EIS condition:

The excitation frequency range is from 0.002Hz~1000kHz and the excitation current amplitudes are 0.01mA, 0.05mA, 0.1mA, 0.5mA, 1mA, 2 mA and 3 mA.

Different SOC:

The EIS tests with different current amplitudes are conducted on the half cells at the specified SOC, i.e., 20%, 50%, 80%.

Different temperature:

The experiences are carried out at -10℃ and the results at 25℃ are also investigated for comparison.

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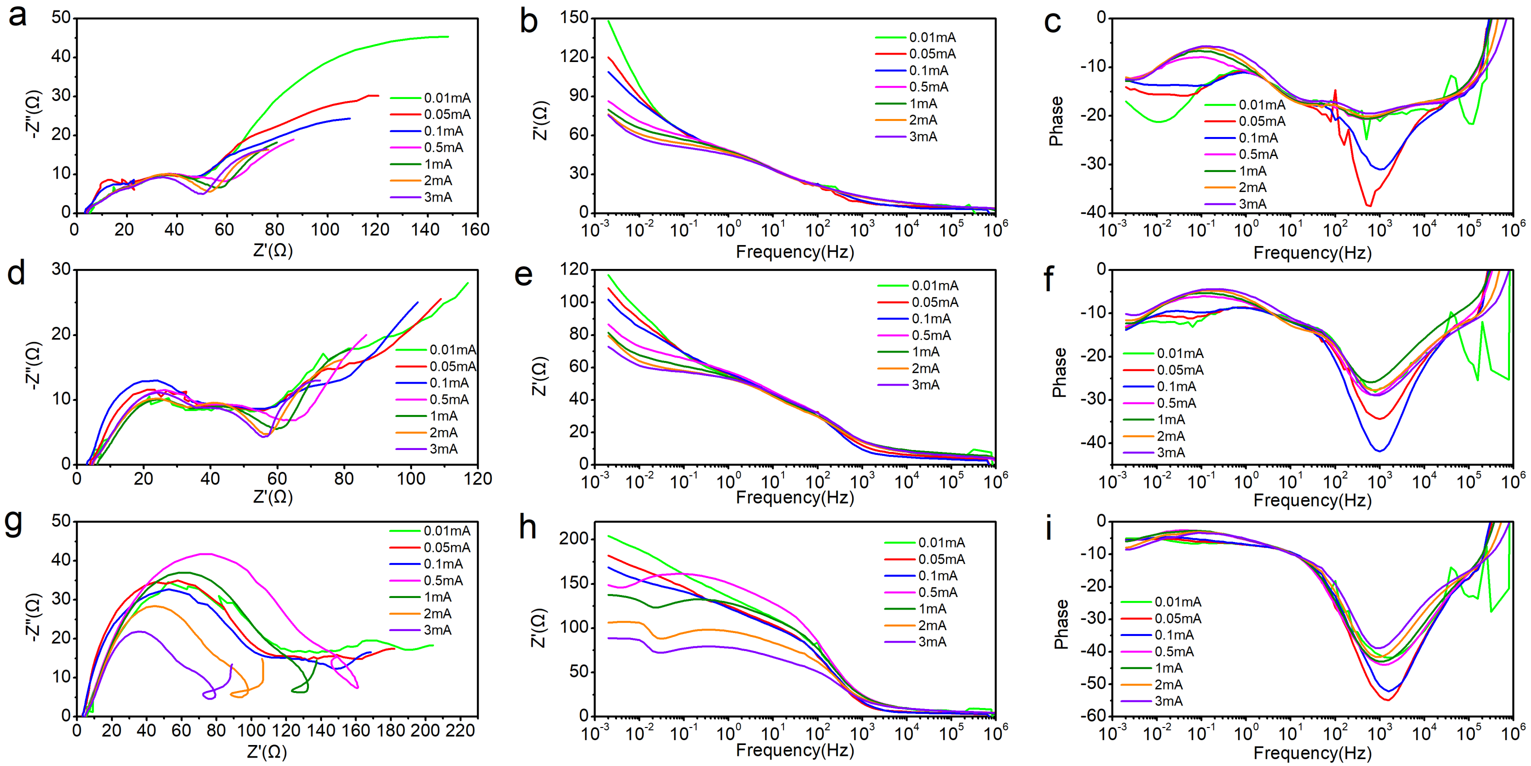
III. Results

2.1 The results at 25°C



EIS, the real parts and phases of anode half cell measured at 25 °C and different AC amplitudes: a,b,c: 0.137V; d,e,f :0.109V; g,h,i :0.076V.

The results can be divided into two categories: the current amplitudes of 0.01mA, 0.05mA and 0.1mA (I) and the current amplitudes of 0.5mA, 1mA, 2mA and 3mA (II).

For 0.137V and 0.109V(the low and medium SOC)

The real impedance : (I) >(II) at low frequency (<1Hz) and the real parts decrease with the increase of AC amplitude.

The phase: three parts.(>100Hz, <1Hz)

For 0.076V (the high SOC)

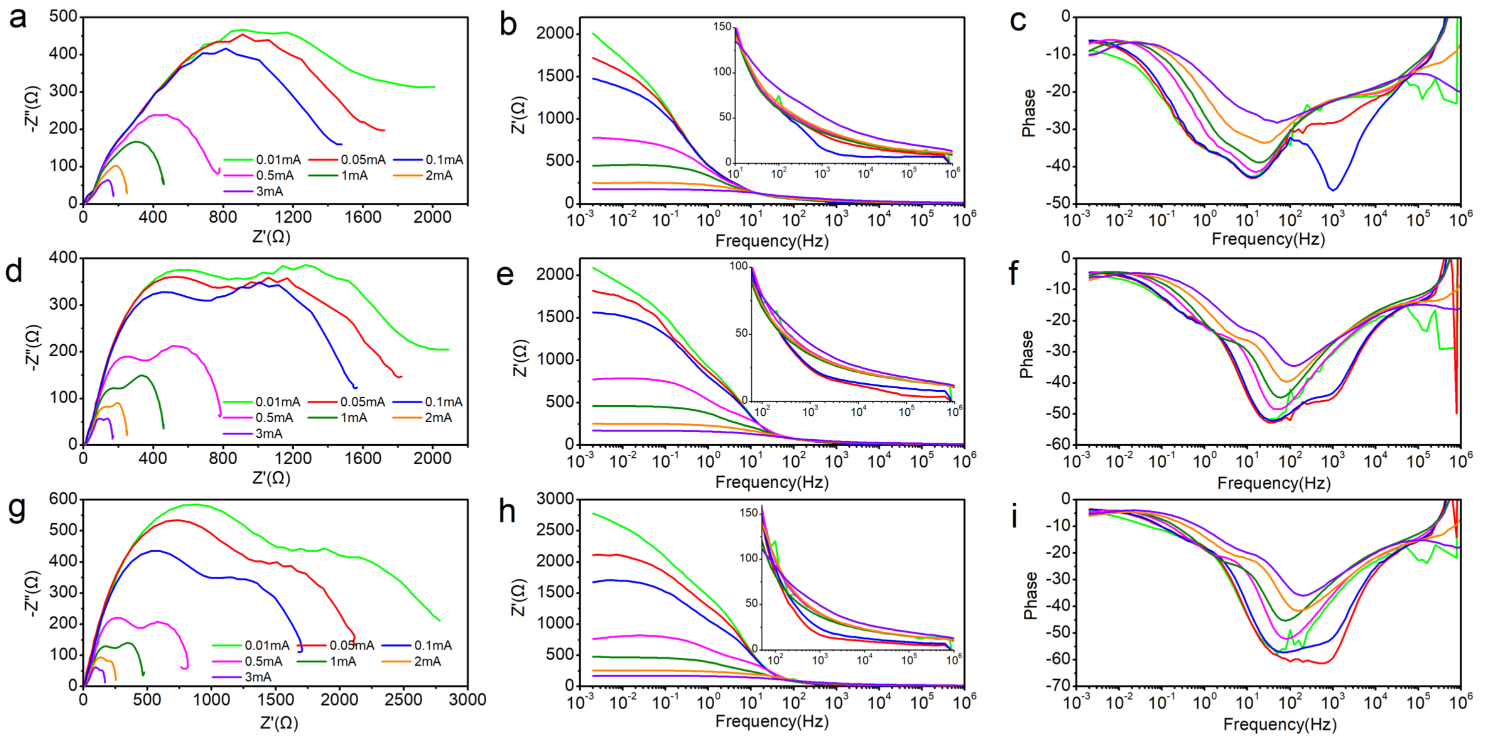
The real impedance: (I) and (II) have different laws.

The phase: The results are similar to 0.137V and 0.109V.

The arcs gradually shrink with the increase of AC amplitude.

III. Results

2.2 The results at -10°C



EIS, the real parts and phases of anode half cell measured at -10 °C and different AC amplitudes: a,b,c: 0.137V; d,e,f :0.109V; g,h,i :0.076V.

At low temperature, the impedance arcs shrink more severely with the increase of AC amplitude.

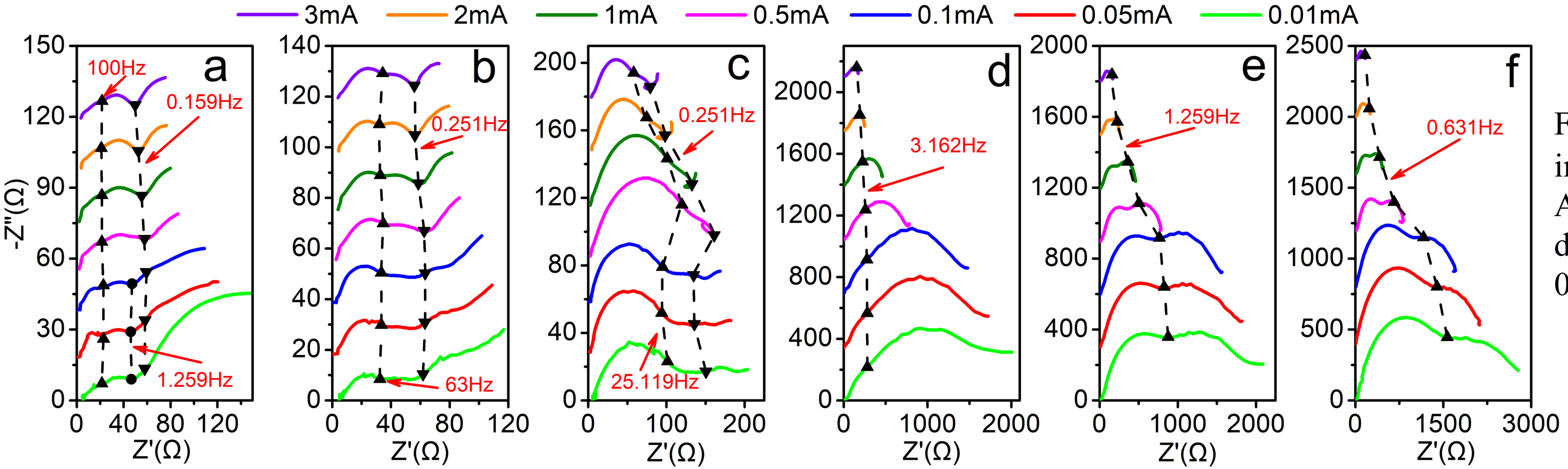
There is a frequency *x* between 10Hz and 100Hz.

The real impedance : (I) >(II) at low frequency (<*x* Hz) and (I) <(II) at high frequency (>*x* Hz).

The phase: Basically, it conforms to the principle that the larger the amplitude, the larger the phase.

III. Results

2.3 Frequency variation of impedance spectra



Frequency variation of impedance spectra at different AC amplitudes: a,b,c 25°C; d,e,f -10°C; a,d 0.137V; b,e 0.109V; c,f 0.076V.

At low temperature and high lithiation state, the impedance arcs of the medium and low frequency (<100Hz) shrink severely with the increase of AC amplitude.

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Summary of the results:

The main phenomenon of the above experimental results is that when the frequency is bigger than a certain frequency x ($1Hz<x<100Hz$), the impedance arc will shrink with the increase of the AC amplitude. The experimental results are in good agreement at low temperature. However, the phenomenon is obvious only when the AC amplitude is bigger than a certain value 0.5mV at room temperature.

Temperature

The temperature rise of the coin cell can be ignored because of the strong convection of the thermal chamber.

SOC

The SOC change is approximately $\pm$1.13% at the maximum AC amplitude (3mA) and 0.01Hz. It shows that the influence of SOC can be ignored.

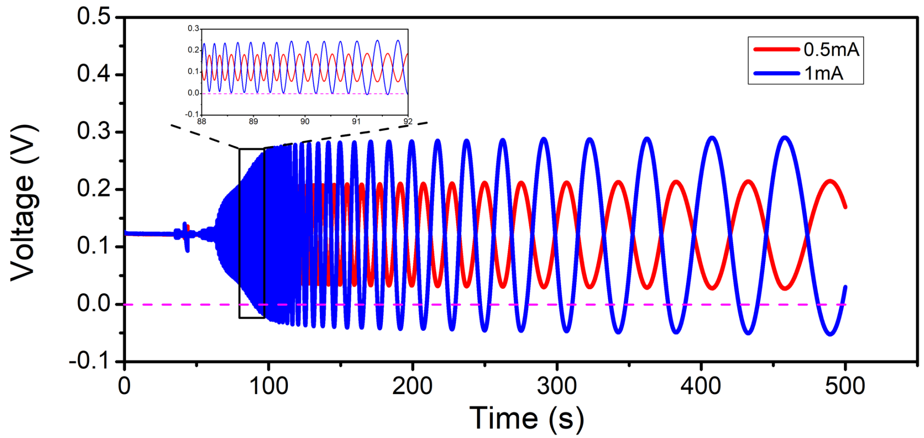
IV. Discussion

Charge-transfer process[1]

The high current rate can reduce the charge-transfer impedance, which lead to arc shrinkage.

Lithium planting[2]

The lithium planting also can reduce the impedance, which also lead to arc shrinkage.



It proves that lithium planting leads to the shrinkage of medium-frequency impedance arc.

[1] Zhu J., Sun Z., Wei X., et al., Studies on the medium-frequency impedance arc for Lithium-ion batteries considering various alternating current amplitudes. Journal of Applied Electrochemistry, 2015.46(2):157-167.

[2] Koleti U.R., Dinh T.Q., and Marco J., A new on-line method for lithium plating detection in lithium-ion batteries. Journal of Power Sources, 2020. 451.

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V. Conclusion

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- Firstly, the impedance arc will shrink with the increase of the AC amplitude at low temperature. However, the phenomenon is obvious only when the AC amplitude is bigger than a certain value 0.5mV at room temperature.

- Secondly, the intersection frequencies of different impedance arcs at low temperature vary with the AC amplitude. But they are nearly unchanged at room temperature.

- Lastly, the shrinkage of anode impedance arc is related to lithium plating, especially at low temperature.

Thanks!

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