Electrochemical Impedance Spectroscopy (EIS) of Lithium Ion Cells

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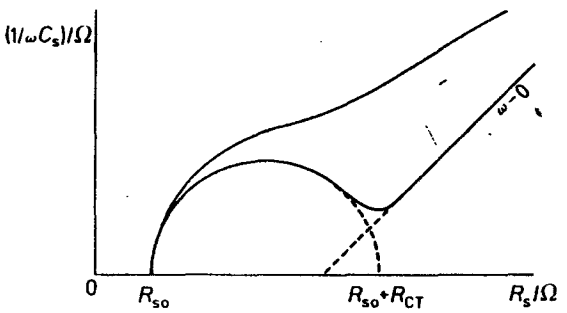
Electrochemical Impedance Spectroscopy (EIS)

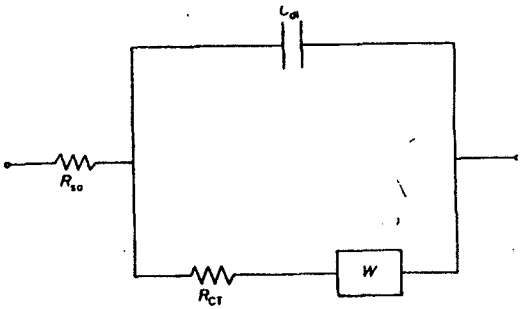
- Advantages
  - Non-destructive
    - Low Perturbations (Linear polarization regime)
    - Fast, reproducible and convenient
  - Ability to quantitatively segregate processes with different rate constants.
- Disadvantages
  - Difficult to interpret
  - Non-ideal behavior
    - Complicated by surface films and adsorbed species and porous electrodes

Electrochemical Impedance Spectroscopy (EIS)

Charge transfer Process with mass transfer effects

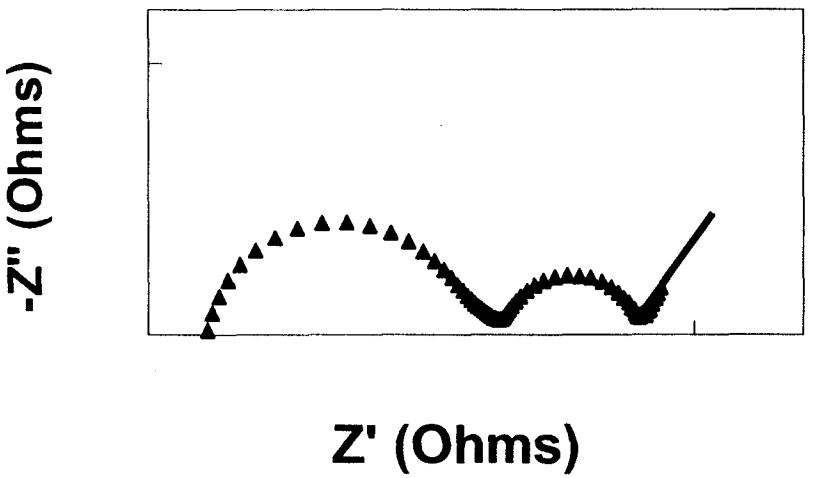


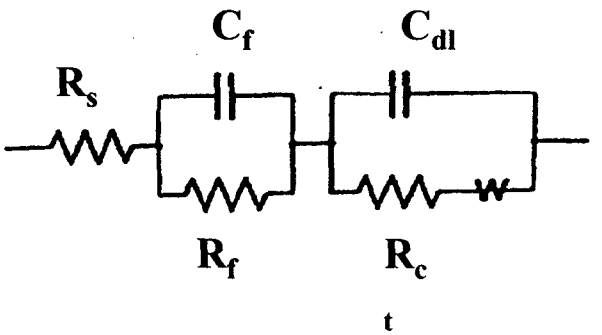
Nyquist Plot



Randles Circuit

Charge transfer Process (with mass transfer effects) on Film-covered electrodes





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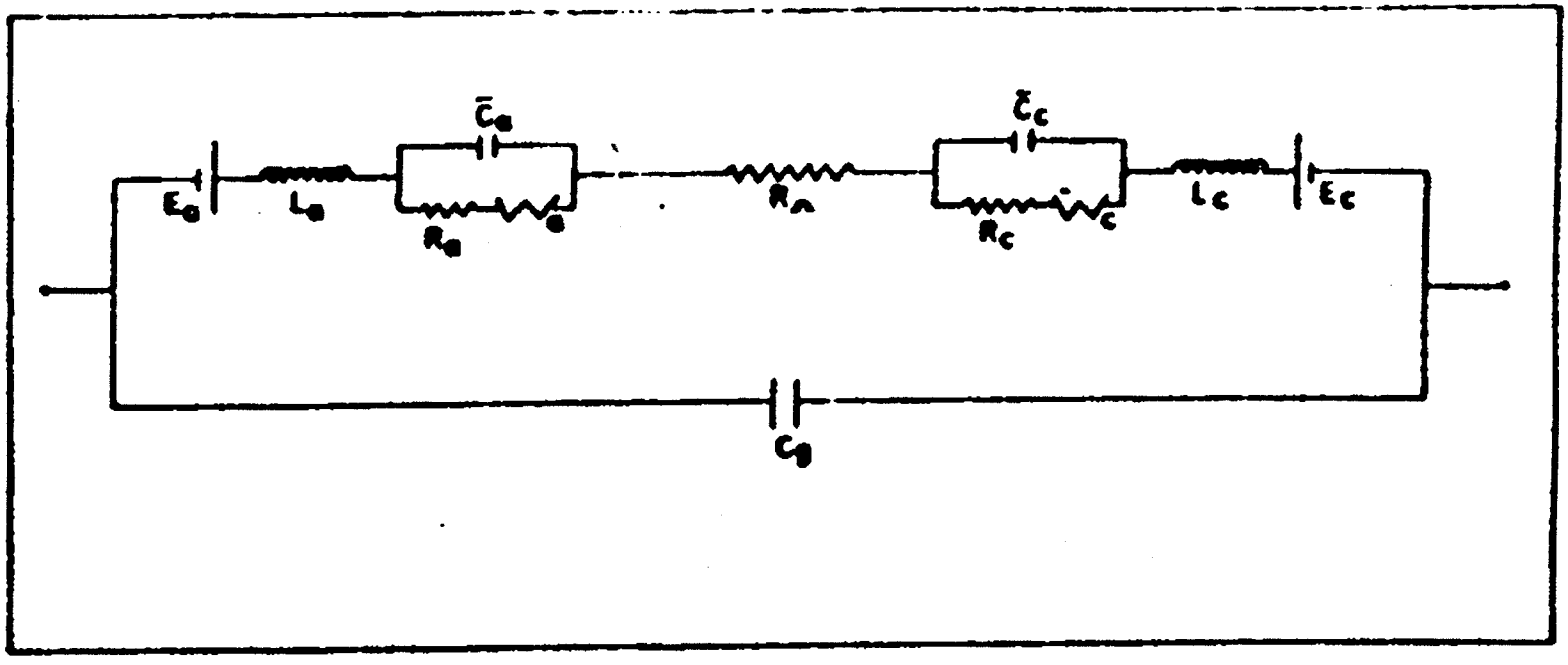
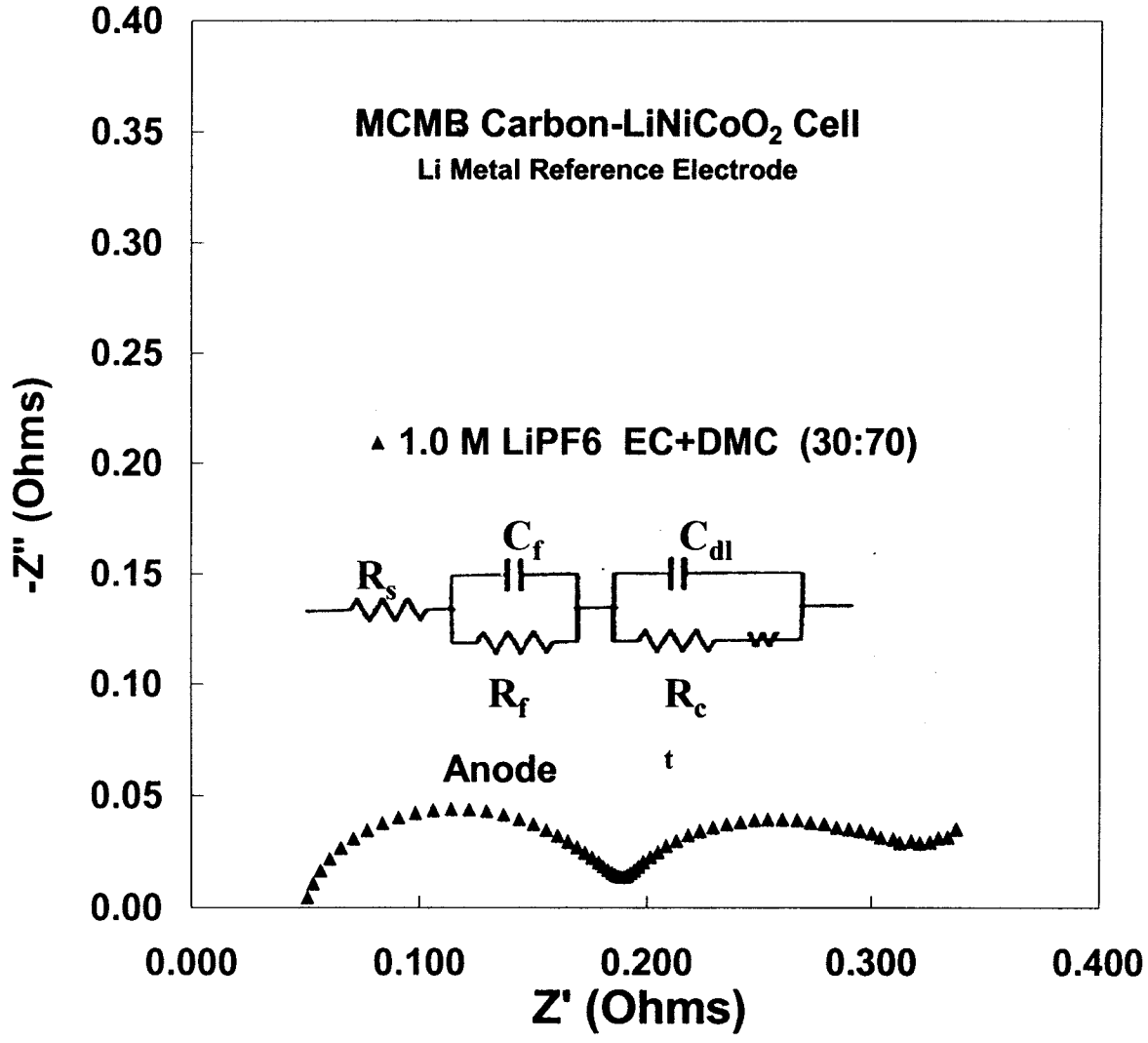


E_a, E_c = Single electrode potentials.
L_a, L_c = Lead inductances.
$\bar{C}_a$, $\bar{C}_c$ = Double layer capacitances.
R_a, R_c = Charge transfer resistances.
W_a, W_c = Diffusional (Warburg) impedance.
R_Ω = Resistance of solution and separator.
C_g = Interelectrode capacitance.

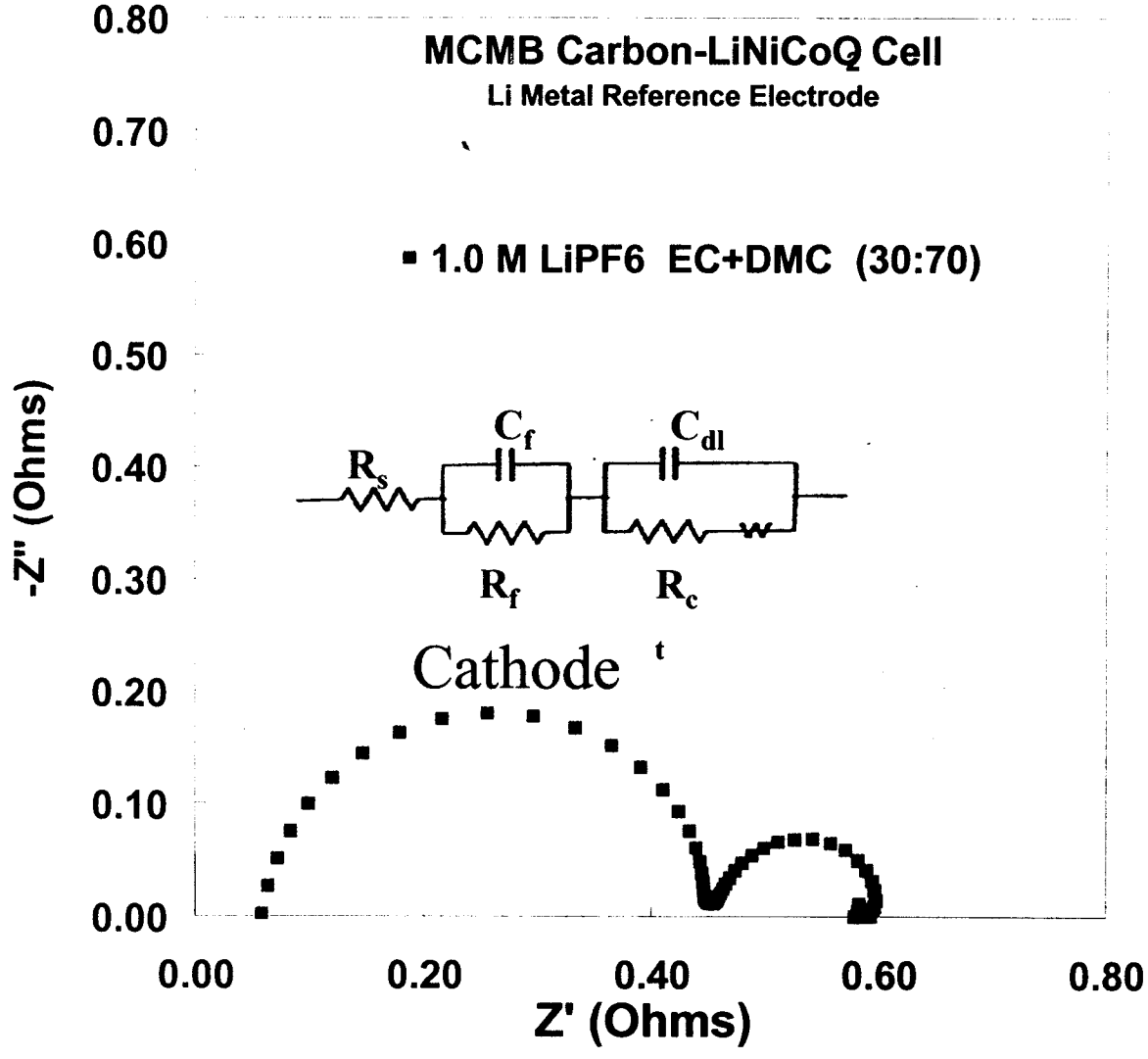
Generalized equivalent circuit of a battery or cell

(Subscripts and c denote anode and cathode, respectively)

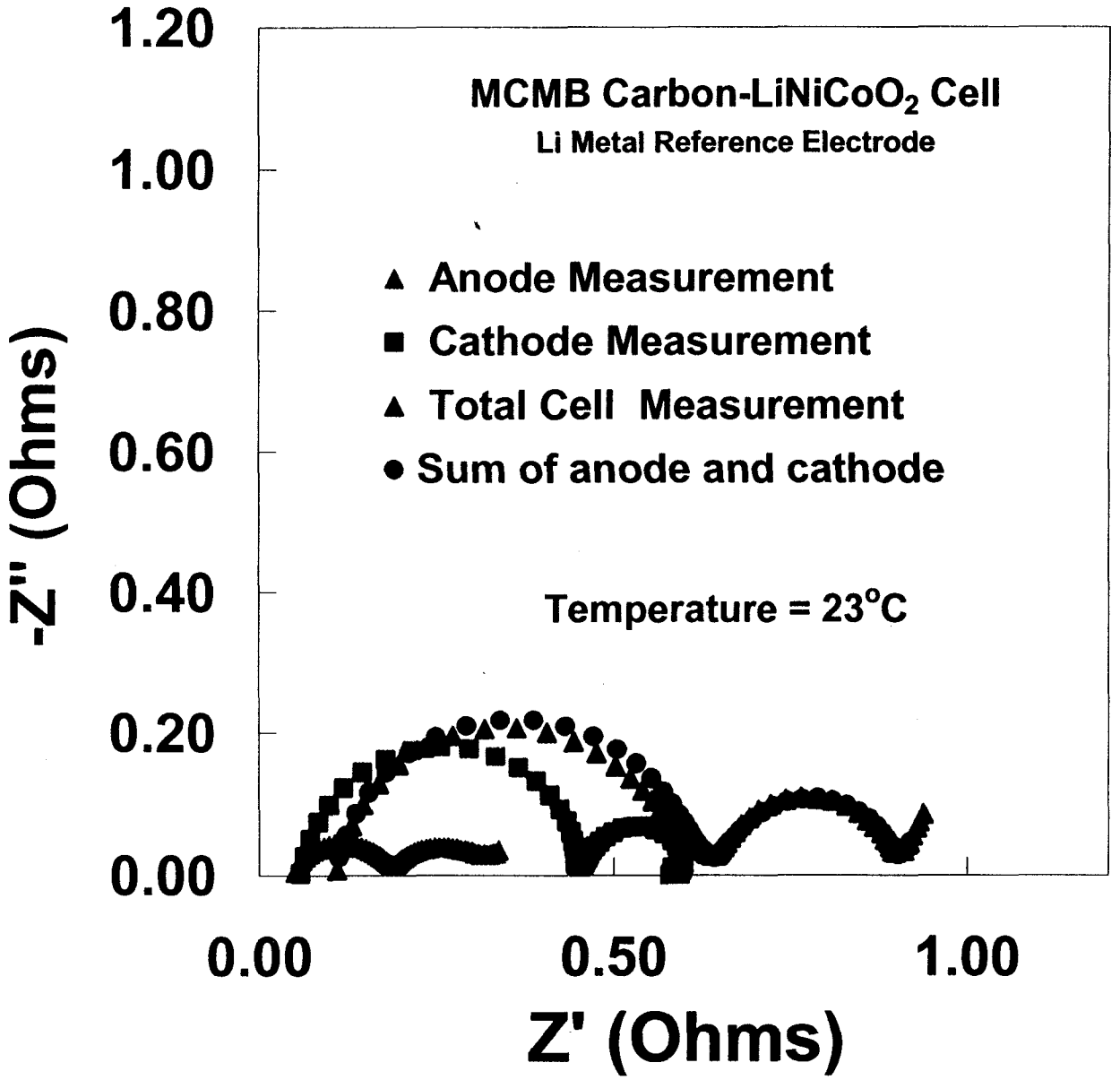
EIS of Carbon Anode in a Li Ion Cell



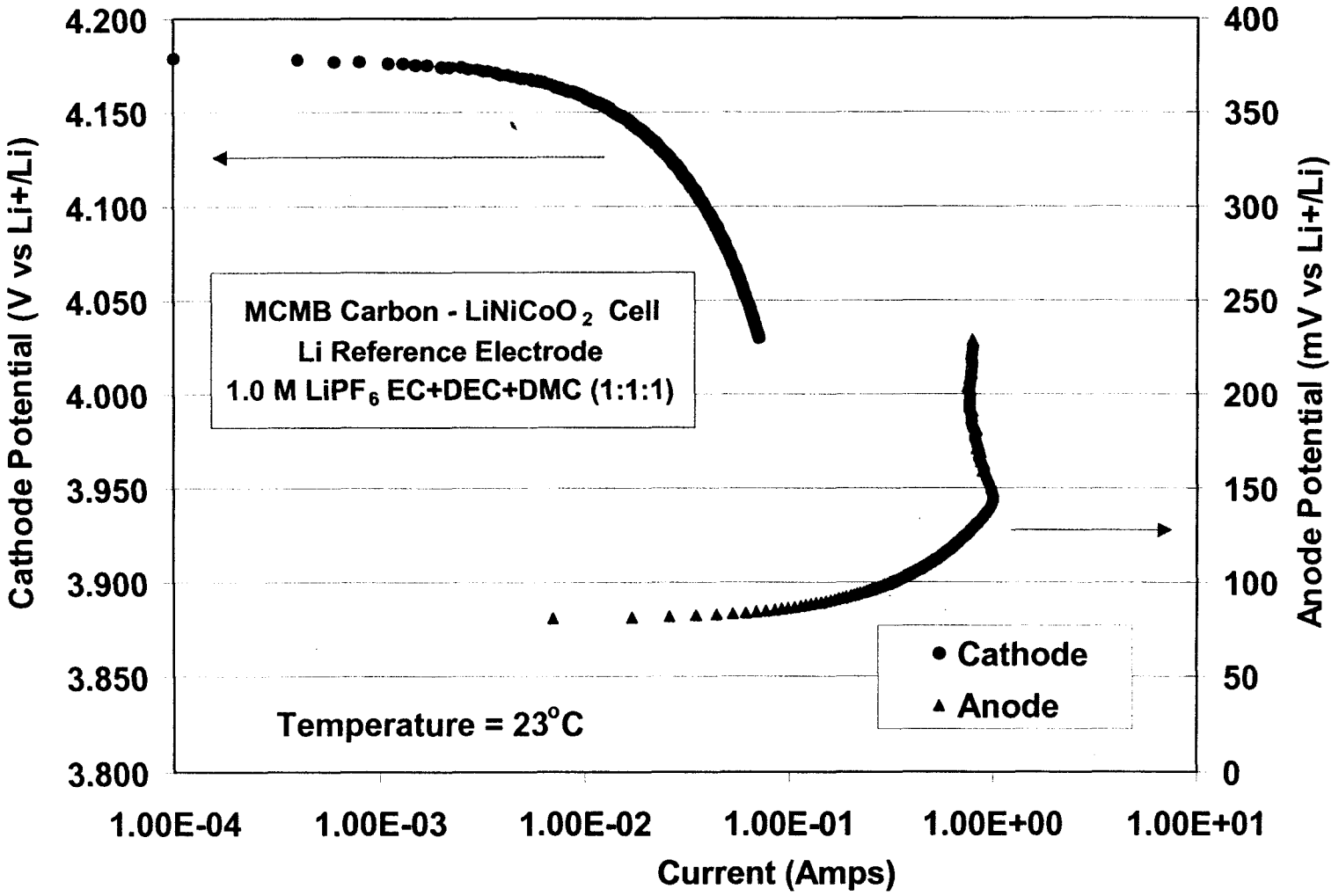
EIS of $LiNi_{1-x}Co_xO_2$ Cathode



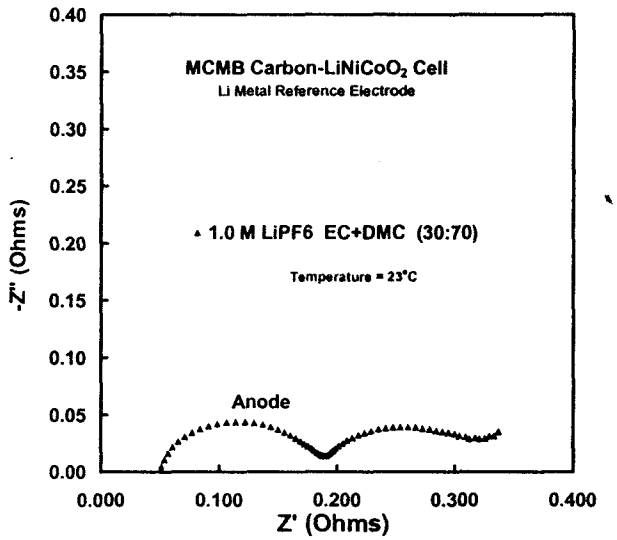
EIS of a Li Ion Cell

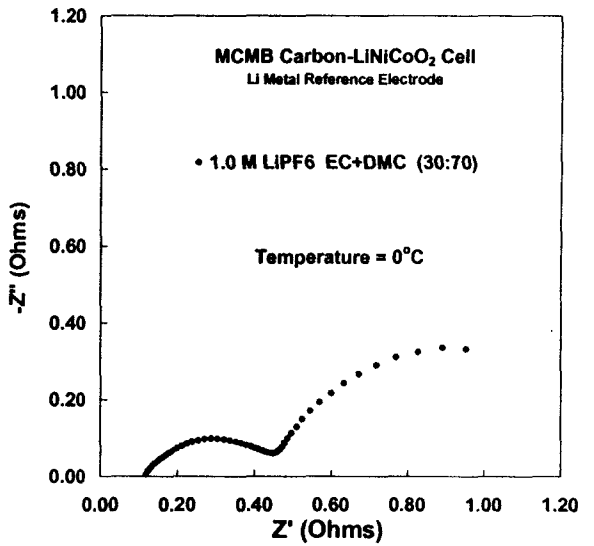


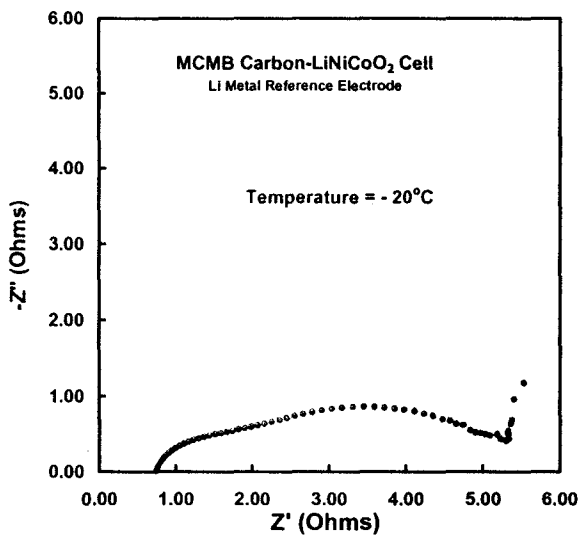
DC Polarizations in Li Ion Cell

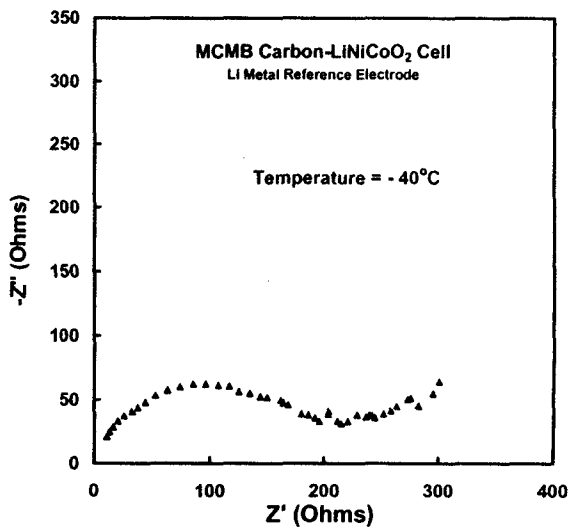


EIS of Carbon Anode at LT

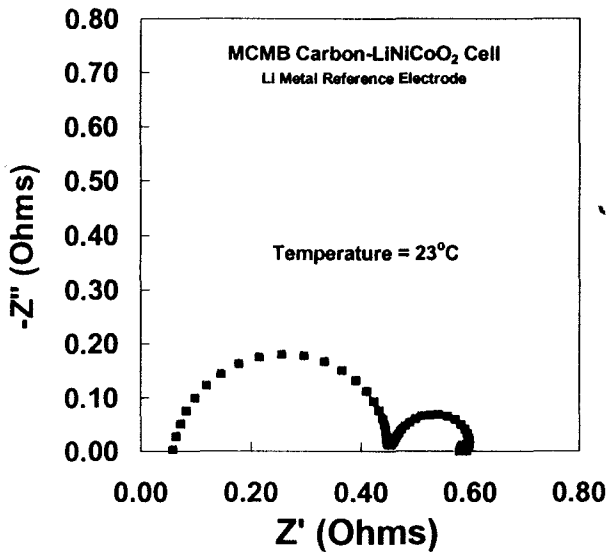


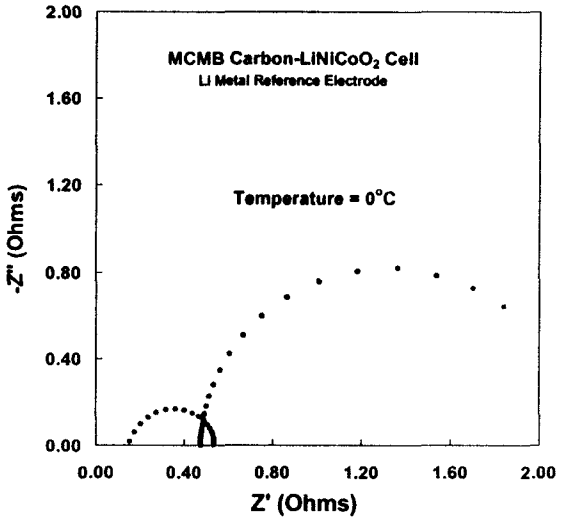


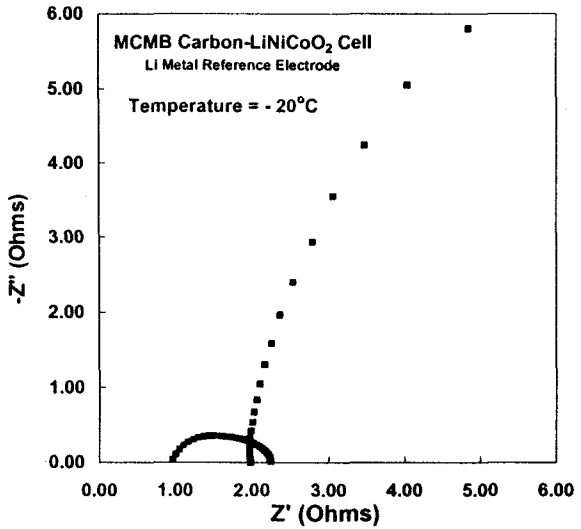


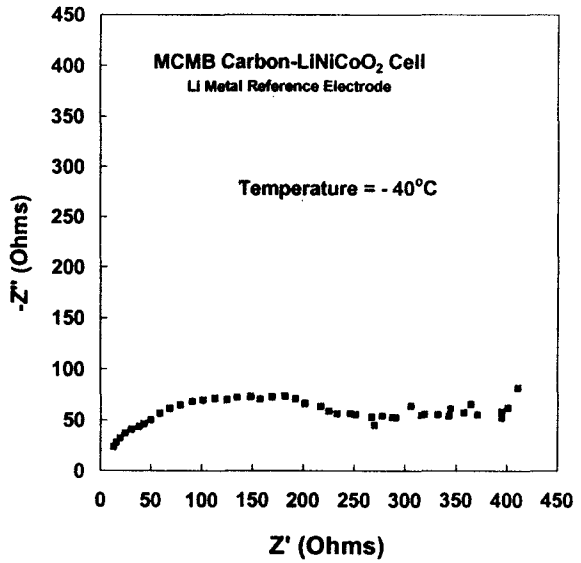


EIS of Oxide Cathode at LT



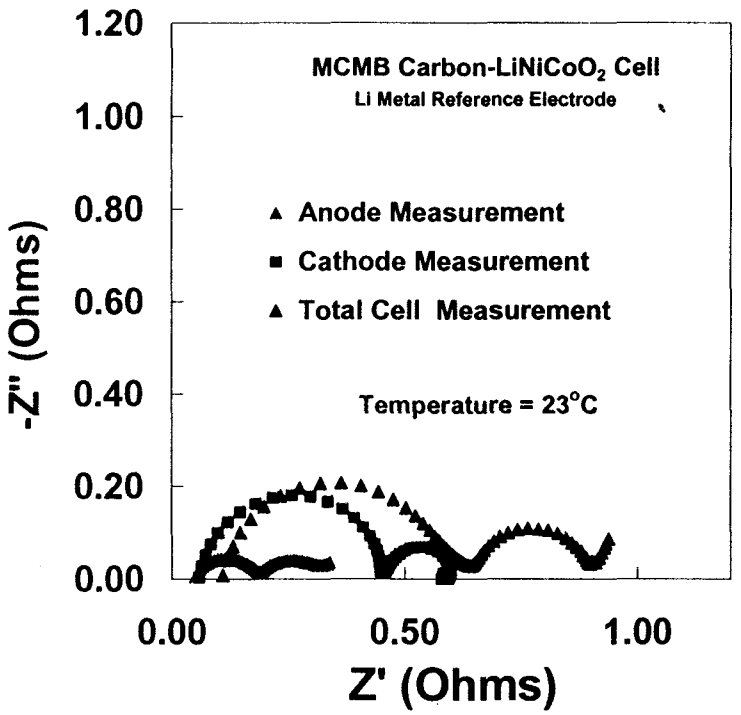




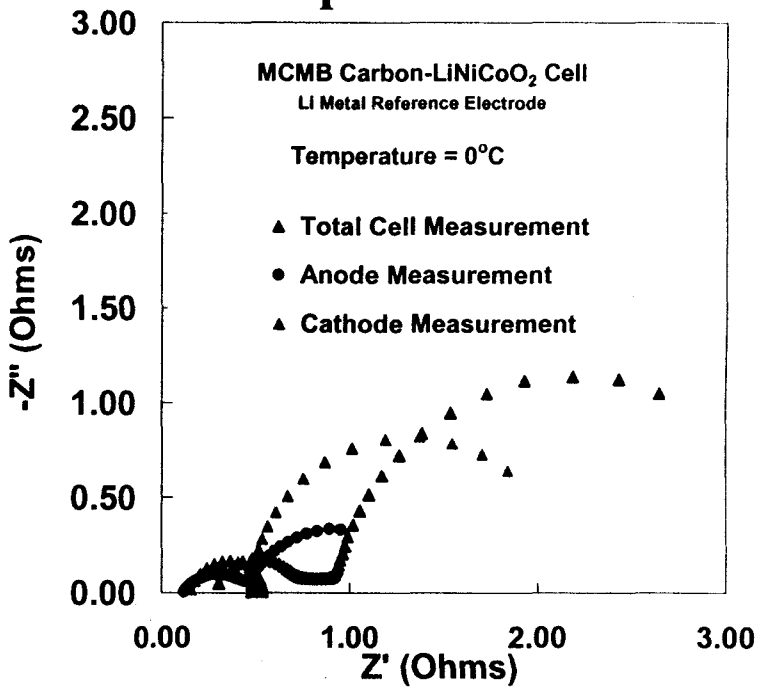


EIS of Li Ion cell at LT

Temperature: 23°C

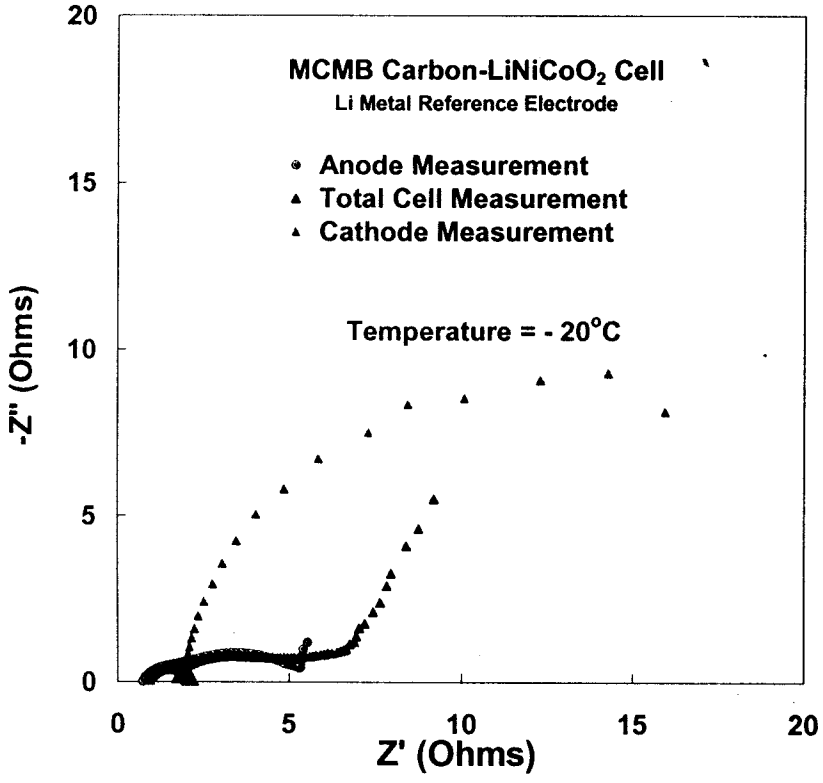


Temperature: 0°C

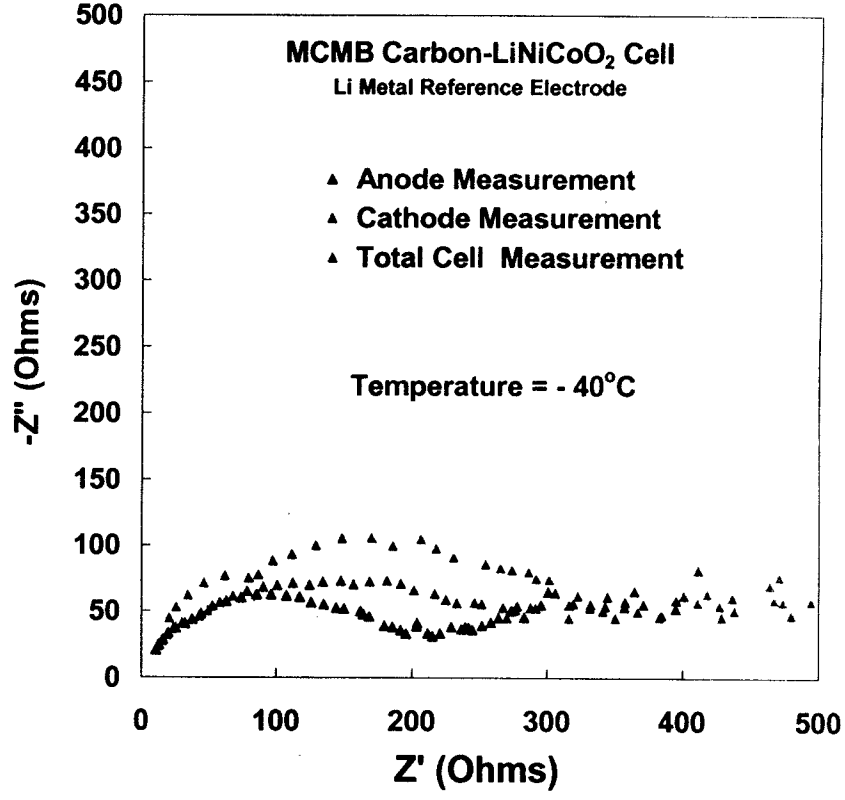


EIS of Li Ion cell at LT

Temperature: -20°C



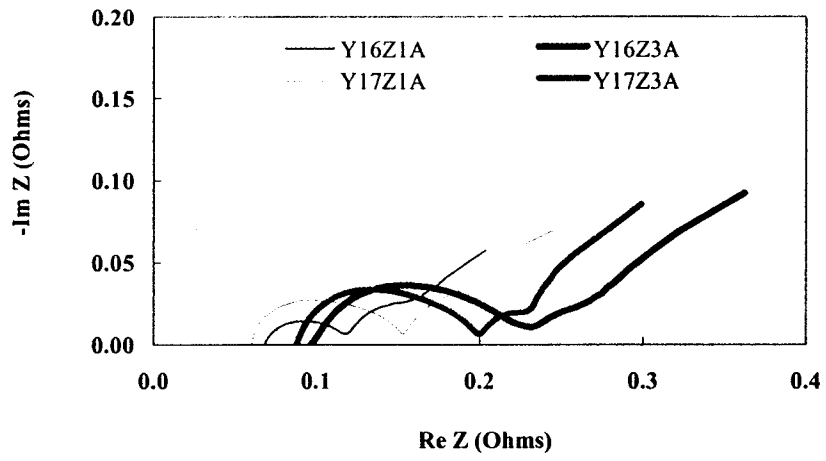
Temperature: -40°C



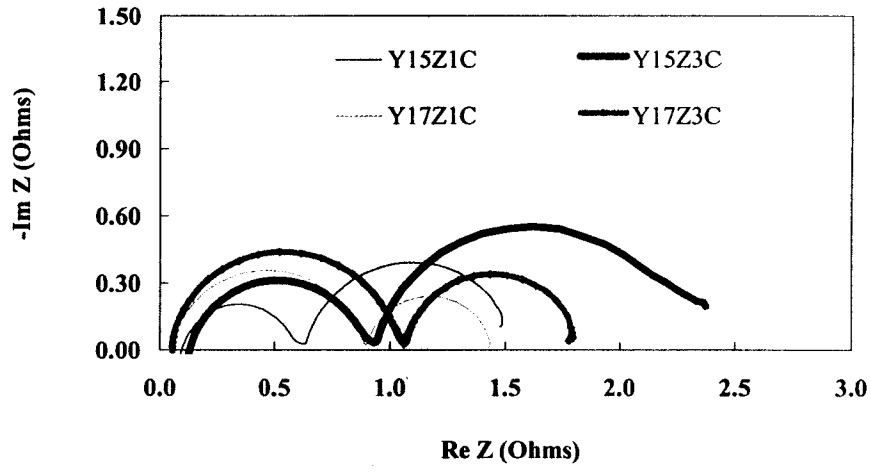
EIS During High Temp. Storage

Stored at 60°C for 1 week

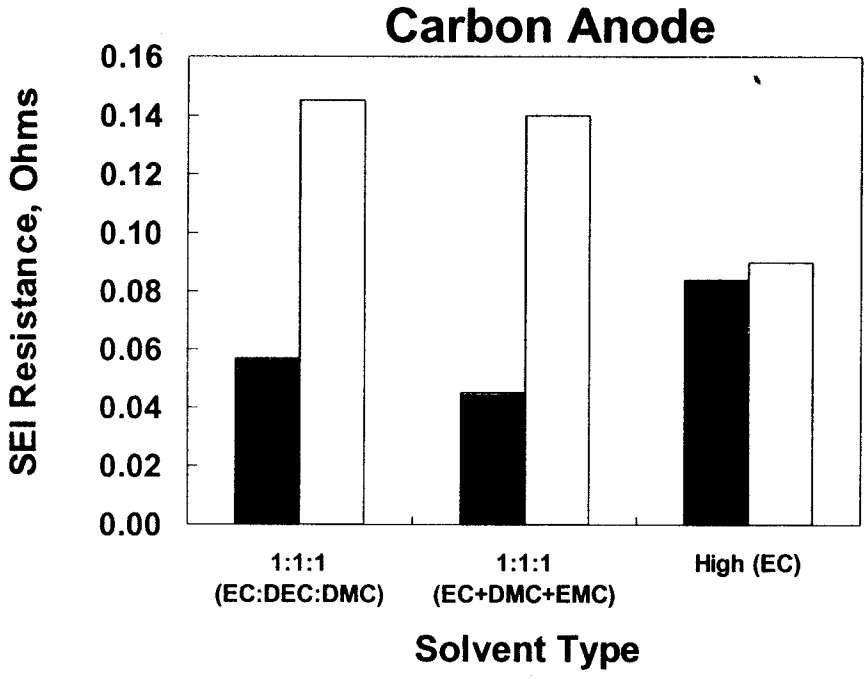
Carbon Anode

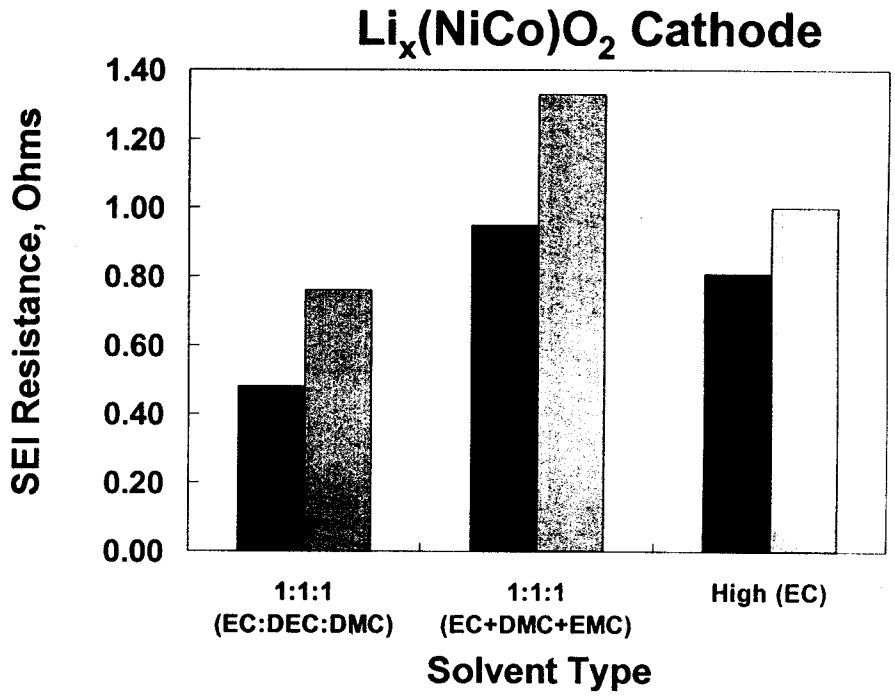


$Li_x(NiCo)O_2$ Cathode



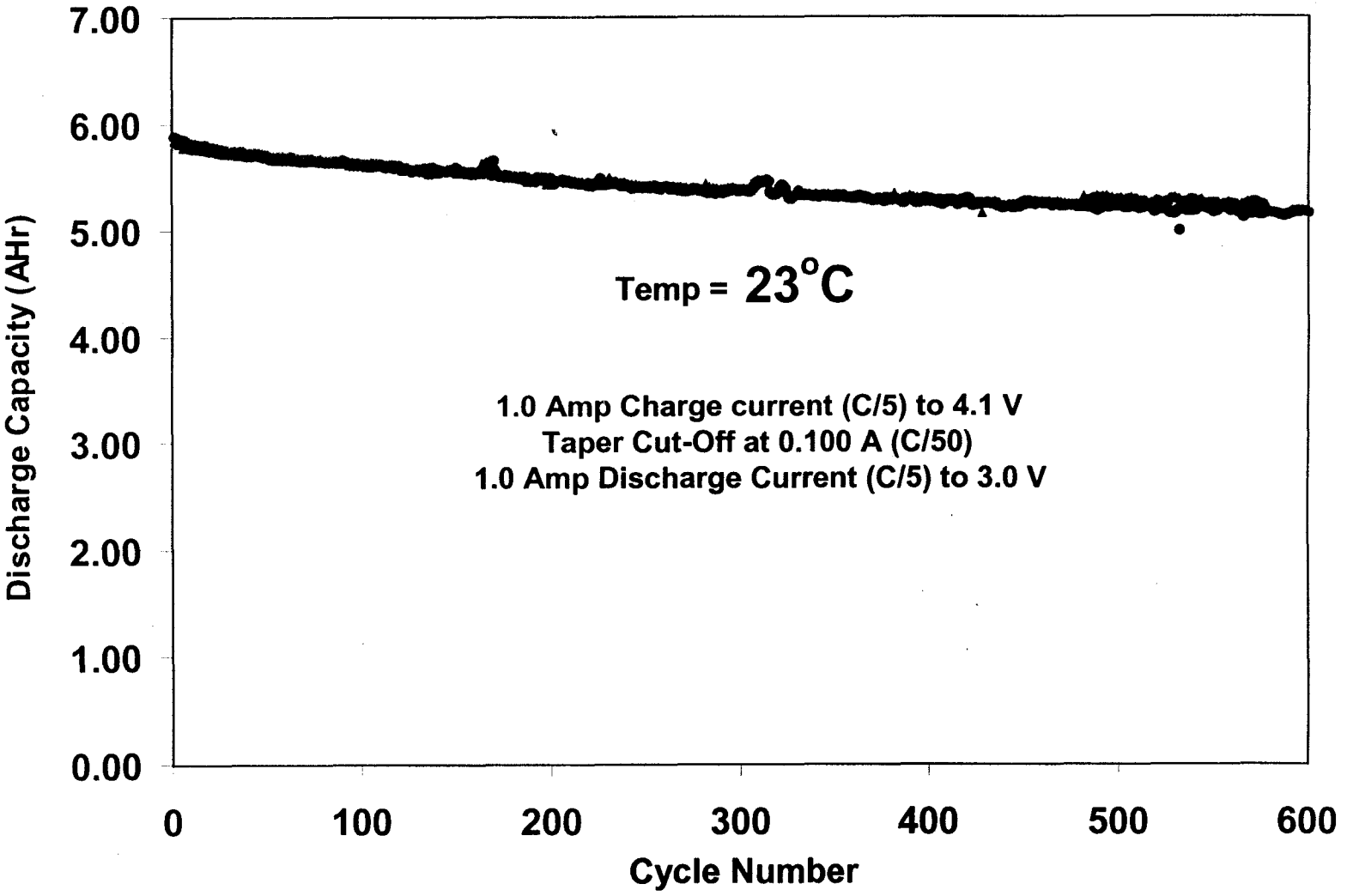
EIS During High Temp. Storage



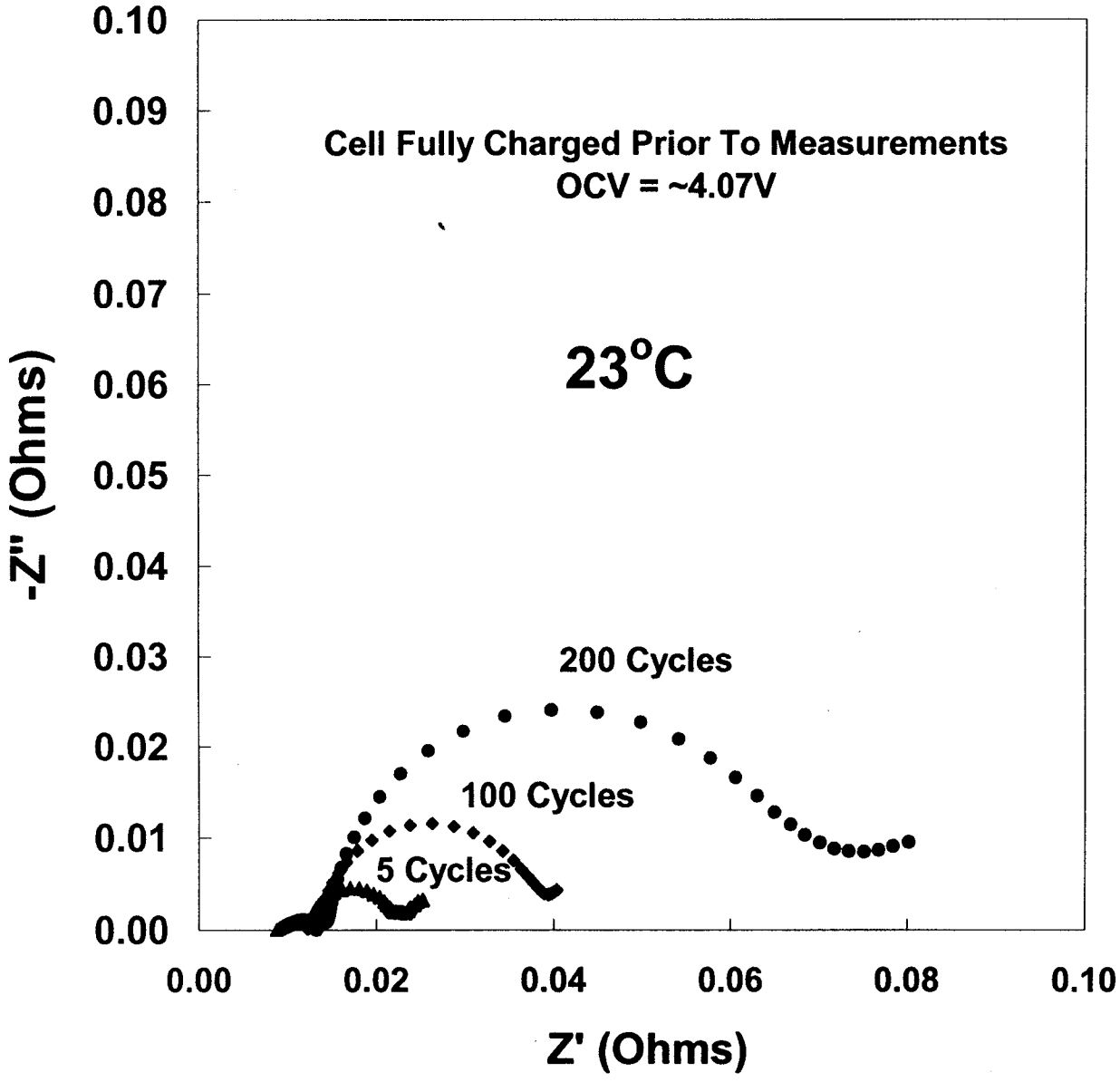


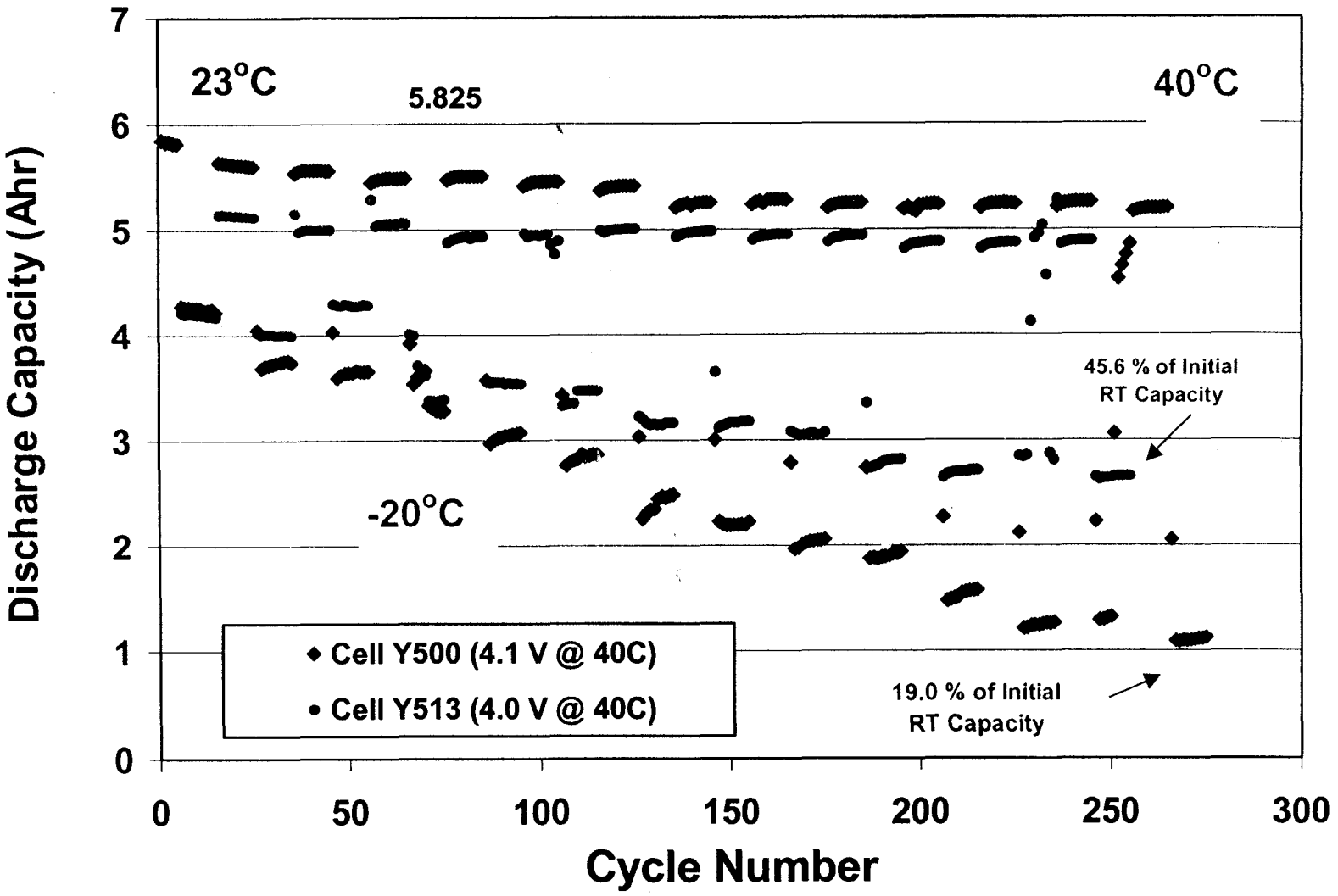
Stored at 60°C for 1 week

Cycling (100%DOD) at 25°C

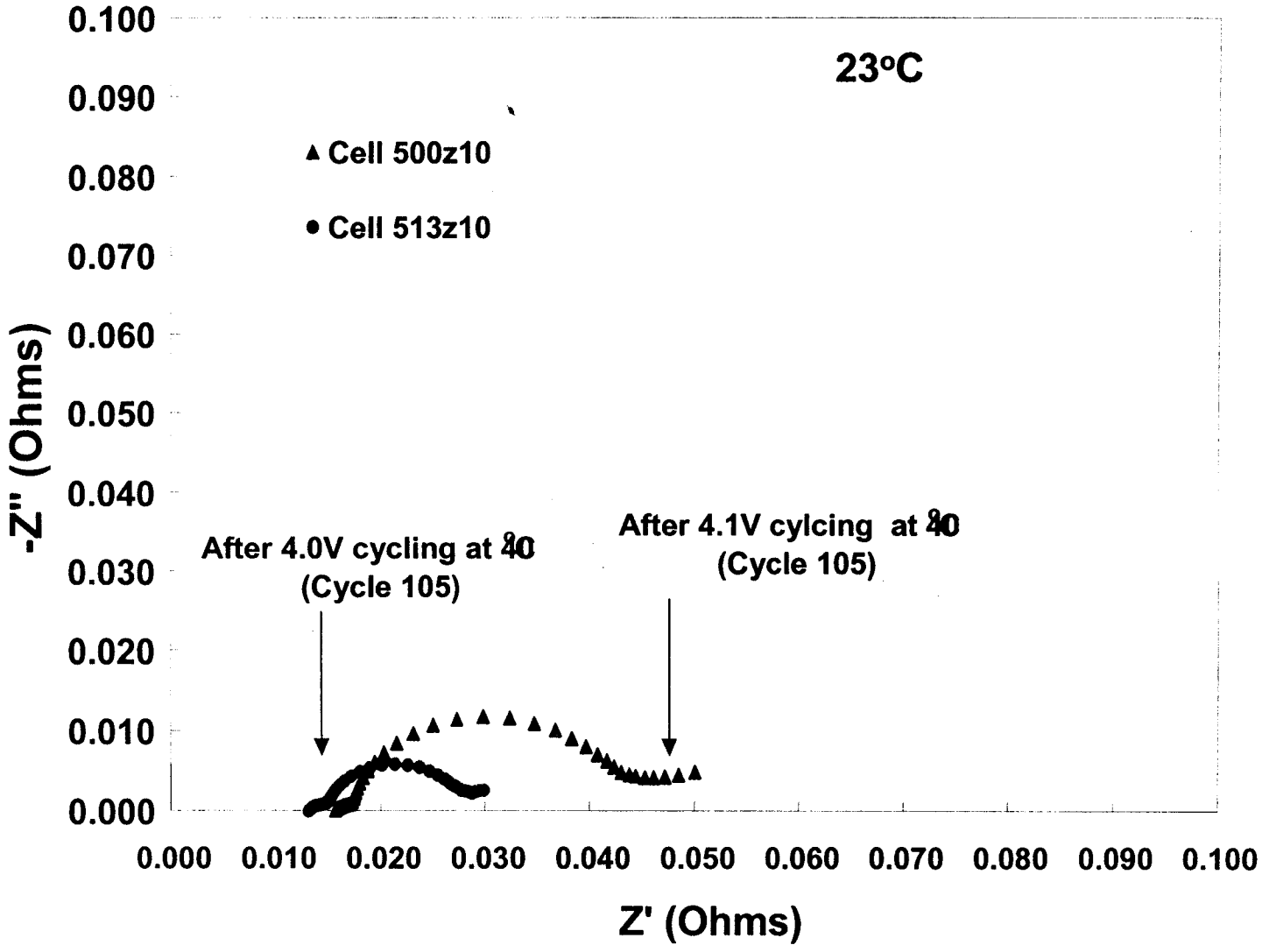


EIS During Cycling

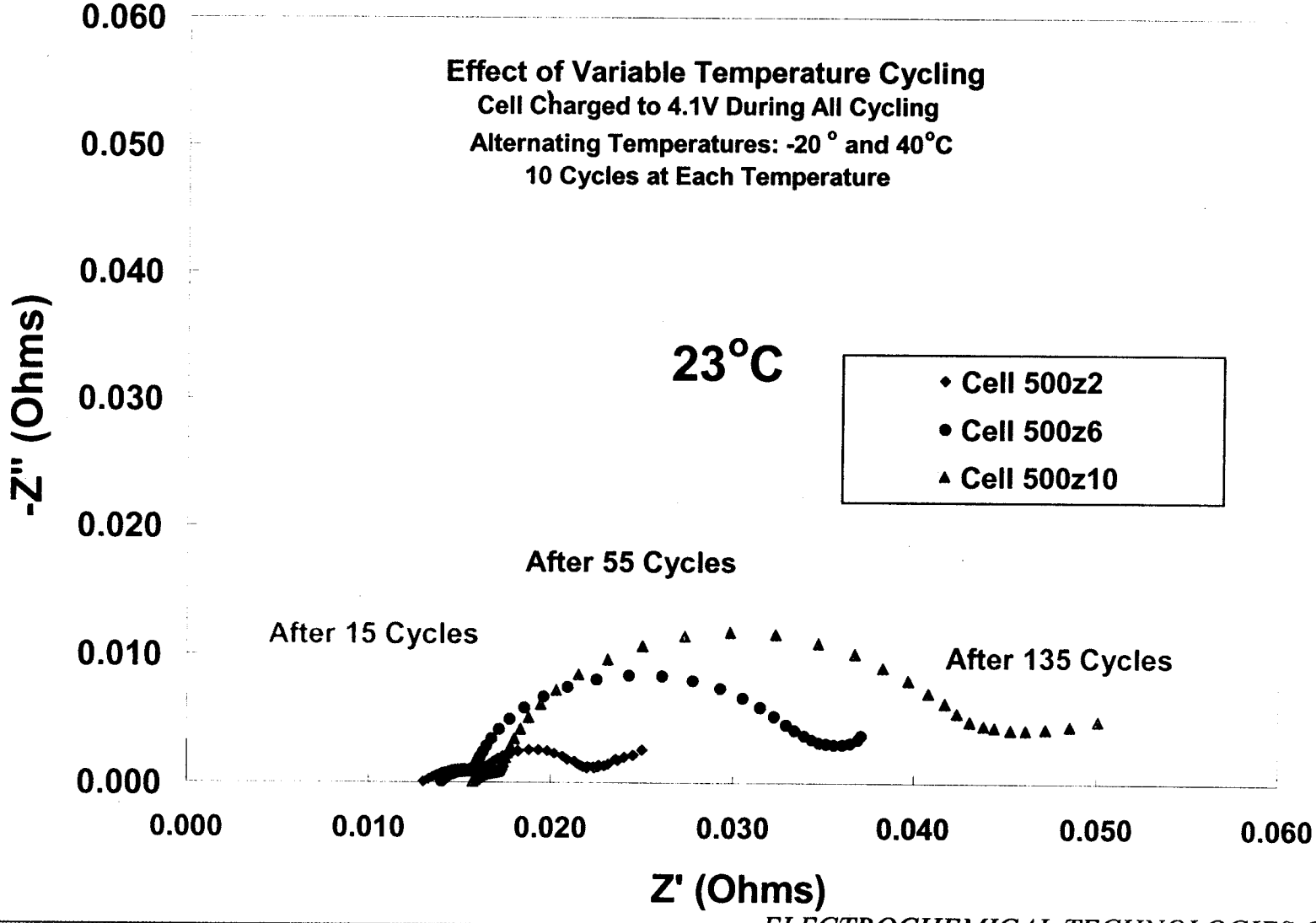



23°C
5.825
40°C
45.6 % of Initial
RT Capacity
-20°C
19.0 % of Initial
RT Capacity
◆ Cell Y500 (4.1 V @ 40C)
• Cell Y513 (4.0 V @ 40C)
Discharge Capacity (Ahr)
Cycle Number
0
1
2
3
4
5
6
7
0
50
100
150
200
250
300

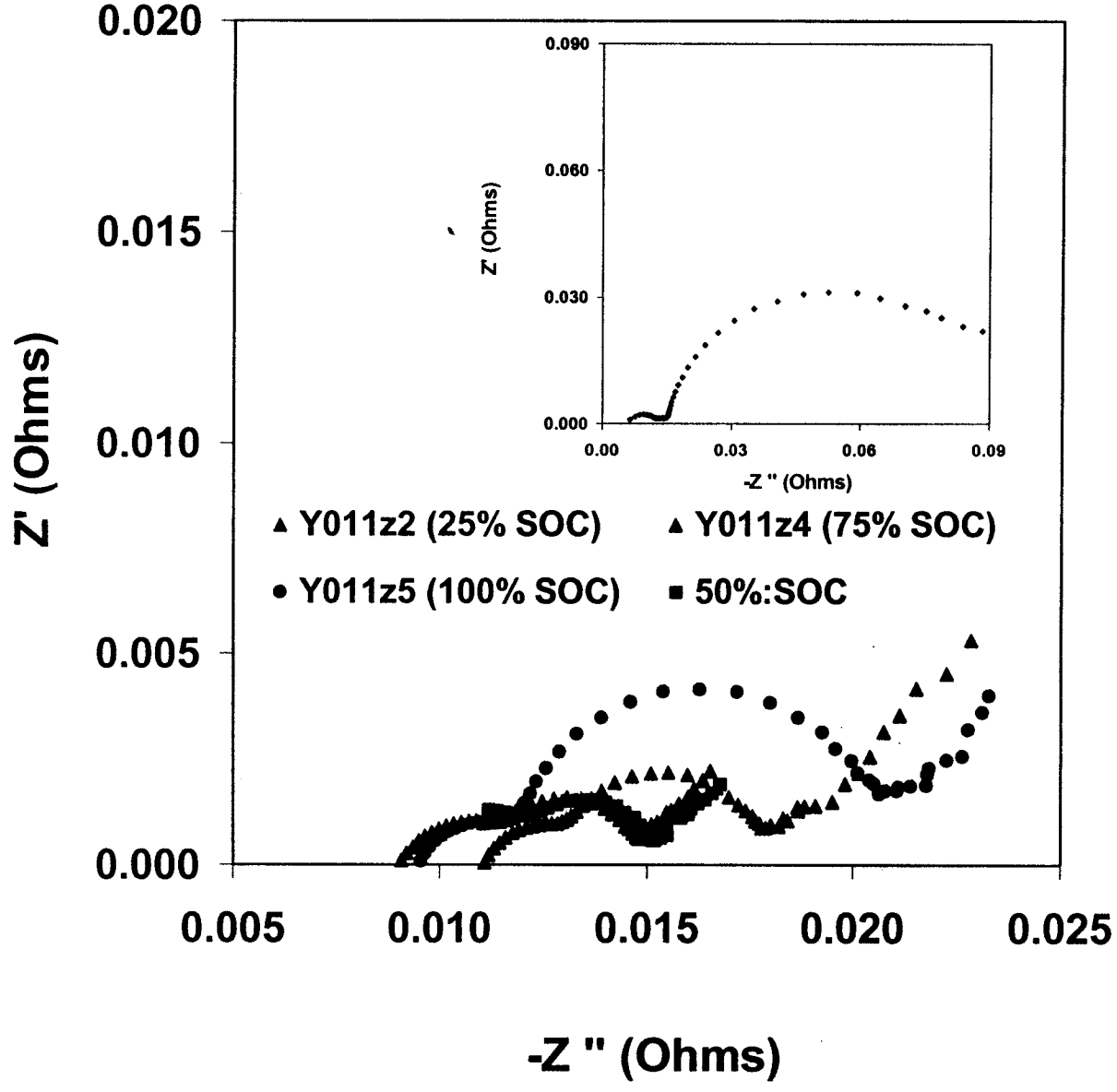
EIS During Cycling



EIS During Cycling



EIS vs. SOC


0.020
0.015
0.010
0.005
0.000
Z' (Ohms)
0.005
0.010
0.015
0.020
0.025
-Z " (Ohms)
Y011z2 (25% SOC)
Y011z4 (75% SOC)
Y011z5 (100% SOC)
50%:SOC
0.090
0.060
0.030
0.000
Z' (Ohms)
0.00
0.03
0.06
0.09
-Z " (Ohms)

Summary

- Electrochemical impedance Spectroscopy is a useful technique to follow the the interfacial changes in a Li ion cell.
- Cathode contributes significantly to the overall cell impedance.
- The SEI resistance of both anode and cathode increase
    - At low temperatures
    - During storage
    - During cycling