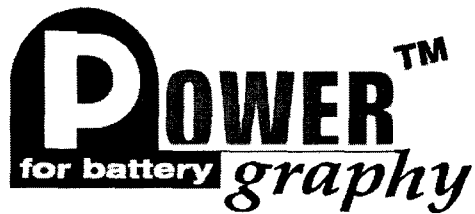

Battery Parameterization System

CHUL OH YOON

(Kumho Chemical Laboratories
Korea Kumho Petrochem. Co. Ltd)



Battery Parameterization System

CHUL OH YOON



**KUMHO CHEMICAL LABORATORIES
KOREA KUMHO PETROCHEM. CO. LTD.**

 **KUMHO CHEMICAL LABORATORIES**

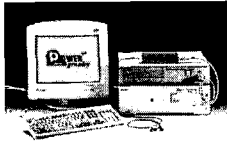
OUTLINE

- INTRODUCTION**
POWERGRAPHY™: New Concept of Battery Evaluation
- MODEL**
Electrochemical Processes in Battery & Equivalent Circuit
- MEASUREMENT**
Real-Time Impedance Measurement
- PARAMETERIZATION**
Generating Numerical Image of Battery
- PREDICTION**
Performance Simulation at Arbitrary Load
- CHARACTERIZATION**
Parametric Analysis of Batteries and Materials
- APPLICATION:**
Quality Control & EV Battery Management

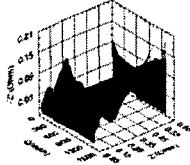


INTRODUCTION

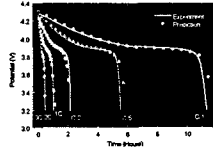
POWERGRAPHY™: **New Concept of Battery Evaluation**



*Measurement
(Hardware)*



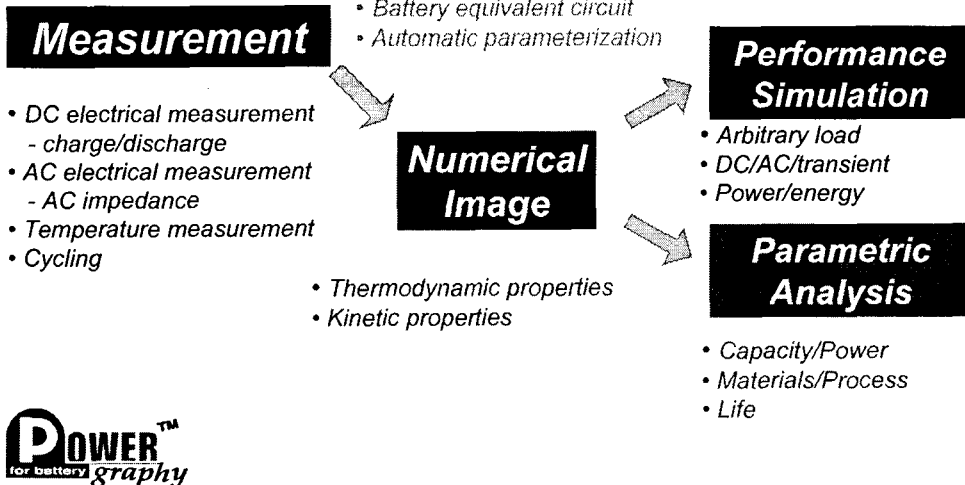
*Parameterization
(Software)*



*Prediction
(Simulation)*

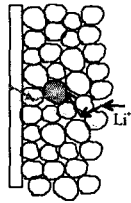


Battery Parameterization System

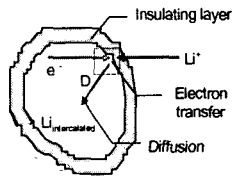


MODEL

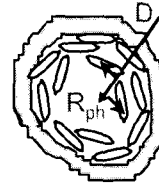
Electrochemical Processes in Battery & Equivalent Circuit



Composite electrode as a transmission line



Single particle processes

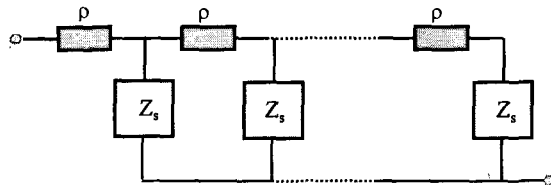
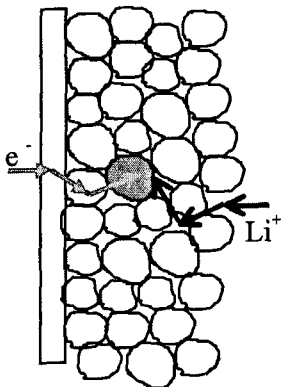


Phase kinetics



Frequency-domain model of kinetic processes

I. Composite Electrode as Transmission Line

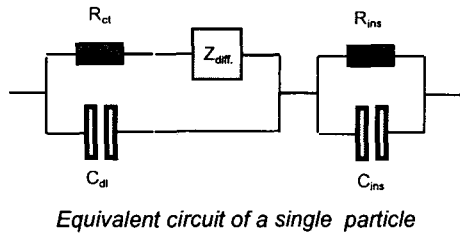
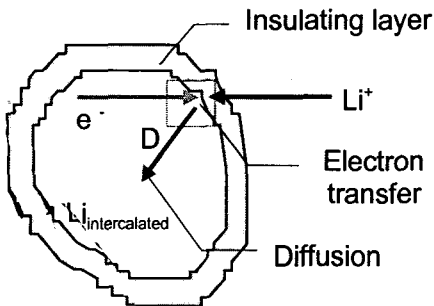


Equivalent circuit of the macroscopic layer of porous material



Frequency-domain model of kinetic processes

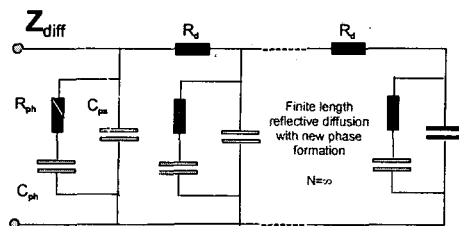
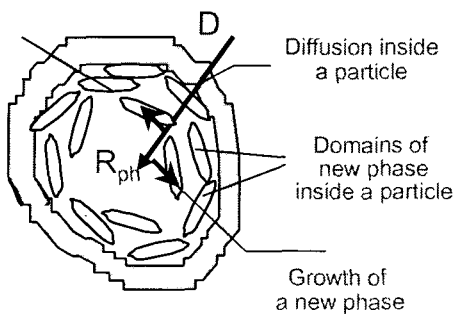
II. Single Particle Processes



POWERTM
for battery graphy

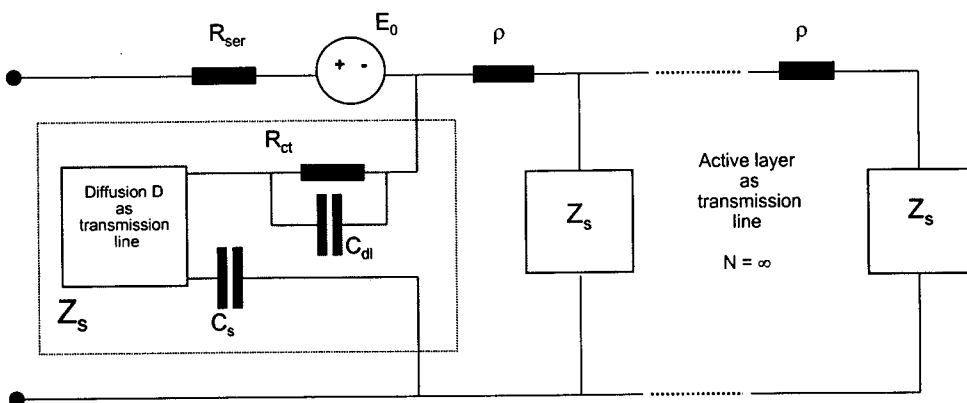
Frequency-domain model of kinetic processes

III. Phase Kinetics



POWERTM
for battery graphy

Generalized Battery Equivalent Circuit

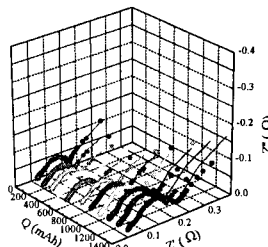


MEASUREMENT

Real-Time Impedance Spectroscopy

Multi-wave FFT
Impedance Measurement

Carrier Function
Laplace Transform
Impedance Measurement



- Nondestructive measurement technique using small signal perturbation
- Parameters relevant to electrochemical processes involved in battery operation
- Equivalent circuit available for numerical analysis, parameterization & simulation

Characterization of dynamic properties at a wide range of frequency (mHz–kHz)

IMPEDANCE SPECTROSCOPY FOR BATTERY TEST & ANALYSIS

IMPEDANCE SPECTROSCOPY FOR BATTERY TEST & ANALYSIS

IMPEDANCE SPECTROSCOPY FOR BATTERY TEST & ANALYSIS

POWERgraphy

Real-Time Impedance Measurement

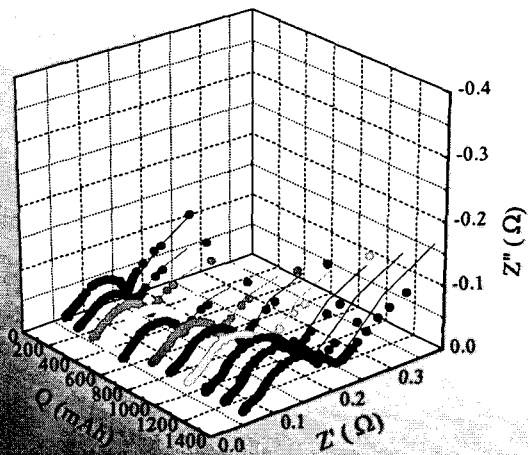
System	Excitation	Response	Impedance	Measurement time*
AC				1 h 40 min
2-D Pulse PFT				33 min
Carrier Function Laplace transform (CF-LT)				17 min

*Measurement at 1 mHz ~ 1 kHz, 50 frequencies. log spaced, 2 period integration

POWERgraphy

Impedance spectra of a Li-ion battery

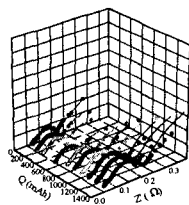
Nyquist plot vs. level of discharge



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PARAMETERIZATION

Generating Numerical Image of Battery

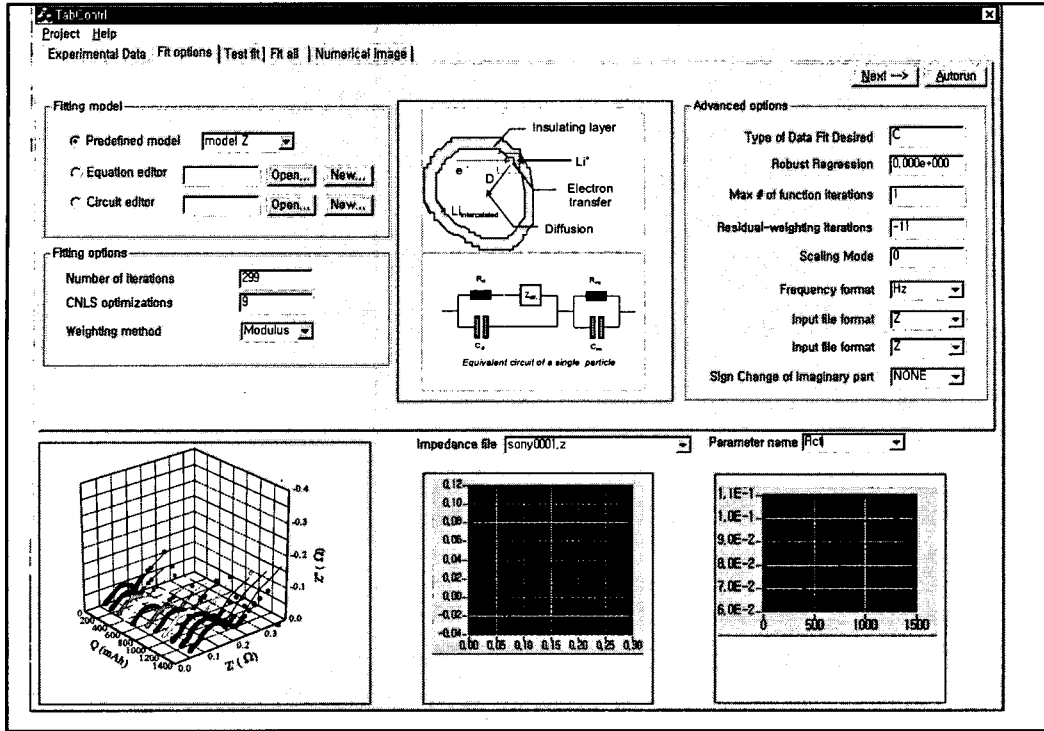


Automatic initial guessing
Battery equivalent circuit
CNLS fitting

Disch. %	Q (mAh)	Z' (Ω)	Z'' (Ω)	R ₁ (Ω)	R ₂ (Ω)	C ₁ (F)	C ₂ (F)	W ₁ (Ω)	W ₂ (Ω)	W ₃ (Ω)	W ₄ (Ω)	W ₅ (Ω)	W ₆ (Ω)	W ₇ (Ω)	W ₈ (Ω)	W ₉ (Ω)	W ₁₀ (Ω)	
0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	100	0.1	-0.1	0.1	0.1	1000	1000	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
20	200	0.2	-0.2	0.2	0.2	2000	2000	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
30	300	0.3	-0.3	0.3	0.3	3000	3000	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
40	400	0.4	-0.4	0.4	0.4	4000	4000	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
50	500	0.5	-0.5	0.5	0.5	5000	5000	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
60	600	0.6	-0.6	0.6	0.6	6000	6000	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
70	700	0.7	-0.7	0.7	0.7	7000	7000	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
80	800	0.8	-0.8	0.8	0.8	8000	8000	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
90	900	0.9	-0.9	0.9	0.9	9000	9000	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
100	1000	1.0	-1.0	1.0	1.0	10000	10000	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Numerical
Image





Battery Parameterization

- CNLS fitting of impedance spectra
- Automatic generation of Numerical image

Including standard battery characterization

- capacity
- average voltage
- energy / power

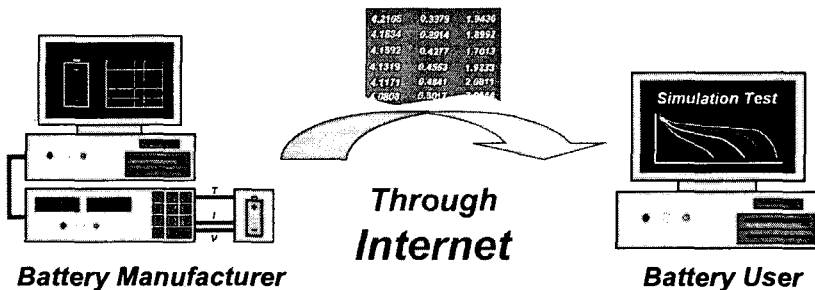
Numerical Image of Li-ion Battery

Q (mAh)	R _{ref} (Ω)	C _{dl} (F)	C _{ps} (F)	ρ (Ω)	R _{ser} (Ω)	D (sec ⁻¹)	E (V)	C _s (F)
0	0.06870	1.361	4142.4	0.08335	0.07012	0.000951	4.1061	4645.9
130	0.06099	1.458	1939.8	0.07980	0.06436	0.003206	4.0142	5318.0
260	0.06129	1.463	2273.0	0.08385	0.05977	0.003186	3.9447	7736.1
390	0.07014	1.504	2132.8	0.09549	0.05667	0.003420	3.8859	8660.8
520	0.06508	1.415	2151.1	0.09269	0.05095	0.003599	3.8372	9675.2
650	0.07299	1.417	1752.4	0.08679	0.07430	0.003466	3.7767	7039.0
780	0.07892	1.408	1610.8	0.08476	0.07473	0.003159	3.6769	3631.1
910	0.08639	1.422	1333.0	0.08491	0.07471	0.003259	3.5226	2674.5
1040	0.09876	1.485	1101.4	0.08939	0.07462	0.003313	3.3132	1977.4
1170	0.10006	1.649	847.1	0.08340	0.07548	0.003738	3.0419	1604.4



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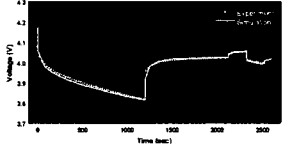
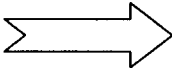
POWERGRAPHY™ represents a method to generate a *Numerical image*, which is an equivalent numerical representation of battery for parametric analysis and numerical simulation under arbitrary load conditions.



PREDICTION

Performance Simulation at Arbitrary Load

Order	V	I	C	R	P	Q	L	W	W	EM	C	P
1	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
3	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
4	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
6	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
7	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
8	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
9	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
10	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
11	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
12	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
13	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
14	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
15	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000



Numerical
Image

System of Nonlinear ODE
SPICE



Untitled - GBatSim

File Edit Analysis View Help

Discharge simulation

Constant Current Analysis

Circuit of analysis

Current's value (A) 0.065

Battery's voltage (V) 4.2

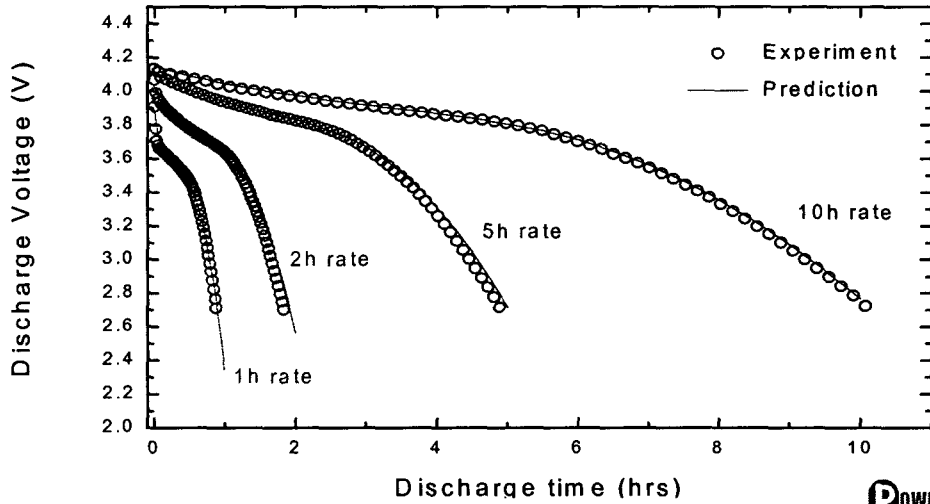
Duration of analysis (s) 40000

Time step (s) 1

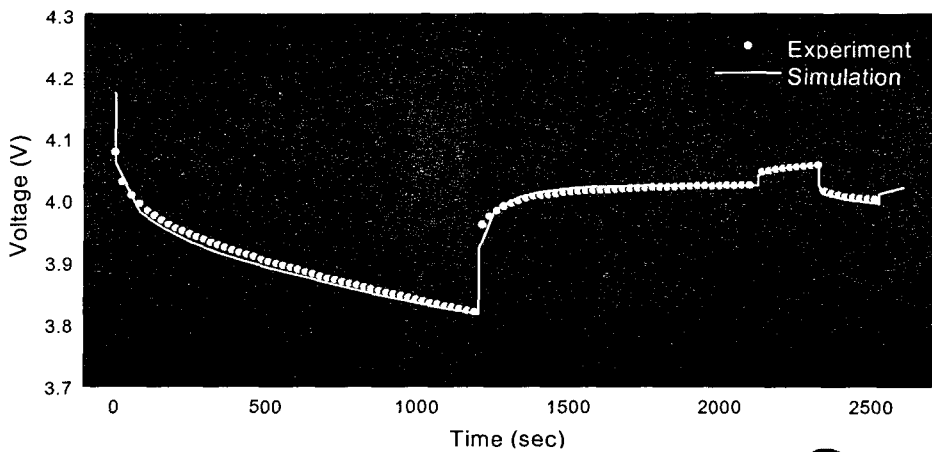
Run Analysis Cancel

Ready

Numerical Simulation of Battery Discharge Curves (Li-ion 18650)

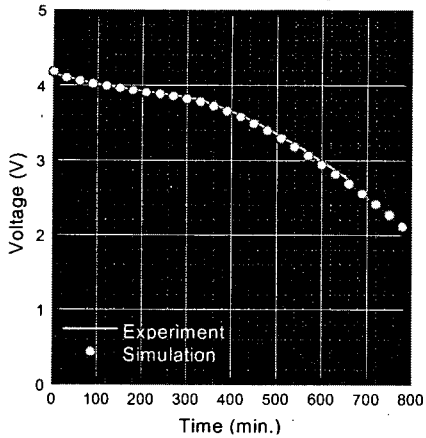


Numerical Simulation of Patterned Discharge (Li-ion 18650)

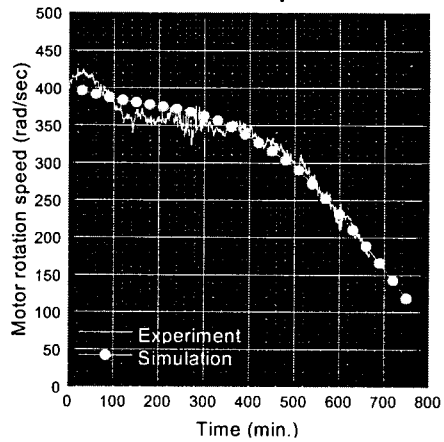


Digital simulation of DC Motor Operation

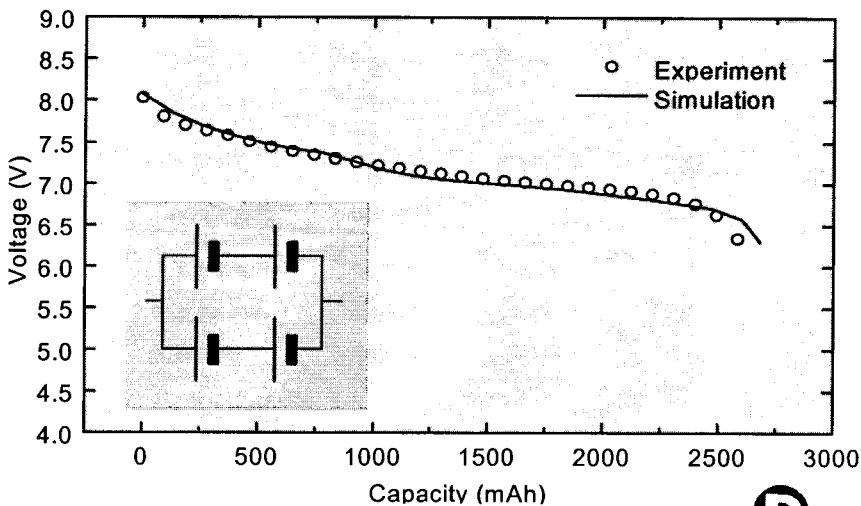
Discharge voltage



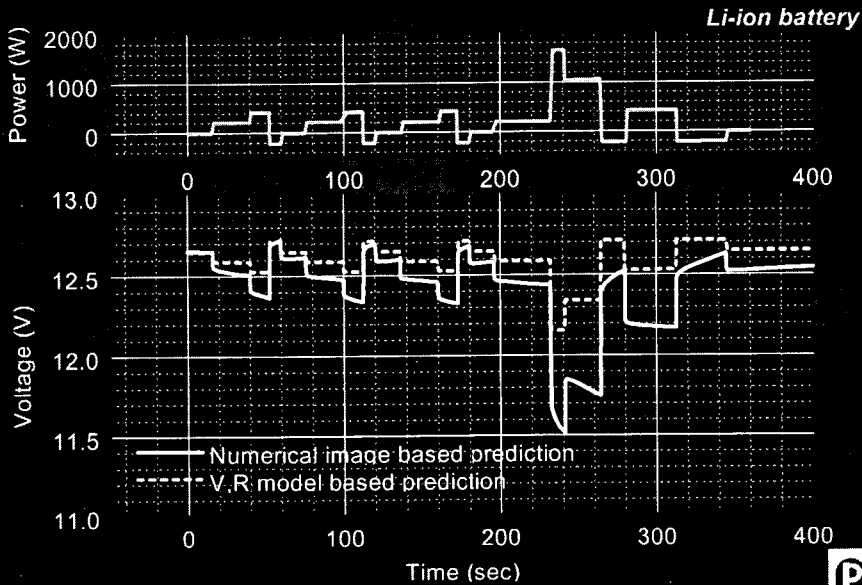
Rotation speed



Digital Simulation of a Battery Pack



Driving Simulation using Numerical Image

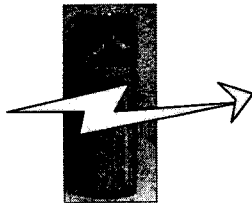


 KUMHO CHEMICAL LABORATORIES

CHARACTERIZATION

Parametric Analysis of Batteries & Materials

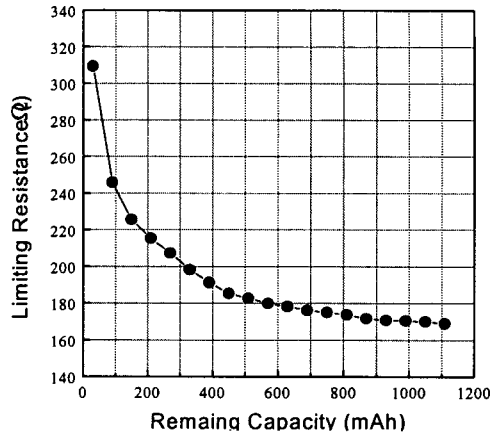
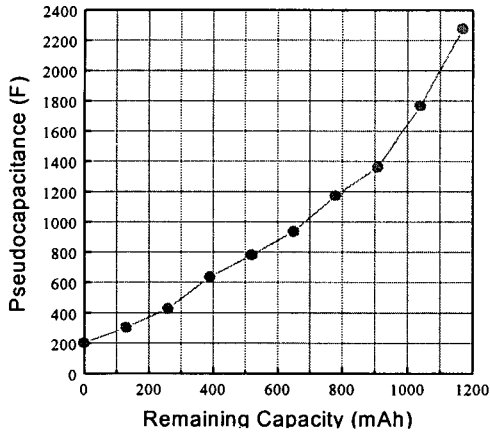
POWER™
for battery graphy



- ✓ Charge / Discharge
- ✓ Energy / Power
- ✓ Internal resistance
- ✓ Capacitance
- ✓ Cycling
- ✓ Temperature
- ✓ Material parameters
- ✓ Control parameters

POWER™
for battery graphy

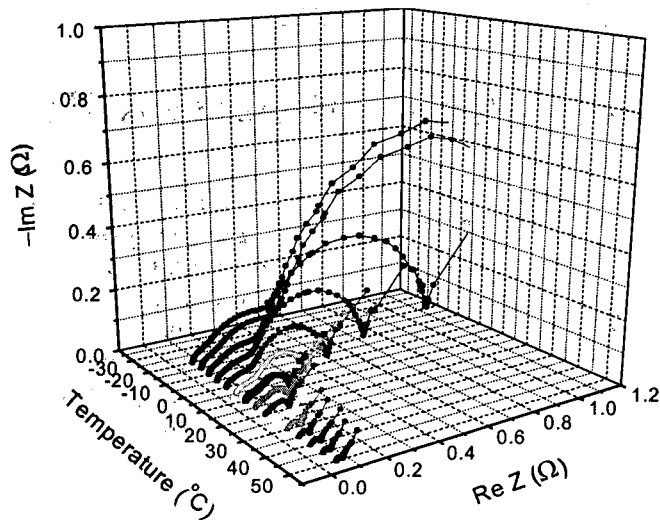
Correlation between Battery parameters & Capacity



POWER™
for battery graphy

Effect of Temperature : Impedance Spectra

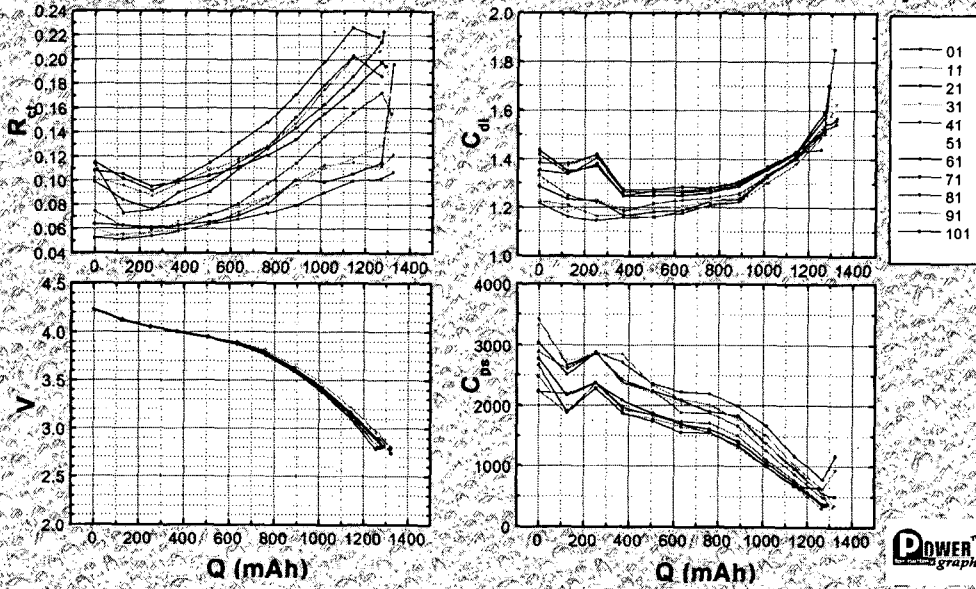
Li-ion battery



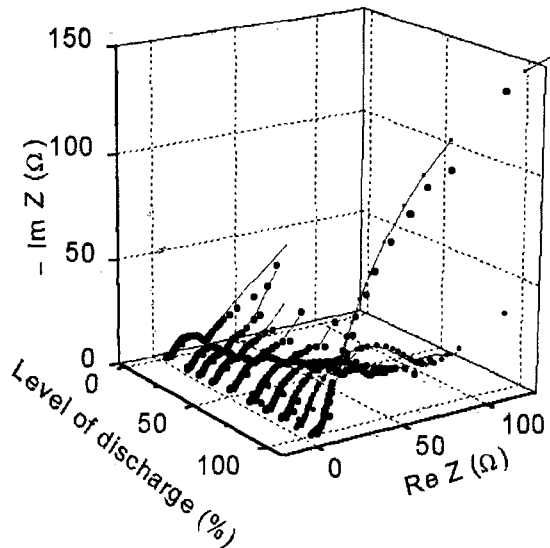
POWER™
for battery graphy

Effect of Cycling : Kinetic Parameters

Li-ion battery

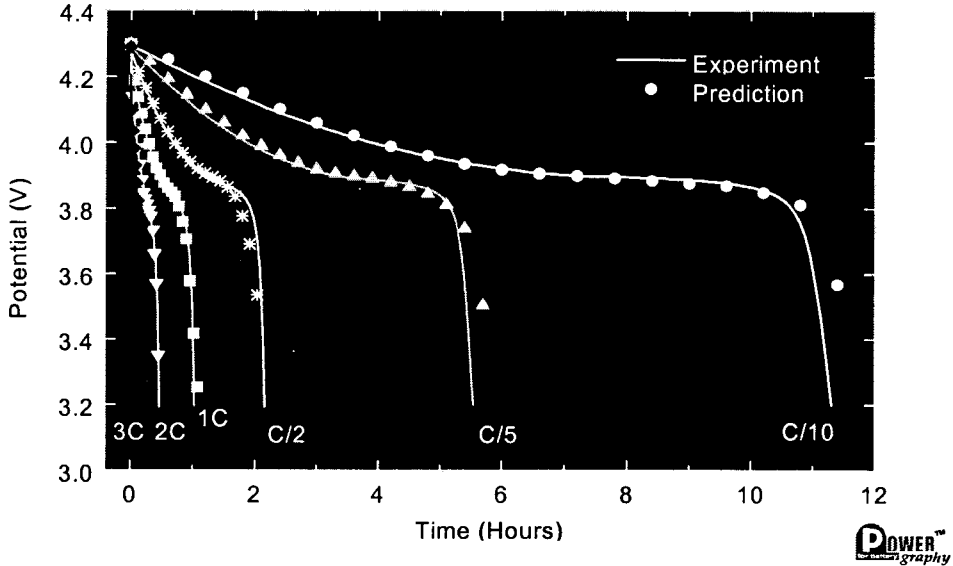


Impedance Spectra of $LiCoO_2$ composite cathode

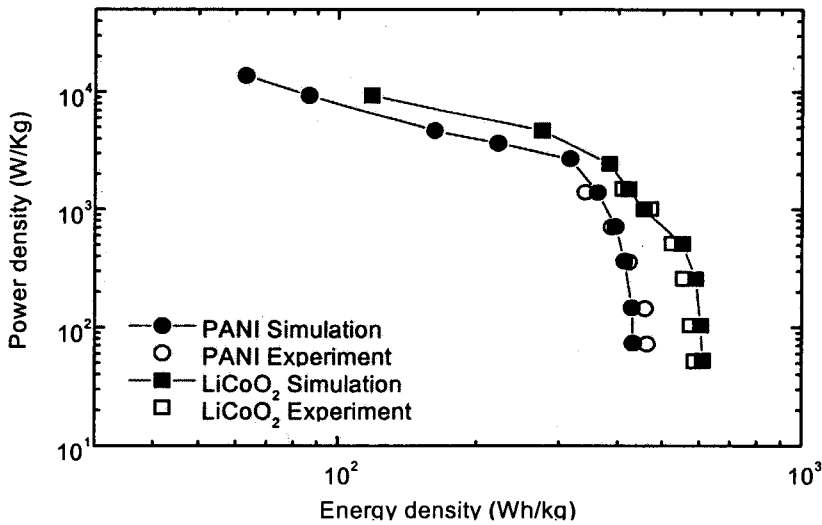


Digital Simulation of Electrode Materials

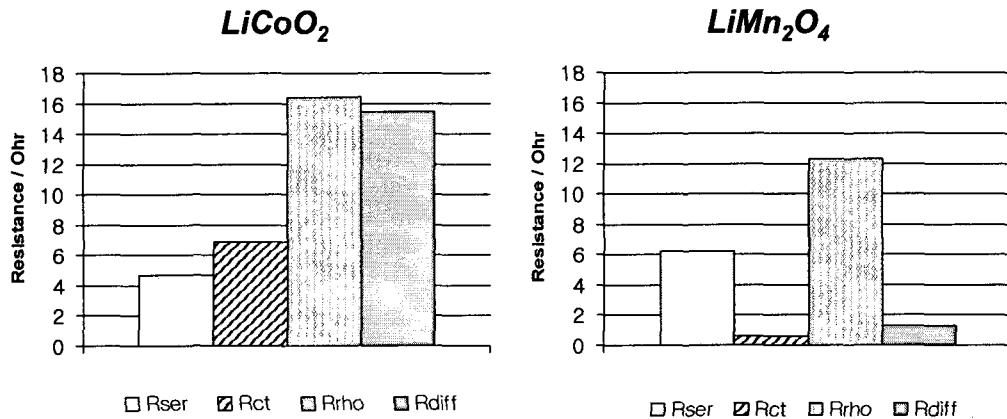
LiCoO₂ cathode vs. lithium



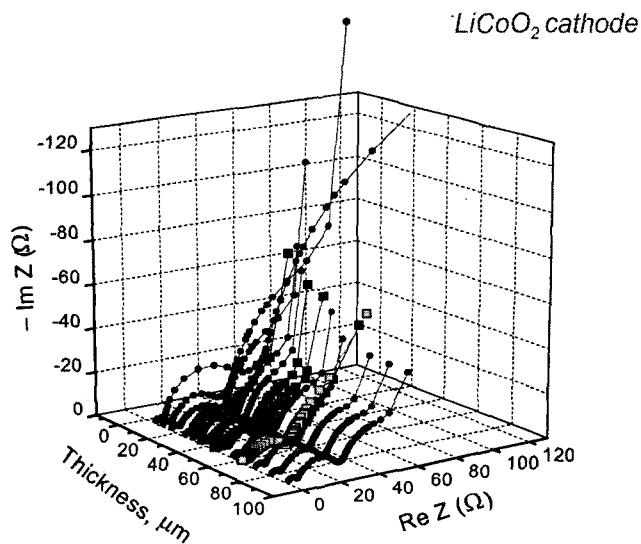
Simulated Ragone Plots



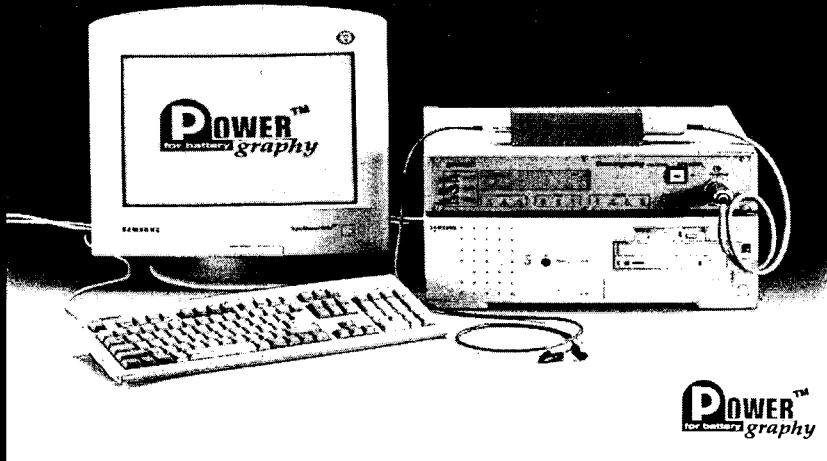
Comparison of kinetic properties of electrodes




Effects of Electrode Thickness



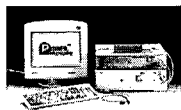
Prototype model BPS 1000 FL



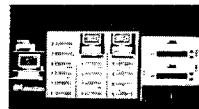
 KUMHO CHEMICAL LABORATORIES

APPLICATION

Battery Test / Quality Control / Battery Management



Battery Test & Design



Battery Quality Control



EV Battery Management



Satellite Battery Remote Control

POWER™
for battery graphy