



Low Cost Components: Advanced High Power & High Energy battery Materials

K. Amine

Chemical Sciences and Engineering Division

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Purpose of the work

- Develop advanced low cost material with improved life and abuse tolerance for use in HEVs and PHEVs
 - Stabilize cathode and anode interface to improve life and abuse tolerance
- Develop very high energy composite cathode material (250mAh/g) to enable the 40 miles PHEVs and engineer the material to obtain suitable morphology, particle size, packing densities to improve energy and power at the electrode level

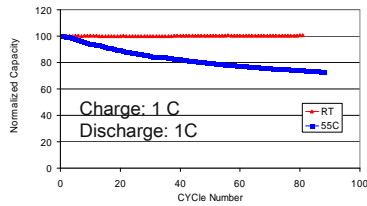


Approaches to stabilizing electrodes for long life and improved safety for HEVs and PHEVs

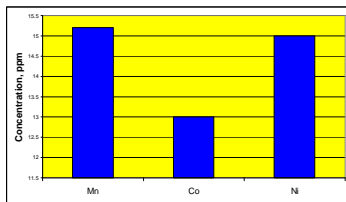
- Surface reactions between cathode and electrolyte and anode and electrolyte are the main cause of capacity and power fade in most of high power lithium ion batteries.
- To address this issue one can:
 - *Develop electrolyte additive that provide stable SEI at the anode and cathode*
 - *Coat the active particles (cathode & anode) with stable oxide or fluoride nano-films that plays a barrier against reactivity with the electrolyte*
 - Effect of AlF_3 coated on different cathode particles



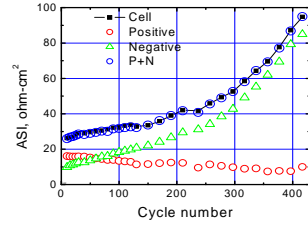
Improving life of $\text{Li}_{1.1}(\text{Ni}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3})_{0.9}\text{O}_2$ (L333)/MCMB10-28 system using electrolyte additives



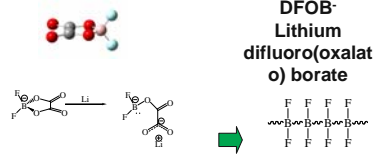
At 55°C, NMC shows capacity fade with cycling



Mn, Ni, Co were found to dissolve in the electrolyte at 55°C



Reference electrode shows impedance of anode increase with cell impedance increase



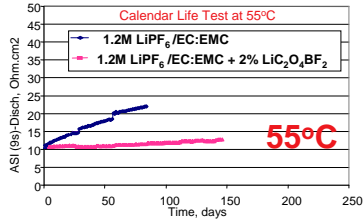
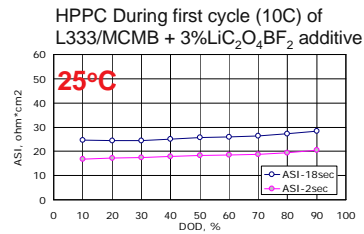
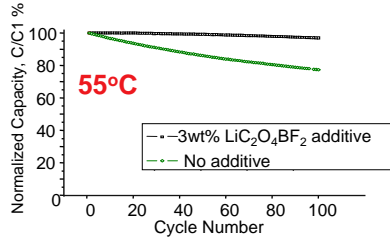
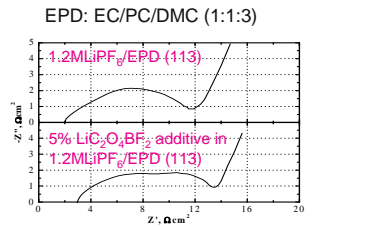
Protecting the surface of carbon using new electrolyte additive can enable L333 material



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Performance of $\text{Li}_{1.1}(\text{Ni}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3})_{0.9}\text{O}_2$ / Graphite Cell using $\text{LiC}_2\text{O}_4\text{BF}_2$ Additive



L333/MCMB cells based on a new $\text{LiC}_2\text{O}_4\text{BF}_2$ additive (at 3 wt%) show low initial ASIs, good capacity retention and limited impedance rise during calendar life test at 55°C.



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Improving the performance of lithium batteries by surface coating of the positive active materials with AlF_3

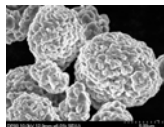
➤ Metal fluoride coating of cathode materials to improve life and safety of lithium batteries

- $\text{Li}_{1.1}(\text{Mn}_{1/3}\text{Co}_{1/3}\text{Ni}_{1/3})_{0.9}\text{O}_2$ (L333), $\text{LiNi}_{0.8}\text{Co}_{0.15}\text{Al}_{0.05}\text{O}_2$ (NCA), and $\text{LiMn}_{0.5}\text{Ni}_{0.5}\text{O}_2$ (L55)
- Technology can be used for both HEV and PHEV

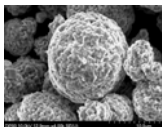


SEM showing no effect of AlF_3 coating on the cathode particle morphology

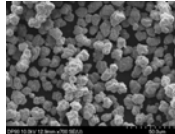
L 333



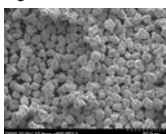
AlF_3 coated L 333



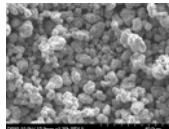
L55



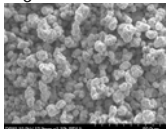
AlF_3 coated L55



NCA



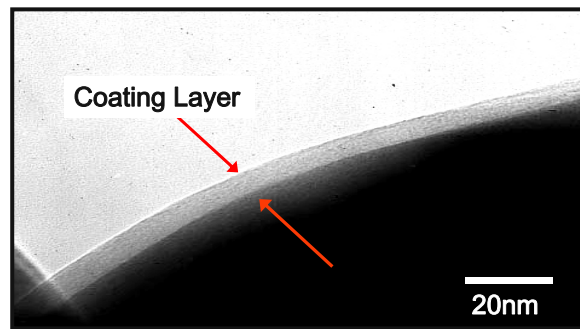
AlF_3 coated NCA



The morphology of the cathode materials is not affected during the AlF_3 coating process.



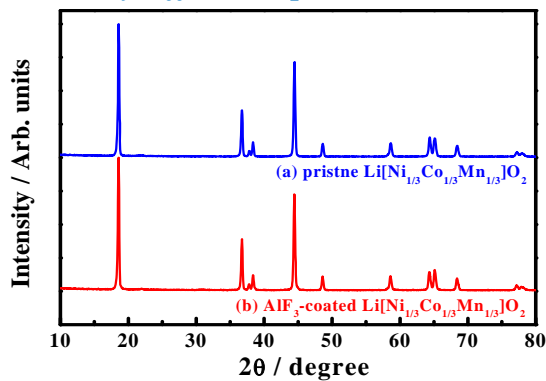
TEM Images of AlF_3 -coated- $\text{Li}_{1.1}[\text{Ni}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}]_{0.9}\text{O}_2$ showing AlF_3 layer on the surface of the cathode particle



Coating thickness is very uniform and less than 8nm

XRD showing no effect of AlF_3 coating on the structure of $\text{Li}_{1.1}(\text{Ni}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3})_{0.9}\text{O}_2$

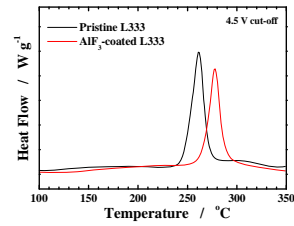
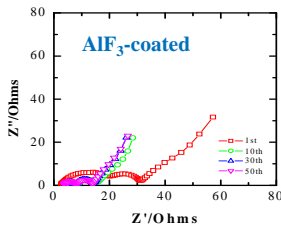
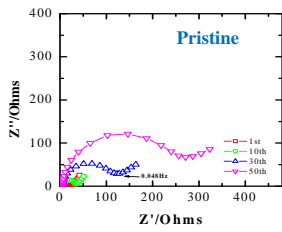
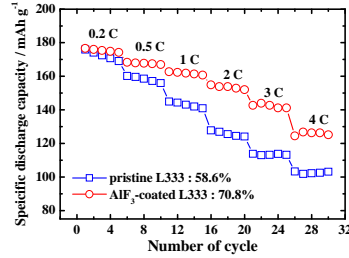
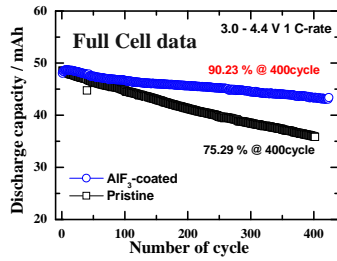
X-ray diffraction patterns



Sample	a-axis (Å)	c-axis (Å)
Pristine $\text{LiNi}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}\text{O}_2$	2.867(5)	14.250(4)
AlF_3 -coated $\text{LiNi}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}\text{O}_2$	2.864(6)	14.277(8)

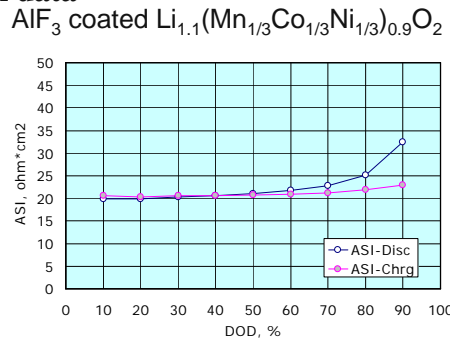
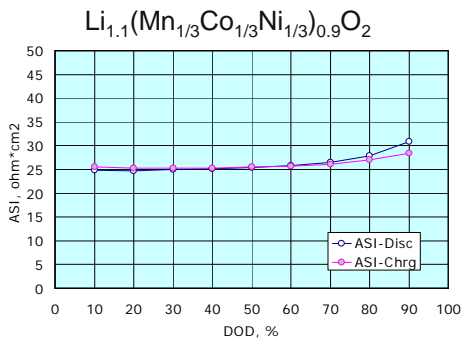
No change to the structure of the material take place

Effect of AlF_3 -coating on $\text{Li}_{1.1}[\text{Ni}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}]_{0.9}\text{O}_2$ (L333) performance



ASI from HPPC test at 10C of $\text{Li}_{1.1}(\text{Mn}_{1/3}\text{Co}_{1/3}\text{Ni}_{1/3})_{0.9}\text{O}_2$ /MCMB cells with and without AlF_3 coating

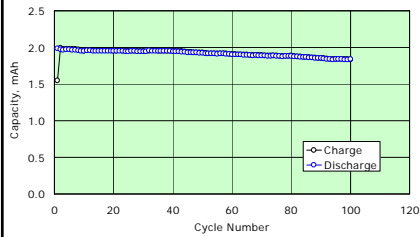
Full Cell data



Cell with AlF_3 coated L333 cathode shows lower ASI's than the cell with pristine cathode during HPPC test

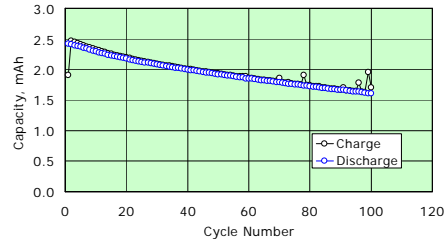
Cycle Performance at 55°C of $\text{Li}_{1.1}(\text{Mn}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3})_{0.9}\text{O}_2/\text{MCMB}$ cells with and without AlF_3 coated cathode

AlF_3 coated $\text{Li}_{1.1}(\text{Mn}_{1/3}\text{Co}_{1/3}\text{Ni}_{1/3})_{0.9}\text{O}_2$



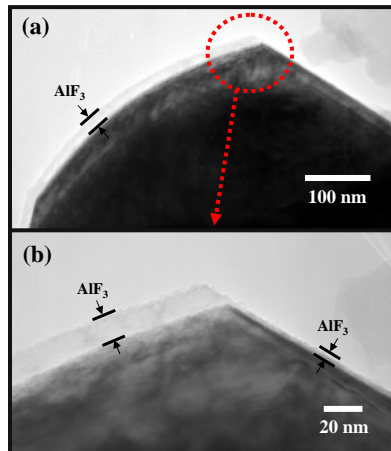
4.4V Cycle life test at C/2

$\text{Li}_{1.1}(\text{Mn}_{1/3}\text{Co}_{1/3}\text{Ni}_{1/3})_{0.9}\text{O}_2$



4.1V Cycle life test at 1C rate

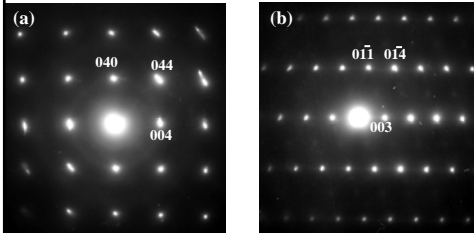
TEM image of AlF_3 -coated $\text{Li}_{1.1}[\text{Ni}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}]_{0.9}\text{O}_2$ after cycling



- The coating thickness also appear to have remained uniform
- The AlF_3 film thickness is strikingly different from one face of the particle to another face.

(a) TEM image of a primary particle from the cycled AlF_3 -coated $\text{Li}_{1.1}[\text{Ni}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}]_{0.9}\text{O}_2$ electrode, (b) magnified image of the circled region in (a).

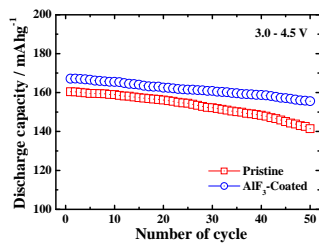
Electron diffraction of AlF_3 -coated $\text{Li}_{1.1}[\text{Ni}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}]_{0.9}\text{O}_2$ after cycling



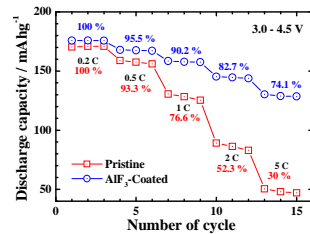
Electron diffraction analysis of the (a) pristine (b) AlF_3 -coated $\text{Li}_{1.1}[\text{Ni}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}]_{0.9}\text{O}_2$ cells after 50 cycles.

- Pristine primary particle underwent a phase transition to a cubic spinel structure during cycling
- No such phase transition was noticed from the observed primary particles of the AlF_3 -coated electrode.

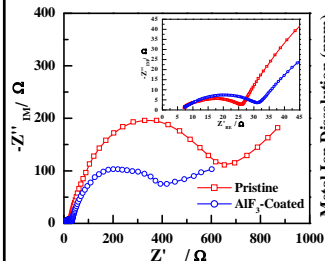
Effect of AlF_3 -coated on $\text{Li}[\text{Ni}_{0.5}\text{Mn}_{0.5}]\text{O}_2$ (L55) performance



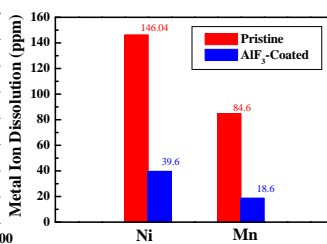
Cycling vs. Li/Li^+



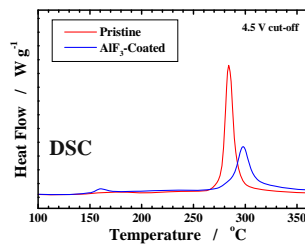
Rate capability



AC impedance

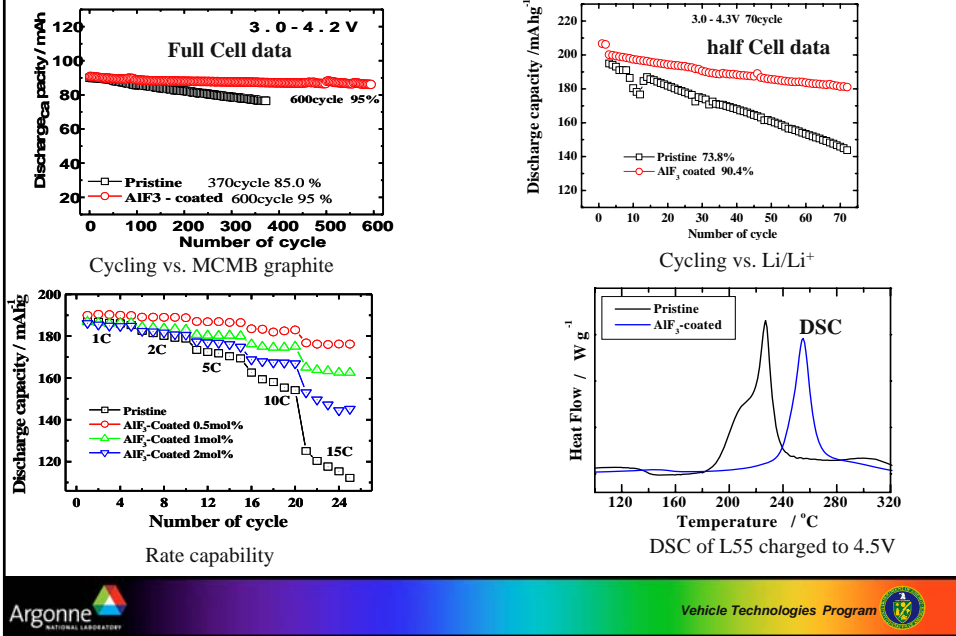


Dissolution in electrolyte at 60°C

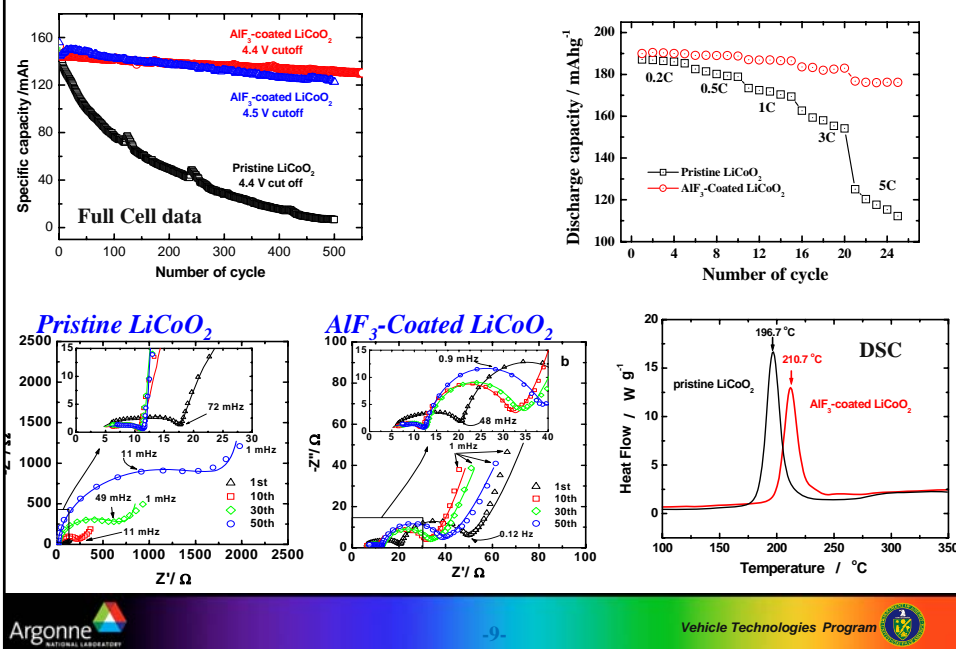


DSC of L55 charged to 4.5V

Effect of AlF_3 -coated on $\text{Li}[\text{Ni}_{0.8}\text{Co}_{0.15}\text{Al}_{0.05}]\text{O}_2$ (NCA) performance



Effect of AlF_3 -coated- LiCoO_2 cell performance



Development of new high energy $\text{Li}[\text{Li}_{(1-2x)/3}\text{Ni}_x\text{Mn}_{(2-x)/3}]\text{O}_2$ layered cathode material for PHEV applications

- Equivalent to $\text{Li}[\text{Li}_{1/3}\text{Mn}_{2/3}]\text{O}_2 \cdot \text{LiNi}_{0.5}\text{Mn}_{0.5}\text{O}_2$ composite notation
- Developed by CMT researchers (3 US patent awarded in 2004)
- The oxidation states of Ni and Mn have been confirmed as Ni^{2+} and Mn^{4+} by many experimental tools.
- Conventional wisdom predicts that only Ni is electrochemically active and, therefore, theoretical capacity decreases with increasing Li content in the TM (transition metal) layer.
- Surprisingly, however, the material exhibits much higher practical capacity than theoretical value, especially for $0.2 \leq x \leq 0.3$.
- Very interesting and important material from fundamental as well as practical point of views



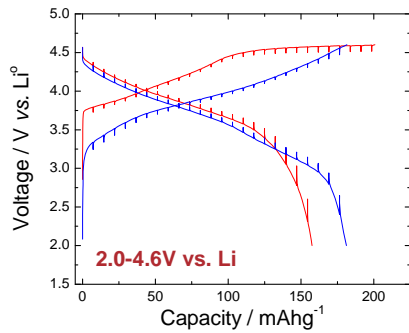
Optimization strategies for high capacity

- $\text{Li}[\text{Li}_{0.2}\text{Ni}_{0.2}\text{Mn}_{0.6}]\text{O}_2$ or $0.5\text{Li}_2\text{MnO}_3 \cdot 0.5\text{LiNi}_{0.5}\text{Mn}_{0.5}\text{O}_2$ was chosen as a starting chemistry.
- Strategies to meet the challenging target (240 ~260mAh/g)
 - Optimization of intrinsic property
 - *Chemical composition*
 - Sol-gel method
 - Optimization of extrinsic properties
 - *Morphology (dense, spherical transition metal precursors)*
 - Coprecipitation

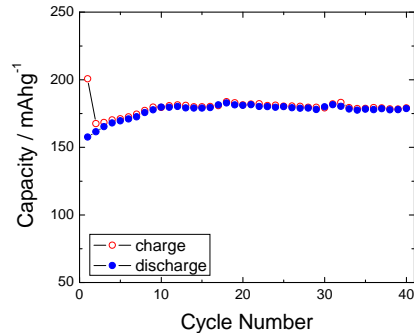


Performance of $\text{Li}[\text{Li}_{0.2}\text{Ni}_{0.2}\text{Mn}_{0.6}]\text{O}_2$ as initial start up composition

Charge/discharge curves



Cycleability



❖ The discharge capacity gradually increased from 158 to 180 mAh/g with good coulombic efficiency.



$\text{Li}[\text{Li}_{0.2}\text{Ni}_{0.2}\text{Mn}_{0.6}]\text{O}_2$ cathode material

- Theoretical capacity of the material is only 126mAh/g based on $\text{Ni}^{2+}/\text{Ni}^{4+}$ redox couple

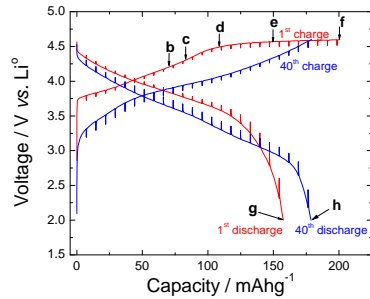


- However, the material delivered higher capacity than theoretical value.
 - 200mAh/g during the first charge: 0.63Li removed
 - 180mAh/g stable discharge capacity: 0.57Li inserted/extracted
 - Question 1: What is the charge compensation mechanism for the extra capacity?
 - Question 2: Was all of the Li extracted from Li layer?

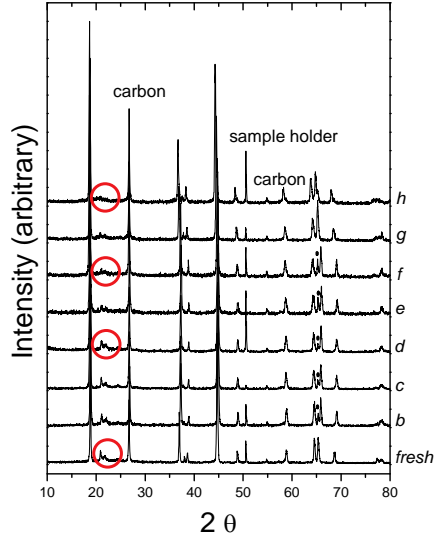


XRD result during cycling of $\text{Li}[\text{Li}_{0.2}\text{Ni}_{0.2}\text{Mn}_{0.6}]\text{O}_2$ cathode material

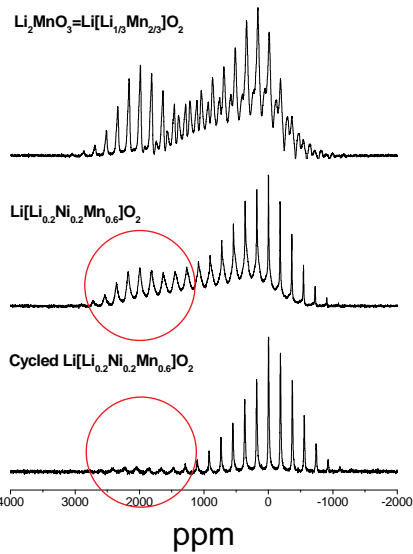
Ex-situ XRD



- ❖ The small diffraction peaks at $\sim 22^\circ$ are due to $\text{Li}^+-\text{Mn}^{4+}$ ordering in the TM layer.
- ❖ The ordering peaks started to reduce at $\sim 4.45\text{V}$.
- ❖ Li was not inserted fully back to the TM layer during discharge.



^7Li NMR of cycled $\text{Li}[\text{Li}_{0.2}\text{Ni}_{0.2}\text{Mn}_{0.6}]\text{O}_2$



^7Li MAS NMR

- ❖ Li_2MnO_3
 - ✓ Two distinct lithium sites, one in the Li layer and the other in TM layer
- ❖ As-prepared $\text{Li}[\text{Li}_{0.2}\text{Ni}_{0.2}\text{Mn}_{0.6}]\text{O}_2$
 - ✓ Similar to Li_2MnO_3
- ❖ Cycled $\text{Li}[\text{Li}_{0.2}\text{Ni}_{0.2}\text{Mn}_{0.6}]\text{O}_2$
 - ✓ Significantly reduced signal from Li in TM layer

- ❖ The XRD and NMR results indicate that Li is also extracted from the TM layer irreversibly.



Approach of improving further energy density of $\text{Li}[\text{Li}_{0.2}\text{Ni}_{0.2}\text{Mn}_{0.6}]\text{O}_2$ cathode material

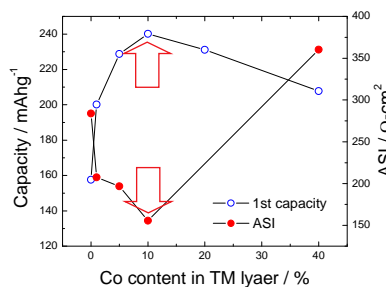
- $\text{Li}[\text{Li}_{0.2}\text{Ni}_{0.2}\text{Mn}_{0.6}]\text{O}_2$ shows higher capacity than theoretical value and many interesting behaviors.
- However, the electrical conductivity of $\text{Li}[\text{Li}_{0.2}\text{Ni}_{0.2}\text{Mn}_{0.6}]\text{O}_2$ is too low and the practical capacity is still far below the target (240mAh/g).
- To increase the conductivity and the capacity as well, chemical substitution was carried out.
 - Chemical substitution on cation sites: Cobalt
 - Chemical substitution on anion sites: Fluorine



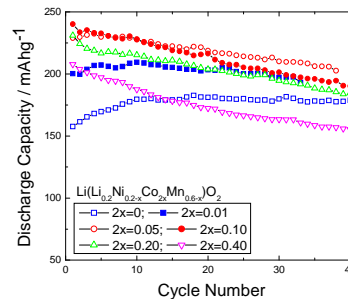
Effect of Co-substitution in $\text{Li}[\text{Li}_{0.2}\text{Ni}_{0.2}\text{Mn}_{0.6}]\text{O}_2$ cathode material

- Stabilization of layered structure
 - Increase of the electrical conductivity
 - 2.5×10^{-8} S/cm ($\text{LiNi}_{0.5}\text{Mn}_{0.5}\text{O}_2$) \Rightarrow 2.3×10^{-4} S/cm ($\text{LiNi}_{0.475}\text{Co}_{0.05}\text{Mn}_{0.475}\text{O}_2$)
- K. Amine et al., J. Power Sources 112, 41, 2002.

1st disch. capacity and impedance



Cycleability



- ❖ Substitution of Ni/Mn with 10% Co exhibited the highest 1st discharge capacity and the lowest impedance. \Rightarrow $\text{Li}[\text{Li}_{0.2}\text{Ni}_{0.15}\text{Co}_{0.10}\text{Mn}_{0.55}]\text{O}_2$
- ❖ However, the cycleability was deteriorated by the Co-substitution.

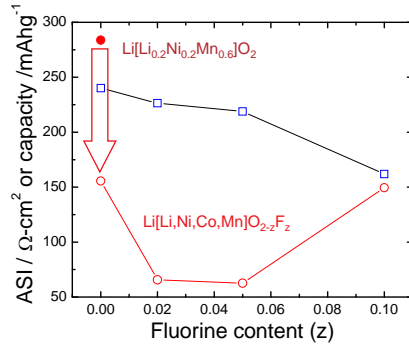


Effect of F-substitution $\text{Li}[\text{Li}_{0.2}\text{Ni}_{0.2}\text{Mn}_{0.6}]\text{O}_2$ cathode material

■ Improvement of cycleability

- Resistance to attack by HF in the electrolyte
- Minimization of Ni-migration due to weak field of F⁻ ligand
- Oxygen was substituted with fluorine in $\text{Li}[\text{Li}_{0.2}\text{Ni}_{0.15}\text{Co}_{0.10}\text{Mn}_{0.55}]\text{O}_2$.
- Possible fluorination of the surface to protect the interface

Initial capacity and impedance



- ❖ The initial discharge capacity decreased almost linearly with the fluorine content.
- ❖ The impedance was significantly lowered by small amount of F-doping.

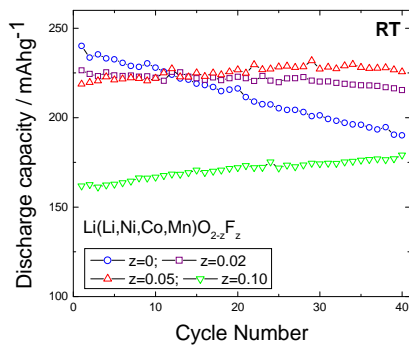


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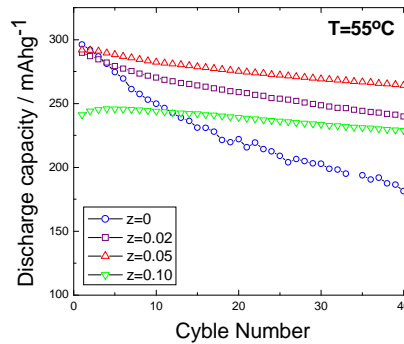


Effect of F substitution $\text{Li}[\text{Li}_{0.2}\text{Ni}_{0.2}\text{Mn}_{0.6}]\text{O}_2$ cathode material (Cont'd)

Room Temp. Cycleability



55°C Cycleability



The RT and 55°C-cycleability was greatly improved by the F-doping.

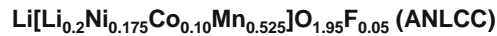


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Li[Li_{0.2}Ni_{0.175}Co_{0.10}Mn_{0.525}]O_{1.95}F_{0.05} (ANLCC) as optimum composition for high energy applications

- Based on the capacity, impedance, and cycling performance, the chemical composition was optimized.



- However, the sol-gel method is not an adequate way for mass production nor gives dense materials.
- To prepare dense ANLCC material in large scale, coprecipitation of (Ni,Co,Mn)-precursor has been investigated.
 - Li-salt + coprecipitated, dense precursor → dense ANLCC
 - (Ni,Co,Mn)-hydroxide
 - (Ni,Co,Mn)-carbonate



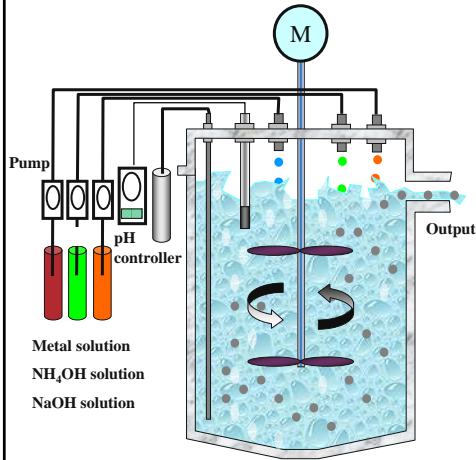
Preparation of ANLCC using Co-precipitated (Ni,Co,Mn)-hydroxide process

- It is very hard to prepare Li[Li,Ni,Co,Mn]O₂ materials with decent properties by using individual transition metal precursors.
- Using precursor materials with homogeneously mixed distribution of transition metal ions is a good strategy.
- In general, dense and spherical morphology is desirable in terms of volumetric energy density, thermal safety, and laminate fabrication.
 - It can be realized by using dense, spherical precursors.
- Coprecipitation of (Ni,Co,Mn)-hydroxide
 - $2\text{NaOH} + \text{MSO}_4 \text{ (M=Ni,Co,Mn)} \rightarrow \text{M(OH)}_2 (\downarrow) + \text{Na}_2\text{SO}_4$
 - Fine control of experimental conditions (pH, temp., feeding speed, atmosphere, etc.) is crucial to obtain dense, spherical hydroxide precursor materials.



ANL advanced continuous process for making Ni,Co,Mn- precursors used to prepare ANLCC material

- Precipitation reactor (continuous process)

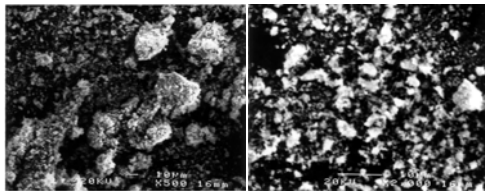


- Temperature:
- pH:
- Stirring speed:
- Concentration of metal solution:



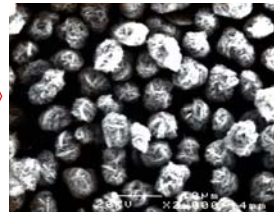
SEM of ANLCC cathode using (Ni,Co,Mn)-Hydroxide

prepared by sol-gel



0.8g/cc

ANLCC prepared by Hydroxide process

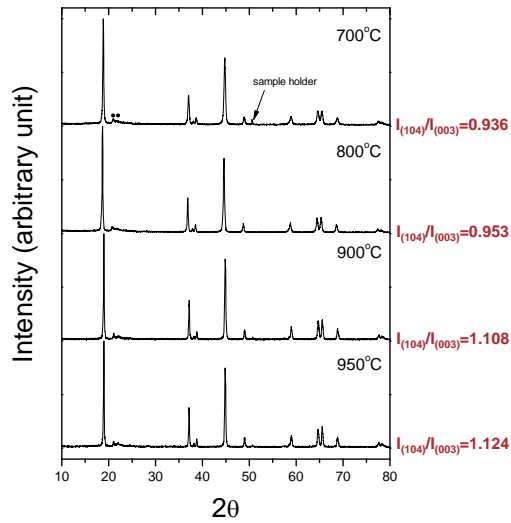


1.3g/cc

The tap density of the ANLCC material increased significantly after using co-precipitation using hydroxide process



Powder X-ray diffraction patterns of ANLCC prepared using different calcination temperature



➤ Most of the peaks could be indexed based on α - NaFeO_2 structure (R-3m).

- layered structure

➤ Small satellite peaks at $\sim 22^\circ$

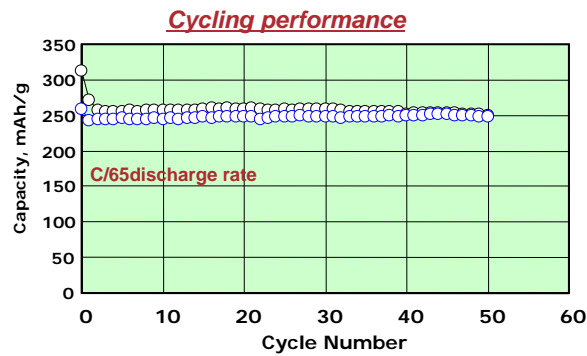
- ordering of $\text{Li}^+/\text{Mn}^{4+}$ in TM layer

➤ Intensity ratio of (104) to (003) peaks increased with increasing calcination temperature.

- increased disorder between Li and TM layers



Capacity & cycling performance of ANLCC prepared at 700°C

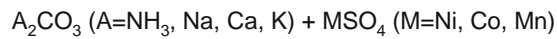


- ANLCC-700 delivered high capacity ($\sim 240\text{mAh/g}$) with good capacity retention at higher rate (C/6) electrode used.



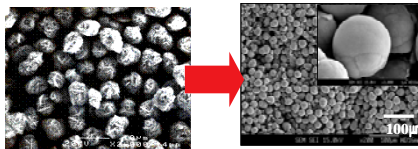
Preparation of ANLCC using Co-precipitated (Ni,Co,Mn)-carbonate process

- To further improve the morphology of ANLCC, another type of (Ni,Co,Mn) precursor is being developed.
- Carbonate co-precipitation process has many advantages over hydroxide coprecipitation process.
 - Mild condition (pH= 7~9) cf pH>12 for hydroxide coprecipitation
 - No atmosphere control is required.
 - Cheaper than hydroxide precipitation
 - Less hygroscopic
- **Carbonate co-precipitation**

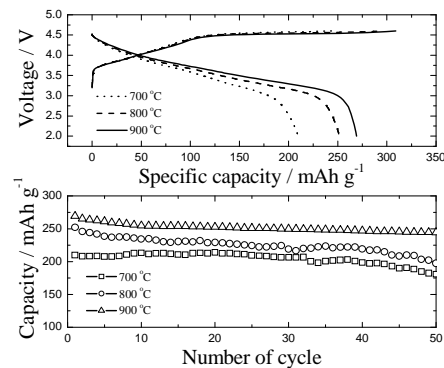


Performance of ANLCC /Li cell using Carbonate Process

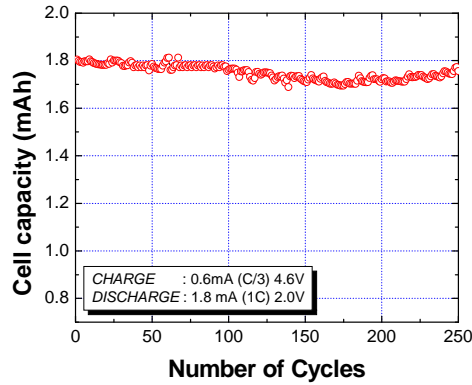
- The particle density has been improved significantly (2.1g/cc)
- The capacity improved to 270mAh/g
- Particle morphology is spherical



Powder density improved from 1.3 to 2.1 g/cc



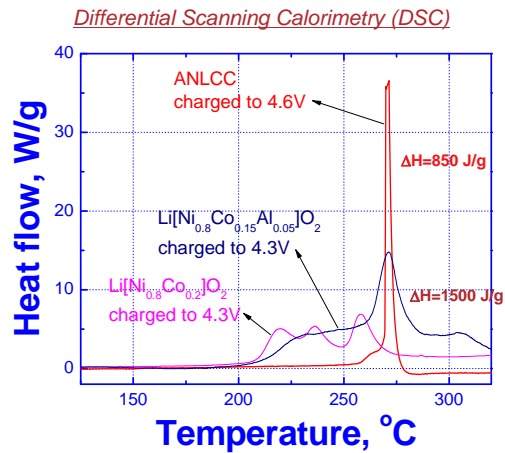
Performance of ANLCC /Graphite cell using Carbonate Process (con't)



<Test Condition>
Cut-off voltage : 2.0-4.6V vs. GDR
Loading : 1.0mAh/cm²
Electrolyte : LP40



Comparison of DSC of ANLCC with other cathode materials



ANLCC vs. Ni-based systems

- ❖ Much higher onset temperature
- ❖ Much less heat from exothermic reactions
- ❖ Much sharper peak shape
- ❖ All of these are attributed to low Ni-content (<20%).

ANLCC exhibited thermal stability superior to the state of the art- Ni-based cathode materials.



Conclusions & future works

- ✓ The AlF_3 -coated on different cathodes (NMC,NCA,NM, LiCoO_2) shows lower impedance, better cycling characteristics at high temperature, improved safety and reduced metal ion dissolution when compared to non coated cathodes
- ✓ AlF_3 coating technology can impact the power, the life and safety of HEV batteries
- ✓ AlF_3 coating technology can possibly enable some of existing cathodes in PHEV by charging to high voltage 4.3~4.4 V and possibly meeting the cycle and calendar life requirement
- ✓ ANL will continue optimizing the process to get a uniform coating on the particles to further stabilize the system
- ✓ ANL will work on scale up this technology and quantify its benefit for both HEV and PHEV in 18650 cell configuration.



Conclusions & future works (con't)

- ✓ ANL was able to optimize the composition of the layered composite via doping to obtain:
 - ✓ Very high capacities of 270mAh/g
 - ✓ Excellent cyclability at high voltage
 - ✓ Very good abuse tolerance compared to conventional layered materials
- ✓ ANL was able to develop a synthesis process to significantly increase the tap density of the materials from 0.8g/cc to 2.1g/cc to take advantage of this material high capacity in the cell.
- ✓ Material has still some issues related to rate capability and ANL will work extensively on improving the power capability of this material for application in PHEVs



Tech Transfer, Papers and patents

Tech-Transfer

- ✓ AlF₃ coating technology has been adopted by other US government agencies for space applications
- ✓ High energy material was licensed by 2 battery companies and Argonne is transferring the technology to these companies via work for others
- ✓ Several major material companies are negotiating the licensing and tech transfer of the high energy material

Patents

- ✓ 3 additional patents on fluorinated high energy materials and processes were issued in 2007



Vehicle Technologies Program



Publications

1. Significant Improvement of Electrochemical Performance of AlF₃-coated Li[Ni_{0.8}Co_{0.1}Mn_{0.1}]O₂ Cathode Materials S.-U. Woo, C.S. Yoon, K. Amine, I. Belharouak, and Y.-K. Sun; *J. Electrochem. Soc.*, **154**(11), A1005-A1009 (2007)
2. Comparative study of different crystallographic structure of LiNi_{0.5}Mn_{1.5}O_{4-δ} cathodes with wide operation voltage (2.0–5.0 V)
3. S.H. Park, S.-W. Oh, S.H. Kang, I. Belharouak, K. Amine; *Electrochimica Acta*, **52**, 7226–7230 (2007)
4. "Improvement of High Voltage Cycling Performance of AlF₃-coated Li[Ni_{1/3}Co_{1/3}Mn_{1/3}]O₂ Cathode Materials for Lithium Secondary Batteries", Y.-K. Sun, S.-W. Cho, S.-W. Lee, C. S. Yoon, and K. Amine, *J. of Electrochem. Soc.*, **154**(3), A168-A172 (2007).
5. "Structural and Electrochemical Properties of Layered Li[Ni_{1-2x}CoxMnx]O₂ (x = 0.1 - 0.3) Positive Electrode Materials for Li-Ion Batteries", K. S. Lee, S.-T. Myung, K. Amine, Y.-K. Sun, *J. of Electrochem. Soc.*, **154**(10), A971-A977 (2007).
6. Impacts of Fluorine on the Electrochemical Properties of Li[Ni_{0.5}Mn_{0.5}]O₂ and Li[Li_{0.2}Ni_{0.15}Co_{0.1}Mn_{0.55}]O₂ K. Amine, Zonghai Chen, and S.-H. Kang, *J. Fluor. Chem.*, **128**(4): 263-268 (2007).
7. Lithium Difluoro(oxalato)borate as a Functional Additive for Lithium-Ion Batteries, J. Liu, Zonghai Chen, S. Busking, and K. Amine, *Electrochem. Commun.*, **9**(3): 475-479 (2007).
8. Lithium Difluoro(oxalato)borate as New Salt for Lithium-Ion Batteries, Zonghai Chen, J. Liu, and K. Amine, *Electrochem. Solid-State Lett.*, **10**(3): A45-A47 (2007).
9. Electrochemical Characterization of MCMB/LiNi_{1/3}Mn_{1/3}Co_{1/3}O₂ Using LiBOB as an Electrolyte Additive Wenqiang Lu, Zonghai Chen, H. Joachin, J. Prakash, J. Liu, and K. Amine, *Thermal and J. Power Sources*, **163**: 1074-1079 (2007).
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11. Synthesis and Electrochemical properties of spherical spinel Li_{1.05}Mg_{0.05}Mn_{1.9}O₄ (M = Mg and Al) as a cathode material for lithium ion batteries by co-precipitation method", K. -S. Lee, H. J. Bang, S.-T. Myung, J. Prakash, K. Amine, *J. of Power Sources*, in press (2008).
12. Effect of AlF₃ Coating Amount on High Voltage Cycling Performances of LiCoO₂; Y.-K. Sun, S.-W. Cho, S.-T. Myung, K. Amine, I. Belharouak, and Jai Prakash.; *Electrochimica Acta*, in press (2008).
13. Improvement of structural and electrochemical properties of AlF₃-coated Li[Ni_{1/3}Co_{1/3}Mn_{1/3}]O₂ cathode materials at high voltage region", B.-C. Park, H.-B. Kim, S.-T. Myung, K. Amine, I. Belharouak, S.-M. Lee, and Y.-K. Sun, *J. of Power Sources*, in press (2008).



Vehicle Technologies Program



Publications (part 2)

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15. "Significant Improvement of High Voltage Cycling Behavior AlF₃-Coated LiCoO₂ Cathode", Y.-K. Sun, J.-M. Han, S.-T. Myung, S.W. Lee, and K. Amine, **Electrochem. Commun.**, **8(5)**, 821-826 (2006).
16. "Synthesis and characterization of spherical morphology Li_{0.4}Ni_{0.4}Co_{0.2}Mn_{0.4}O₂ materials for lithium secondary batteries", Sung Woo Oh, Sang-Ho Park, K. Amine, and Yang-Kook Sun, **J. of Power Sources**, **160(1)** 558-562 (2006).
17. "High capacity Li_{0.2}Ni_{0.2}Mn_{0.6}O₂ cathode materials via carbonate co-precipitation method", D.-K. Lee, S.-H. Park, K. Amine, H J Bang, J. Prakash, and Y.-K. Sun, **J. of Power Sources**, **162(2)**, 1346-1350 (2006).
18. Significant improvement of high voltage cycling behavior AlF₃-coated LiCoO₂ cathode
Y. K. Sun, J. M. Han, S. T. Myung, S. W. Lee and K. Amine; **Electrochemistry Communications**, **8**: 821-826 (2006).
19. Synthesis and characterization of spherical morphology [Ni_{0.4}Co_{0.2}Mn_{0.4}]O₂ materials for lithium secondary batteries
S. W. Oh, S.-H. Park, K. Amine and Y.-K. Sun; **Journal of Power Sources**, **160**: 558-562 (2006).
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Z. H. Chen, Y. K. Sun and K. Amine; **Journal of the Electrochemical Society**, **153**: A1818-A1822 (2006).

