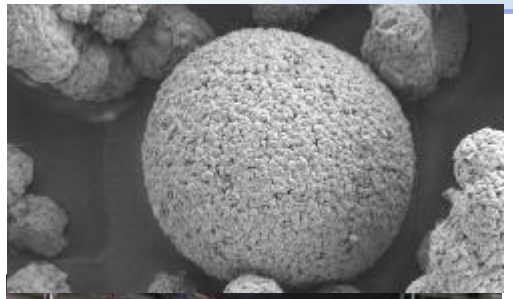

GEMX™ : A Platform for Advanced High-Nickel Cathode Active Materials

Product Overview

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CAMX Power
35 Hartwell Avenue
Lexington, MA
02421-3102

www.camxpower.com

GEMX™ A Platform for Advanced High-Nickel Cathode Active Materials

- CAMX Power ("CAMX") based in Lexington, MA has invented GEMX™, a class of cathode materials which enables high-performance, high-nickel, low-cobalt materials for Li-ion batteries.
  - CAMX-invented GEMX™ cathode platform is based on the engineering of grain boundaries of cathode particles to help overcome the issues associated with high-nickel, low-cobalt cathode materials.
  - Published peer-reviewed articles have characterized and confirmed many benefits of enrichment of the grain boundaries of high-nickel cathode materials, with demonstrated application in leading cathode chemistries such as NMC, NCA, and LNO.
- The GEMX™ cathode platform is protected by granted patents worldwide, including USA, Europe, China, Japan and Korea, and are valid beyond 2030.
- Samsung and Johnson Matthey have licensed GEMX™.
- Li-ion cells with GEMX™ cathode platform are available on the market today.

High-Nickel Cathode Materials will Enable the EV revolution

- In 2020, ~2 MM electric vehicles (EVs) will be sold worldwide. This will grow to ~10 MM EVs in 2025 and ~25 MM in 2030. (Bloomberg New Energy Finance)
- These EVs will be powered by Li-ion cells with high-nickel, low-cobalt cathodes.
- ~1 MM tons of cathode will be required in 2025 and ~2.5 MM tons in 2030, for a cathode material market size of ~$25 B and ~$65 B in 2025 and 2030, respectively.
- Today the cathode material cost assumes ~30% of the total cell cost and largely determines the overall performance of the cell.
- Cells with conventional high-nickel cathode materials suffer from premature performance decline that can be traced to degradation of the grain boundary region of these materials.

GEMX™ Cathode Platform Benefits

GEMX™ overcomes the issues associated with high-nickel cathode materials and offers unique benefits

- Reduced Total Cobalt
- Higher Power
- Higher Energy
- Better Extreme Temperature Performance
- Longer Cycle Life
- Lower Impedance Growth
- Flexible Synthesis with Minimal Processing Steps
- Improved Electrode & Cell Fabrication Properties

GEMX™ Excels Across the Manufacturing Chain

Synthesis

- Reduced total cobalt content
- Flexibility in tuning composition
- Low LiOH and Li_2CO_3 in cathode material
- No need for water washing
- No waste water from synthesis
- Ability to use impure LiOH

Electrode & Cell Fabrication

- Improved slurry properties
  - reduced gelling
  - stable rheology
- Improved fracture resistance
- Press electrodes to higher densities while preserving life

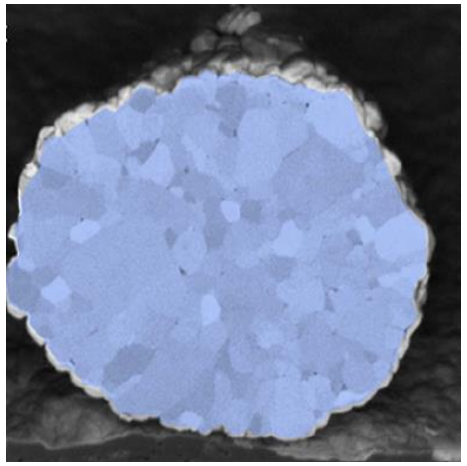
Excellent Performance

- Higher rate & power capability
- Wider state-of-charge window
- Better low-temperature performance
- Higher cycle life
- Less impedance increase
- Less gas generation
- Less metals dissolution

GEMX™ cathode platform simultaneously benefits synthesis, electrode & cell fabrication, and performance

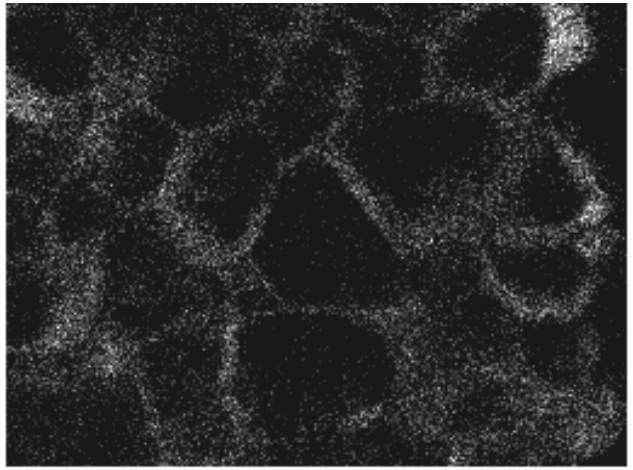
GEMX™ Engineers the Grain Boundaries of High-Nickel, Low-Cobalt Materials

Uncycled High-Nickel Cathode Material (conventional)

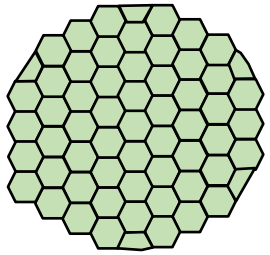


SEM micrograph*

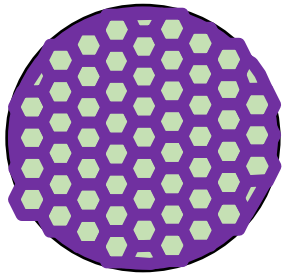
Uncycled Grain Boundary-Enriched High-Nickel Cathode Material (GEMX™)



STEM with EDS map of cobalt



Conventional High-Nickel



GEMX™

- High-nickel cathode powders are composed of dense agglomerates of smaller particles, allowing for both high tap-density and low impedance.
- However, exposure of internal surface upon cycling accelerates degradation and performance decline.
- GEMX™ grain boundary cobalt enrichment is a fundamental enhancement of cathode active materials in Li-Ion batteries.
- GEMX™ enriches the cobalt in the regions within the particle where it is needed the most, thereby enabling reduction elsewhere in the particle.

Chem. Mater. 31.2 (2018): 491-501.

NCA, NCM, and LNO are Enhanced by GEMX™ Cathode Platform: gNCA™, gNCM™, gLNO™

$LiNi_bCo_cAl_dO_2$ (NCA)	$LiNi_bCo_cMn_eO_2$ (NCM)	$LiMg_aNi_bCo_cQ_fO_2$
• Core is stabilized by Co and Al	• Core is stabilized by Co and Mn	• Core is stabilized by Mg and Co

Further stabilized by enrichment of the grain boundaries with cobalt (and other elements)

GEMX™

gNCA™	gNMC™	gLNO™
➢ gNCA™ demonstrates similar performance as conventional NCA (15 mol % Co) but with significantly less Co	➢ gNMC™ with 10 mol % Co exhibits superior performance compared to commercial NMC(811)	➢ gLNO™ has best combination of capacity and life

Several Papers From the Recent Published Literature Characterize in Detail and Confirm the Benefits of Grain Boundary Enrichment

1. *A New Coating Method for Alleviating Surface Degradation of $LiNi_{0.6}Co_{0.2}Mn_{0.2}O_2$ Cathode Material: Nanoscale Surface Treatment of Primary Particles*, Hyejung Kim, Min Gyu Kim, Hu Young Jeong, Haisol Nam, and Jaephil Cho. Nano Lett. 2015, 15, 2111−2119.

2. *High-Performance and Industrially Feasible Ni-Rich Layered Cathode Materials by Integrating Coherent Interphase*. Kyoungmin Min, Changhoon Jung, Dong-Su Ko, Kihong Kim, Jaeduck Jang, Kwangjin Park, and Eunseog Cho. ACS Appl. Mater. Interfaces 2018, 10, 20599−20610.

3. *Enhancing Interfacial Bonding between Anisotropically Oriented Grains Using a Glue-Nanofiller for Advanced Li-Ion Battery Cathode*, Hyejung Kim, Sanghan Lee, Hyeon Cho, Junhyeok Kim, Jieun Lee, Suhyeon Park,, Se Hun Joo, Su Hwan Kim, Yoon-Gyo Cho, Hyun-Kon Song, Sang Kyu Kwak, and Jaephil Cho. Adv. Mater. 2016, 28, 4705–4712.

4. *A Highly Stabilized Nickel-rich Cathode Material by Nanoscale Epitaxy Control for High-energy Lithium-ion Batteries,* Junhyeok Kim, Hyunsoo Ma, Hyungyeon Cha, Hyomyung Lee, Jaekyung Sung, Minho Seo, Pilgun Oh, Minjoon Park and Jaephil Cho. Energy & Env. Sci. 2018, 11, 1449–1459

5. *Residual Li Reactive Coating with Co_3O_4 for Superior Electrochemical Properties of $LiNi_{0.91}Co_{0.06}Mn_{0.03}O_2$ Cathode Material*, Kyoungmin Min, Kwangjin Park, Seong Yong Park, Seung-Woo Seo, Byungjin Choi, and Eunseog Cho, Journal of The Electrochemical Society 2018, 165 (2) A79-A85.

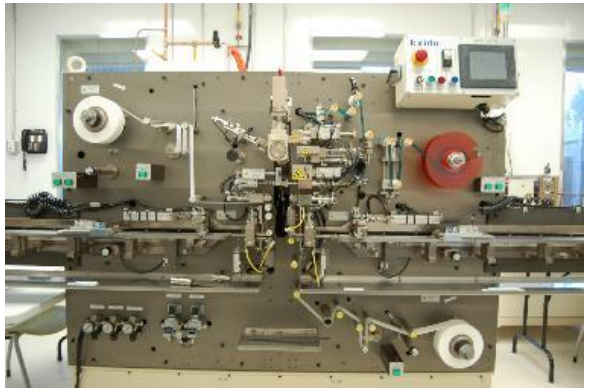
The GEMX™ Cathode Platform in the Market

- Recently Samsung **ACQUIRED** a global non-exclusive license to the GEMX™ cathode platform.
- Samsung is already selling cells with GEMX™ equivalent cathode material in the US and internationally.
- Samsung and a Korean partner are adding a 150,000 ton capacity to an existing 30,000 ton plant in South Korea to be completed by 2023.
- CAMX believes a significant fraction of this capacity will be dedicated to gNCA™ and gNMC™ equivalent cathode materials.

- Previous licensees of GEMX™ include Johnson Matthey and of CAMX's earlier cathode platform CAM-7®, BASF and Johnson Matthey.

The Success of GEMX™ in the Marketplace with Major Manufacturers is a Validation of CAMX's Business Model

Early Stage Technologies (Internal and External Sources) → **CAMX Technology Processing** → **Low-Rate Initial Production at CAMX** → **Technologies and Products for Rapid Adoption by Manufacturers** → **Partnering with High-Volume Manufacturers**



- De-Risked
- Scaled-up
- IP-Protected

- Accelerated Growth
- Shortened Time to Market & Profitability
- Lower Risk & Cost
- CAMX Staff Engageable for Interactive Technology Transfer