Using nano scale materials to create a new generation of high performance Lithium-Ion batteries

A123Systems owes its name to the Hamaker force constant which is used to calculate the attractive and repulsive forces between particles at nano dimensions.

$$A_{123} \equiv \frac{3}{4} kT \left(\frac{E_1 - E_2}{E_1 + E_2} \right) \left(\frac{E_3 - E_2}{E_3 + E_2} \right) + \frac{3}{8} \frac{h\nu_e}{\sqrt{2}} \frac{(n_1^2 - n_2^2)(n_3^2 - n_2^2)}{(n_1^2 + n_2^2)^{1/2} (n_3^2 + n_2^2)^{1/2} \{ (n_1^2 + n_2^2)^{1/2} + (n_3^2 + n_2^2)^{1/2} \}}$$

About A123Systems

- A123Systems is an energy company founded at MIT in 2001. We are headquartered in Watertown, MA and operate 100,000 s.f. of dedicated space through a combination of wholly owned and exclusive use partner facilities in Detroit (HEV R&D center), China, Korea and Taiwan.

- We have developed a new generation of lithium-ion batteries offering a quantum improvement in power, safety and life. This game changing technology will enable a new age of cordless and transportation products that are portable yet offer more power than corded alternatives.

- Projects with multiple Fortune 500 customers in excess $100M. Manufacturing capacity in place to support $40M revenue in 2006.

- Strong traction with multiple automakers for the use of A123 batteries in hybrid vehicles and electric drive systems. Our unique performance capabilities address power and cost barriers limiting HEV adoption.

- The company has raised $62M in financing to date from investors including:

2002 - Seed funding

The New York Times on the web

From Humble Materials, a Burst of Power for Batteries

October 3, 2002
By ANNE EISENBERG

ATTERY development may have gotten a boost from an unexpected source. A research group at the Massachusetts Institute of Technology has found that adding a pinch of a metal-containing compound to an inexpensive material greatly increases its conductivity.

Rechargeable batteries made with the souped-up material may one day prove useful in hybrid gas-electric vehicles, power tools and other applications in which a lot of relatively inexpensive power is required.

At present, most rechargeable batteries in portable electronics use lithium cobalt oxide for the positive electrode. But cobalt is a relatively expensive metal, so for years researchers have been looking for a replacement that costs less.

Now, Yet-Ming Chiang, a professor of materials science and engineering at M.I.T., and members of his research group there say they have found a way to transform an extremely inexpensive base material, lithium iron phosphate, into one every bit as conductive as its cobalt-based counterpart, at a fraction of cobalt's cost. Details of the experiment are reported in the October issue of the journal Nature Materials.

Lithium iron phosphate has long been of interest to researchers for potential use in batteries because it is inexpensive, nontoxic and stable. But commercial development has been held back by its low conductivity.

In a series of experiments, the M.I.T. group inserted a small amount of a metal doping agent, or additive, to the lithium iron phosphate that markedly improved its conductivity.

Other groups have sought to increase the conductivity of lithium iron phosphate by coating particles of it with carbon. But Dr. Chiang believed that there were advantages to improving the intrinsic properties of the material.

"I did not believe the conventional wisdom in the battery field that the material could not be made inherently conductive," he said. Instead, Dr. Chiang borrowed a page from solid-state physicists, who have long put different elements in materials to make them more conductive.

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Dr. Chiang's experiments took about a year. Most of that time, he said, was spent trying to distribute the elemental additive, a metal ion like niobium, uniformly in the crystal lattice of the parent compound, as well as place it at the necessary positions in the crystal to affect conductivity. Along the way, the group synthesized more than 50 experimental samples of the material.

In an accompanying article in Nature Materials, Michael Thackeray, a researcher at Argonne National Laboratory in Illinois who specializes in lithium battery materials, wrote that the remarkable increase in the bulk electronic conductivity of lithium iron phosphate had exciting implications for the future use of the material in a new generation of lithium-ion batteries.

"By inducing inherent conductivity by this eight orders of magnitude," he said in an interview, "the group has transformed the electrical properties of the material substantially."
Dr. Thackeray did have one reservation. The materials used for the experiment were synthesized from carbon-containing substances and retained carbon residue. This raises the possibility that the carbon was responsible for the increase in conductivity.

"But the authors address this possibility carefully in the paper," he said, ruling it out on the ground that samples to which no doping agent was added contained similar amounts of carbon and that high-resolution electron microscopy did not reveal any surface carbon. The deep black color of the doped sample, too, was an outward indication of the material's enhanced conductivity.

Dr. Chiang has jointly founded a battery technology company that has licensed the process from M.I.T. and is working on commercializing it. "The raw materials that go into the compound are about a quarter of the cost of those for lithium cobalt oxide," he said.

George E. Blomgren, a consultant in battery technology in Lakewood, Ohio, said that the material's potential to yield very high power made it particularly interesting.

"The power capability Chiang has shown is well beyond that of the current nickel metal hydride batteries used in present hybrid electric vehicles," Dr. Blomgren said. High battery power density is required, for example, in most hybrid electric vehicles for rapid acceleration and to generate electricity for later use when someone slams on the brakes.

Ralph J. Brodd, a battery industry consultant in Henderson, Nev., said that Dr. Chiang's material offered advantages not only in terms of cost and power but in stability as well. "There's less likelihood of its decomposing, liberating oxygen inside the cell and creating safety problems," he said.

But the new material is unlikely to find much use in laptop computers and related applications in which a lot of energy must be supplied in a small space, said M. Stanley Whittingham, a professor of materials and inorganic chemistry and director of the Institute for Materials Research at the State University of New York at Binghamton.

"The energy stored per unit volume in his material is poorer than that in present lithium batteries," he said, "though the material may find a use in large batteries, where cost is very important."

Jeff Dahn, a professor of physics and chemistry at Dalhousie University in Halifax, Nova Scotia, who specializes in new materials for advanced batteries, agreed that materials like Dr. Chiang's might have a home in large batteries, whose developers have to worry about the cost of the cathode material and its stability with respect to other cell components. "It might have a place, for instance, in abusive situations like automobile accidents where the battery is crushed," he said.

Dr. Dahn, meanwhile, has not abandoned the alternative route of coating lithium iron phosphate particles with carbon to increase their conductivity. "Just mixing the substances efficiently with carbon might still do the trick," he said. "In the end, lithium iron phosphate is going to make a big difference to all of us in battery technology."

- 5 people
- $100,000 DoE Phase I SBIR
- 0.5g of material from MIT

2006 - Mass production

THE WALL STREET JOURNAL. ONLINE — DOWJONES

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November 2, 2005

New Type of Battery Offers Voltage Aplenty—at a Premium

By WILLIAM M. BULKELEY
Staff Reporter of THE WALL STREET JOURNAL

A new generation of rechargeable batteries—delivering far more power than their predecessors—is energizing the power-tool industry and generating widespread interest in applications in everything from vacuum cleaners to ride-on lawn mowers to hybrid cars.

The new lithium-ion batteries—powering a host of products already on the market and envisioned for others on the drawing board—are made possible by technical breakthroughs in lightweight lithium-ion cells, introduced in rechargeables in the 1990s but until recently deemed too volatile for safe high-power use.

Black & Decker Corp. says that early next year it plans to introduce a family of 36-volt power tools in its professional DeWalt line, including circular saws, reciprocating saws, a rotary hammer for drilling into concrete and an impact wrench powerful enough to unscrew lug nuts on truck tires. They will have double the power of 18-volt tools, now the most common cordless devices carried by carpenters and contractors.

Charged Up
World-wide battery sales in 2004, in billions:

Lead acid auto	$15.8
Alkaline	6.0
Rechargeable lithium ion	5.0
Other lead acid	3.2
Rechargeable nickel	1.8

Source: Frost & Sullivan

DeWalt's lithium-ion batteries come from **A123 Systems** Inc., a Watertown, Mass., start-up that has licensed patents from the Massachusetts Institute of Technology. Germany's Robert Bosch GmbH also plans new high-powered cordless tools next year, and says it is working with two lithium-ion battery suppliers. Earlier this year, Milwaukee Electric Tool Corp., a unit of Hong Kong's TechTronics Ltd., introduced slightly less powerful 28-volt cordless tools powered by lithium-ion batteries made by a Canadian unit of Taiwan's E-One Moli Energy Corp.

When A123 showed DeWalt its technology two years ago, "it was the first thing we saw that could meet all our needs, particularly on durability and run time," says Christine Potter, DeWalt's cordless-product manager. In DeWalt tests, drills with the new batteries bored 200 to 300 holes through a two-by-four on a single charge versus 100 holes with the 18-volt model.

The technology driving A123 is based on discoveries by MIT professor Yet-Ming Chiang, a materials scientist. Dr. Chiang, who co-founded A123, says "research in batteries is very seductive," because it initially looks easy to boost power, but many variations turn out to shorten battery life or make batteries so unstable that runaway oxidation explosions occur. "They are chemically complex, electrically complex and mechanically complex," he says.

- Producing millions of batteries per year and over 100 tons of active materials
- Over $100M in contr.acts from Fortune 500 customers
- 170 employees, $62M in financing

Management team

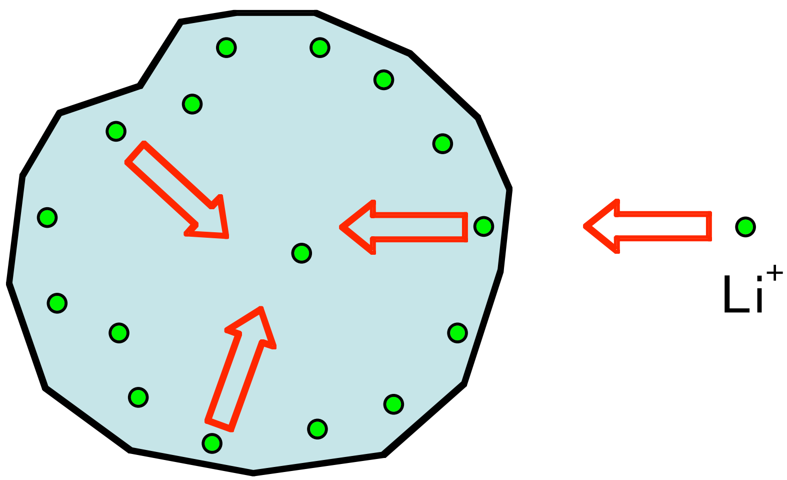
- **David Vieau (CEO and President):**
  Former VP of BD and Marketing for American Power Conversion (NASDAQ: APCC), the world leader in UPS systems
- **Ed Bednarcik (VP and GM of Pack and Systems):**
  Former VP Global Sales at American Power Conversion, VP/GM for $1B+ product division at APC.
- **Prof. Yet-Ming Chiang (Founder):**
  Co-Founder of American Superconductor (NASDAQ: AMSC) and MIT Professor
- **Ric Fulop (Founder and VP BD and Marketing):**
  Founder of 4 venture backed startups in semiconductors, software and wireless communications
- **Lou Golato (VP of Operations):**
  30 semiconductor ops career, most recently VP Ops with Unitrode (acq. by Texas Instruments).
- **Guy Hudson (VP Sales):**
  15 year career in sales and management with Sanyo, world leader in rechargeable batteries
- **Dr. Bart Riley (Founder and VP R&D):**
  Leader in developing world's first High Temperature Superconductor wire products at American Superconductor
- **Mike Rubino (CFO):**
  CFO of: Maker (IPO, acq. Conexant), Telephotonics (acq. DuPont), Agile (acq. Lucent), BICC (acq. 3COM)

Outside directors and investors*

- **Desh Deshpande (Chairman of A123Systems):** Chairman of Cascade (NASDAQ: CSCC) and Sycamore (NASDAQ: SCMR)
- **Paul Jacobs**, President and CEO of Qualcomm
- **Jeff McCarthy**, General Partner, NorthBridge
- **Michael Moritz**, General Partner, Sequoia Capital*
- **Howard Anderson**, Prof. MIT Sloan School of Mgmt.*

Core technology behind our high power chemistry

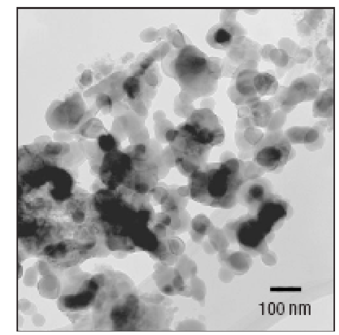
Oxides based Li Ion (conventional technology)

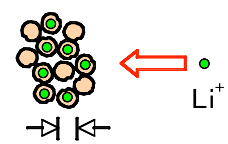


Conventional Li Ion diffusion: particle size needs to be large in order to prevent side-reactions and for safety reasons, as a result conventional Li Ion has poor rate capability

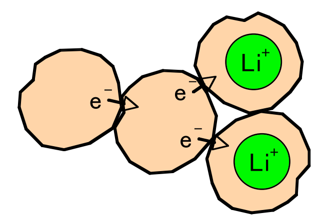
A123 doped nanophosphate

Better battery enabled by new nano-materials





100 times smaller than conventional oxides.



Orders of magnitude more conductive than conventional phosphates

A123Systems active materials are so intrinsically stable that particle size can be reduced to nano-scales for drastically increased power without safety or life degradation

First product: The 26650 high power cell

Features

- **Power:** >110Wh/kg, >3000W/kg and 100C pulse discharge capability
- **Safety:** Intrinsically safe chemistry and environmentally friendly
- **Life:** Significant improvement in life vs. other high power cells

Novel cell design IP

- New mechanical cell design (5 distinct design features with patents applied for)
- Ultra low impedance electrode design

A123 SYSTEMS

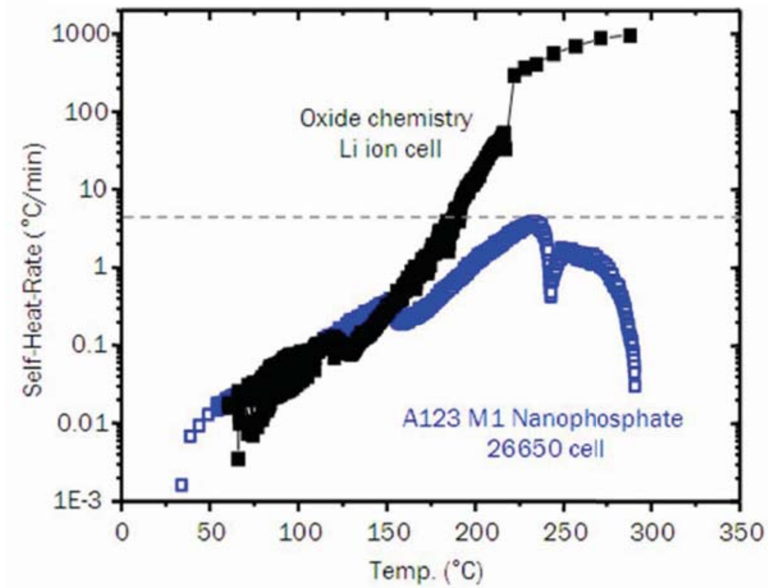
Power

A123 doped nanophosphate cells deliver excellent power density

Pulse duration	Pulse current	Pulse power density
5 sec	100 A	3120 W/kg
5 sec	150 A	3400 W/kg
5 sec	175 A	3480 W/kg
5 sec	200 A	3300 W/kg

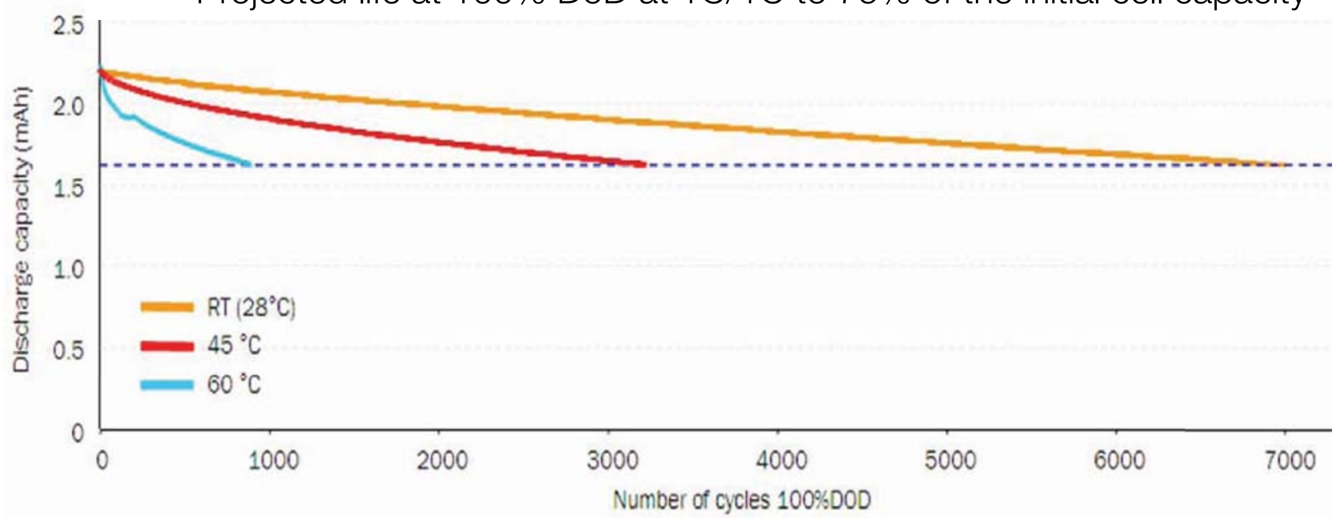
Intrinsic safety

A123 cells do not undergo thermal runaway thanks to their intrinsically safe chemistry



Excellent Life

Projected life at 100% DoD at 1C/1C to 75% of the initial cell capacity



A123Systems technology is ideal for hybrid electric vehicle objectives

HEV battery requirements:

- Low cost and long life ($20/kW and 15 year life)
- Small and light (<40 kg)
- Safe

	Toyota PEVE Prius NiMH (21kW)	Current Li Ion HEV alternatives
Weight	100 lbs	40 lbs
Safety	Excellent	Not acceptable
Life	> 10 years	> 10 years

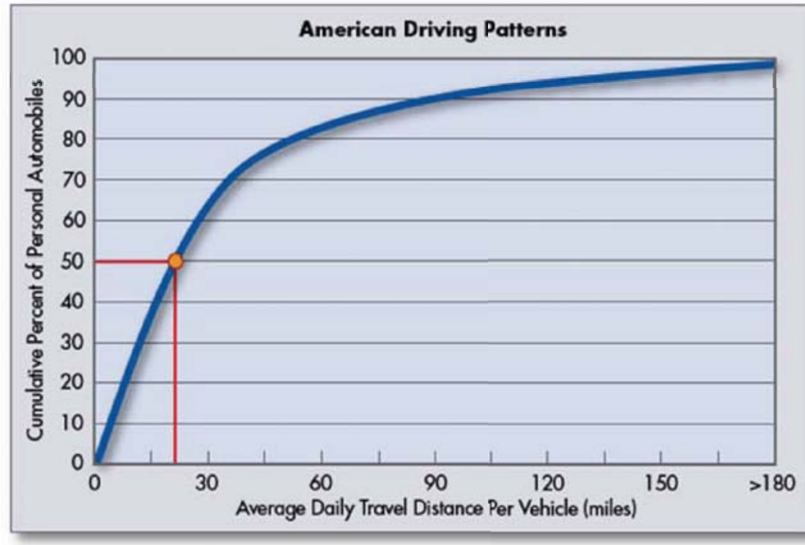
A123 2006 (using current cells)	A123 2008* (using HEV optimized cells)
20 lbs	15 lbs
Excellent	Excellent
> 10 years	15 years

(*) USABC proposal submitted to optimize cells and packaging for HEV application

An enabling technology for Plug In Hybrids

Plug In Hybrid battery requirements:

- Safety
- Low cost
- Long life
- Small size



Because half the cars on U.S. roads are driven 25 miles a day or less, a plug-in electric hybrid vehicle with even a 20-mile-range battery could reduce petroleum consumption by about 60%.

Sedan PHEV 20	NiMH	Li Ion	A123 2006 current cell	A123 2009*
Weight	398 lbs	199 lbs	110 lbs	110 lbs
Safety	Excellent	Not acceptable	Excellent	Excellent
Life	> 10 years	Unknown	15 years	15 years

(*) Pending development and funding

Stationary batteries for solar and wind

Stationary power battery requirements:

- Low cost for 20 years of service
- Small size (for residential solar)
- Safety

	Lead acid 2010	Li Ion 2010	A123* 2010
Battery life at >80% DoD	4 years	7 years	20 years
Size per 20kWh	12.3 cu. ft	5 cu. ft.	4 cu. ft
Safety	Excellent	Not acceptable	Excellent

(*) Pending development and funding

Summary

Our mission

To develop rechargeable batteries with unmatched power, safety and life, and thereby enable a new generation of portable, cordless, transportation and alternative energy products

- Good combination of University, Government, Venture Capital and Business to create a new world leading technology
- Differentiated technology with dramatic performance and cost benefits
- Technology validation in significant commercial application provides traction for transportation and storage for alternative energy sources