"Breaking Down the Barriers to Commercialization of U.S. Battery Innovation"

Opportunities and challenges for private companies in licensing and commercialization of technologies from the U.S. national laboratory system

Sion Power, Building the Future of Batteries, Now

Michael Fetcenko

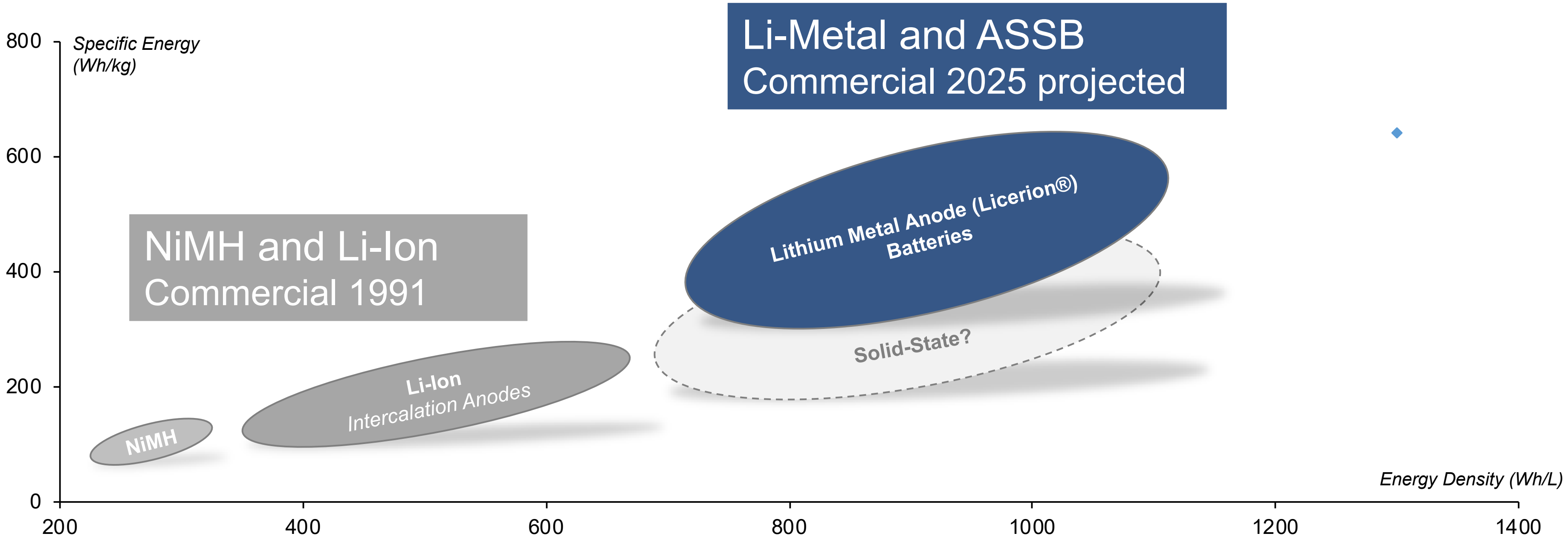
Executive Chairman, Sion Power Corporation

mfetcenko@sionpower.com

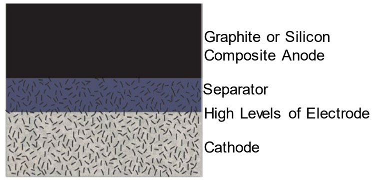
NAATBatt, February 22, 2023 Phoenix

Rechargeable Battery Technology

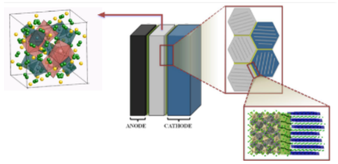
For 100 years, only Lead-Acid and Nickel Cadmium. NiMH and Li-Ion in 1991.
What is next and when?



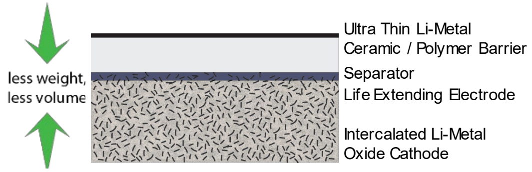
TRADITIONAL LITHIUM BATTERY



SOLID-STATE



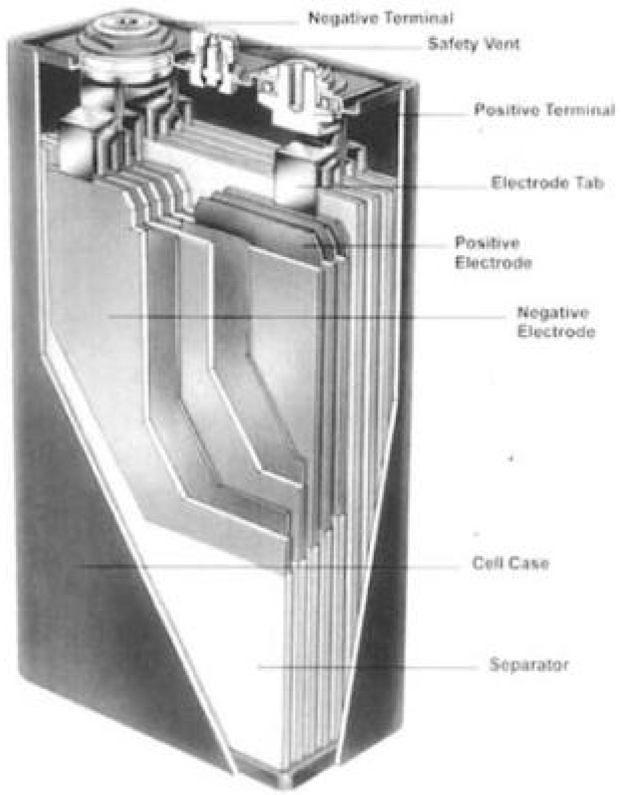
Li Metal Anode LICERION®



Nickel – Metal Hydride (NiMH)

Nickel-Metal Hydride

Metal hydride anode, nickel hydroxide cathode, water based alkaline electrolyte



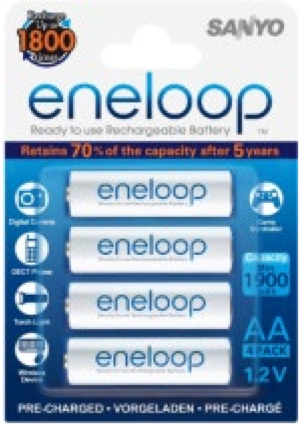
Button, Cylindrical, Prismatic Cells 50 mAh→ 200 Ah

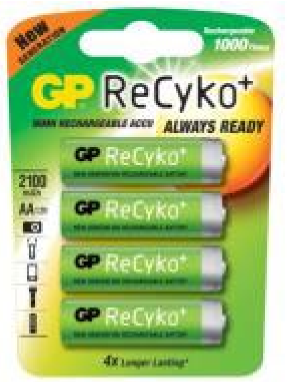
30 Million Hybrid Cars, Billions per year Consumer Cells

Major NiMH Consumer Producers

Creating Chemistry for a Sustainable Future

1 NiMH AA cell replaces 1000 Primary Alkaline Cells





Technology creating a better future
FDK

GP Batteries

eneloop
Ready to use Rechargeable Battery

GS YUASA

SANYO

Panasonic

HP® 深圳市豪鹏科技有限公司
SHENZHEN HIGHPOWER TECHNOLOGY CO.,LTD.

NiMH continues to replace Primary Alkaline

Reprint Series
9 April 1993, Volume 260, pp. 176–181

SCIENCE

1993 Article in Science – "A Nickel Metal Hydride Battery for Electric Vehicles"

A Nickel Metal Hydride Battery for Electric Vehicles

S. R. Ovshinsky, M. A. Fetcenko, and J. Ross

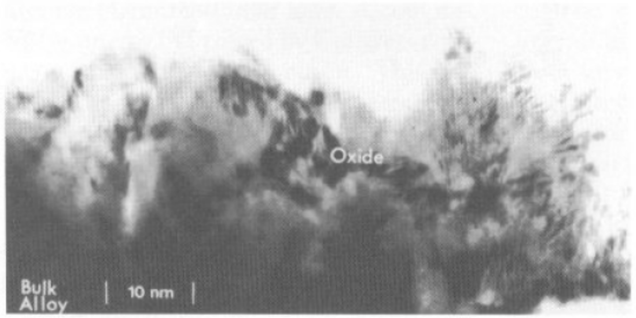


Fig. 2. Scanning transmission electron micrograph of the metal-electrolyte interface of an Ovonic MH battery electrode that shows the structure of the engineered multiphase bulk alloy and surface oxide.

A Nickel Metal Hydride Battery for Electric Vehicles

S. R. Ovshinsky, M. A. Fetcenko, J. Ross

Widespread use of electric vehicles can have significant impact on urban air quality, national energy independence, and international balance of trade. An efficient battery is the key technological element to the development of practical electric vehicles. The science and technology of a nickel metal hydride battery, which stores hydrogen in the solid hydride phase and has high energy density, high power, long life, tolerance to abuse, a wide range of operating temperature, quick-charge capability, and totally sealed maintenance-free operation, is described. A broad range of multi-element metal hydride materials that use structural and compositional disorder on several scales of length has been engineered for use as the negative electrode in this battery. The battery operates at ambient temperature, is made of nontoxic materials, and is recyclable. Demonstration of the manufacturing technology has been achieved.

The interest in electrically powered vehicles extends nearly as far back as interest in vehicles powered by hydrocarbon fuels. Throughout this period, however, there has been a major technological barrier to the development of practical electric vehicles (EVs) that can compete in performance and cost with those that use internal combustion (IC) engines. This barrier has been the lack of an economical battery with sufficient energy density and other essential performance criteria. In this article, we describe the science and technology of a nickel metal hydride (NiMH) battery that will permit future EVs to replace IC-powered vehicles in many applications.

Recently, U.S. federal and state governments have been providing an impetus for the development of an EV industry through legislation aimed at increasing national energy independence and reducing the impact of automobile emissions on the environment. California has passed laws that demand that 2% of new cars sold in 1998 be emission-free, and this percentage is slated to grow to 10% by the year 2003; 12 eastern states are planning similar laws. A comprehensive energy bill passed by Congress contains a tax credit for EV buyers. This bill also requires state and federal governments to purchase alternative-fuel fleet vehicles, with the percentage of new, cleaner fuel vehicles growing to 90% by the year 2000. It is expected that EVs will make up an increasing portion of alternative fuel vehicles as the market grows.

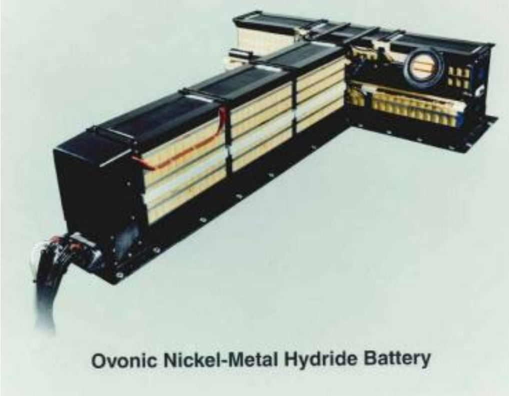
There are several important advantages of EVs compared with IC-powered vehicles. First, EVs are emission-free: they produce no pollution during operation. This quality is particularly important in city centers where congested automobile traffic is the primary source of local air pollution. The overall unwanted emissions that result from combustion of fossil fuels for the generation of electricity are also far less per mile of EV travel than the emissions produced directly by a fossil fuel-powered car. This fact, discussed in detail in a study by the Electric Power Research Institute (EPRI) (1), results from the sophisticated emissions controls that can be used economically by large, efficient, central power-generation facilities. Second, the EPRI study also details how the primary energy efficiency of electric transportation can exceed the efficiency of gasoline-powered vehicles in many instances. For example, the study shows that electric-powered commercial fleet vans that are used in urban areas have a significant advantage in energy efficiency over their gasoline-powered counterparts, traveling about 1100 miles per barrel of oil consumed at the power plant compared with 620 miles per barrel of oil refined into gasoline. This difference results primarily from the higher energy efficiency of power plant combustion—approximately twice as high as combustion of gasoline in an IC engine in urban traffic. Third, conversion from cars directly powered by fossil fuel to ones powered by electricity can shift the choice of hydrocarbon fuels that are consumed in the United States from oil to coal and gas. This change could possibly reduce the oil imports and, consequently, reduce the U.S. trade imbalance and the strategic vulnerability of its energy supply. Photovoltaic and other renewable energy sources are

S. R. Ovshinsky and M. A. Fetcenko are at Energy Conversion Devices, Inc., 1675 West Maple Road, Troy, MI 48084. J. Ross is in the Chemistry Department, Stanford University, Palo Alto, CA 94305, and consultant to Energy Conversion Devices, Inc.

NiMH replaced Lead Acid in iconic GM EV1

Led to formation of GM – Ovonic Joint Venture

USABC
UNITED STATES ADVANCED BATTERY CONSORTIUM LLC



GM EV1 Battery Pack

- Voltage 340 V
- Capacity – 87 Ah
- Energy - 32 kWh
- Pure electric range - 240 miles

- Excellent customer response

Ovonic Battery Company received the very first development contract from USABC in 1993, also first chemistry to become commercial.

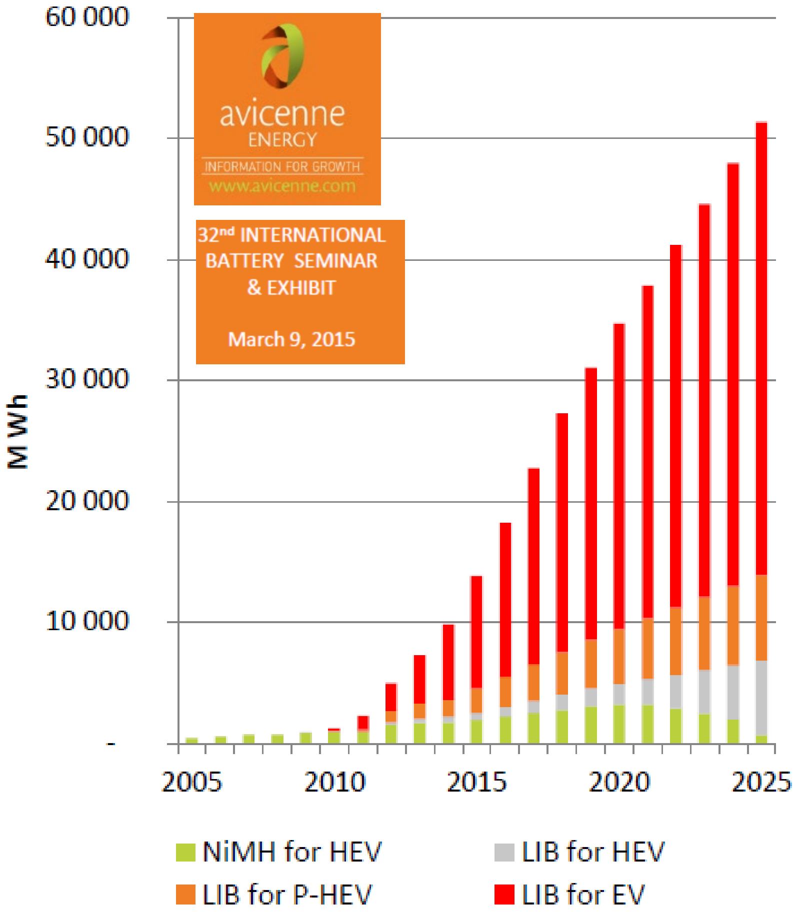
NiMH doubled the driving range of the incumbent lead-acid battery

30 Million Commercial Hybrids use NiMH

Exceptional Track Record of Success

UNITED STATES ADVANCED BATTERY CONSORTIUM LLC

ovonic consumer battery



Real world 55 mpg
Life of the car battery

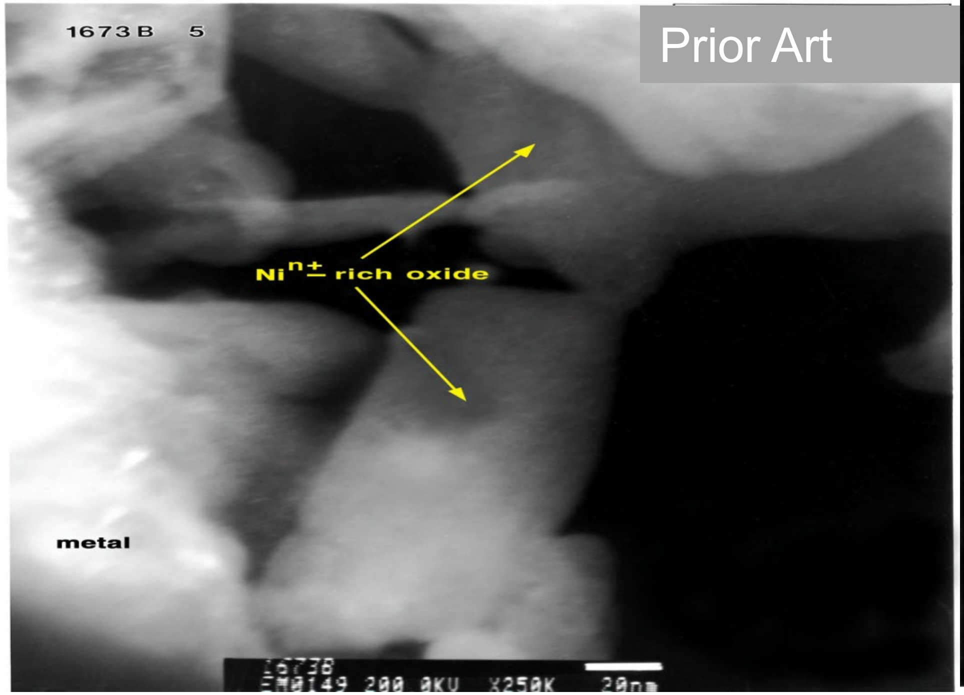
- Over 30 million hybrids with NiMH
- Proven safety, life, reliability and cost
- NiMH – "Life of the Car"
- Sustainable materials and recycle capability

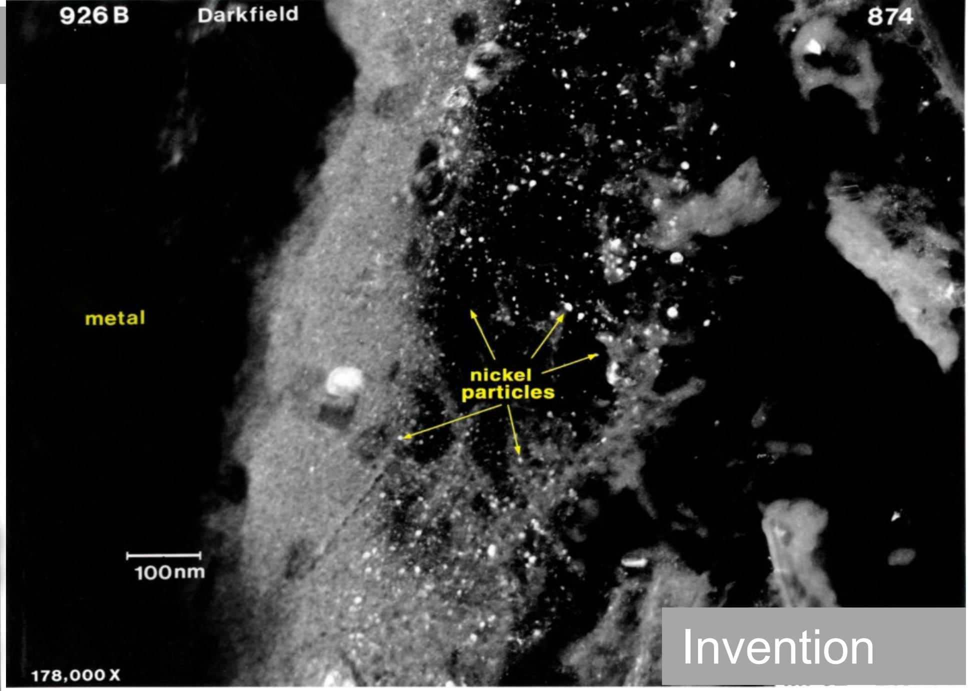
"The hybrid batteries used in Toyota and Lexus models can last longer the vehicles themselves, so often they are only recovered when the cars reach the end of their useful life, or if they have been involved in an accident."

Battery collection and recycle more than 90%, targeting 100%.

Hybridcars.com February 9, 2015

While NiMH cannot compete with LiB in xEV applications, NiMH remains an important HEV and Consumer Technology



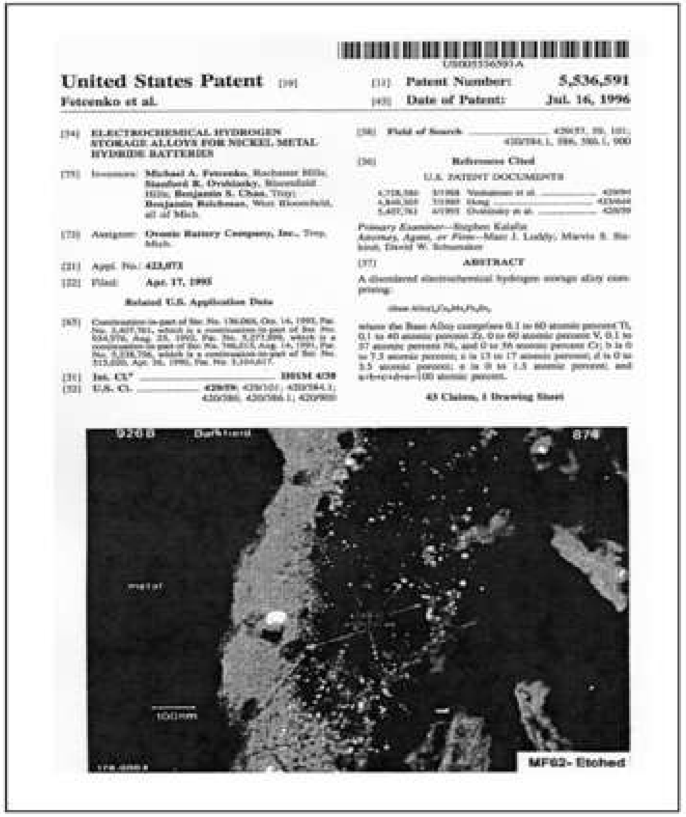


Original surface oxide inhibited the high rate discharge capability of the NiMH battery.

By adding the catalytic sites to the oxide surface (SEI Layer), NiMH batteries could operate at extremely high rate, opening many new product applications.

SEI layer on Metal Hydride alloy surface enables rate, power capability, low temperature
Hybrid vehicles were enabled by NiMH Surface Oxide

Crucial NiMH Battery Patent – Enablement of High Power



United States Patent [19] [11] Patent Number: 5,536,591

Fetcenko et al. [45] Date of Patent: Jul. 16, 1996

[54] ELECTROCHEMICAL HYDROGEN STORAGE ALLOYS FOR NICKEL METAL HYDRIDE BATTERIES

[75] Inventors: Michael A. Fetcenko, Rochester Hills; Stanford R. Ovshinsky, Bloomfield Hills; Benjamin S. Chao, Troy; Benjamin Reichman, West Bloomfield, all of Mich.

[73] Assignee: Ovonic Battery Company, Inc., Troy, Mich.

[21] Appl. No.: 423,072

[22] Filed: Apr. 17, 1995

Related U.S. Application Data

[58] Field of Search

[56] References Cited

U.S. PATENT DOCUMENTS

Primary Examiner—Stephen Kalafut

Attorney, Agent, or Firm—Marc J. Luddy; Marvin S. Siskind; David W. Schumaker

[57] ABSTRACT

A disordered electrochemical hydrogen storage alloy comprising:

43 Claims, 1 Drawing Sheet

Brazil

Canada

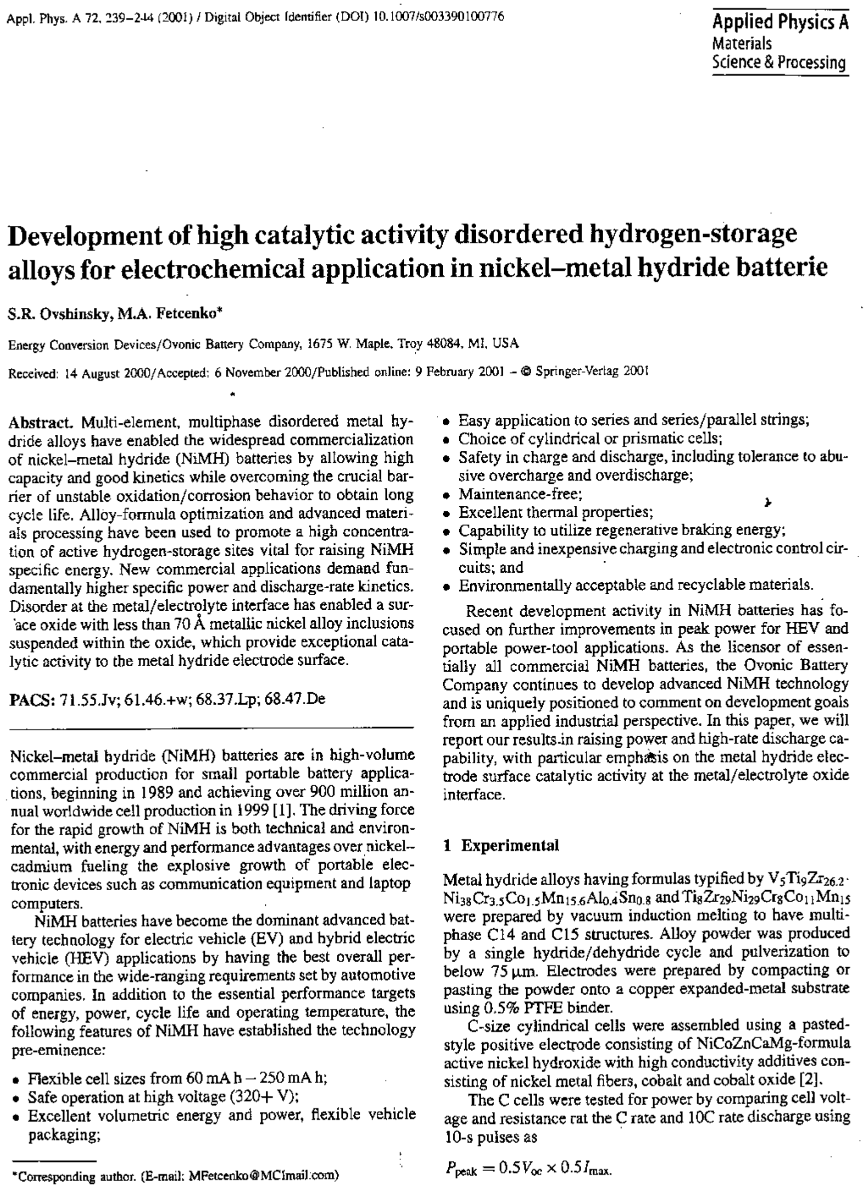
Europe

Japan

Korea

Mexico

Taiwan



Appl. Phys. A 72, 239–244 (2001) / Digital Object Identifier (DOI) 10.1007/s003390100776

Applied Physics A
Materials
Science & Processing

Development of high catalytic activity disordered hydrogen-storage alloys for electrochemical application in nickel–metal hydride batterie

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Abstract. Multi-element, multiphase disordered metal hydride alloys have enabled the widespread commercialization of nickel–metal hydride (NiMH) batteries by allowing high capacity and good kinetics while overcoming the crucial barrier of unstable oxidation/corrosion behavior to obtain long cycle life. Alloy-formula optimization and advanced materials processing have been used to promote a high concentration of active hydrogen-storage sites vital for raising NiMH specific energy. New commercial applications demand fundamentally higher specific power and discharge-rate kinetics. Disorder at the metal/electrolyte interface has enabled a surface oxide with less than 70 Å metallic nickel alloy inclusions suspended within the oxide, which provide exceptional catalytic activity to the metal hydride electrode surface.

PACS: 71.55.Jv; 61.46.+w; 68.37.Lp; 68.47.De

Nickel–metal hydride (NiMH) batteries are in high-volume commercial production for small portable battery applications, beginning in 1989 and achieving over 900 million annual worldwide cell production in 1999 [1]. The driving force for the rapid growth of NiMH is both technical and environmental, with energy and performance advantages over nickel–cadmium fueling the explosive growth of portable electronic devices such as communication equipment and laptop computers.

NiMH batteries have become the dominant advanced battery technology for electric vehicle (EV) and hybrid electric vehicle (HEV) applications by having the best overall performance in the wide-ranging requirements set by automotive companies. In addition to the essential performance targets of energy, power, cycle life and operating temperature, the following features of NiMH have established the technology pre-eminence:

- Flexible cell sizes from 60 mA h – 250 mA h;
- Safe operation at high voltage (320+ V);
- Excellent volumetric energy and power, flexible vehicle packaging;
- Easy application to series and series/parallel strings;
- Choice of cylindrical or prismatic cells;
- Safety in charge and discharge, including tolerance to abusive overcharge and overdischarge;
- Maintenance-free;
- Excellent thermal properties;
- Capability to utilize regenerative braking energy;
- Simple and inexpensive charging and electronic control circuits; and
- Environmentally acceptable and recyclable materials.

Recent development activity in NiMH batteries has focused on further improvements in peak power for HEV and portable power-tool applications. As the licensor of essentially all commercial NiMH batteries, the Ovonic Battery Company continues to develop advanced NiMH technology and is uniquely positioned to comment on development goals from an applied industrial perspective. In this paper, we will report our results in raising power and high-rate discharge capability, with particular emphasis on the metal hydride electrode surface catalytic activity at the metal/electrolyte oxide interface.

1 Experimental

Metal hydride alloys having formulas typified by $V_5Ti_9Zr_{26.2}Ni_{38}Cr_{3.5}Co_{1.5}Mn_{15.6}Al_{0.4}Sn_{0.8}$ and $Ti_8Zr_{29}Ni_{29}Cr_8Co_{11}Mn_{15}$ were prepared by vacuum induction melting to have multiphase C14 and C15 structures. Alloy powder was produced by a single hydride/dehydride cycle and pulverization to below 75 μm. Electrodes were prepared by compacting or pasting the powder onto a copper expanded-metal substrate using 0.5% PTFE binder.

C-size cylindrical cells were assembled using a pasted-style positive electrode consisting of NiCoZnCaMg-formula active nickel hydroxide with high conductivity additives consisting of nickel metal fibers, cobalt and cobalt oxide [2].

The C cells were tested for power by comparing cell voltage and resistance rat the C rate and 10C rate discharge using 10-s pulses as

$P_{peak} = 0.5V_{oc} \times 0.5I_{max}$.

*Corresponding author. (E-mail: MFetcenko@MCImail.com)

Inventor and Licensor of NiMH Technology

Fundamental Worldwide Patent Position

- 96 US patents
- Worldwide counterparts
- 3rd party recognition of patent value
- 40+ licensees

BASF The Chemical Company

http://www.catalysts.basf.com/NiMH-licenses

Canon	Panasonic – PEVE
Cobasys	Saft
Daido Steel	Samsung
Energizer	SANIK Battery Co., Ltd.
FDK	Sanoh
Furukawa	Sanyo Electric Co.
G4 Synergetics	Shenzhen GREPOW Battery Co., Ltd.
Gold Peak Batteries	Shenzhen High Power Tech Co.
GS-Yuasa	Sovlux Battery
Guangdong Shida Battery	Toshiba Battery
Harding Energy	TWD Battery
Henan Huanyu Group Co. Ltd.	Union Suppo Battery Company
Hitachi Maxell	Unitech Battery Limited
Hyundai	USABC
KAN BATTERY	Varta Microbattery
Lexel Battery	Walsin
Nan Ya Plastic	YiYang Corun Battery Co. Ltd.
Shenzhen EPT Battery Co., Ltd.	Guangzhou Great Power Energy & Technology Co., Ltd.
McNair	

All major suppliers of NiMH globally are licensed

Lithium – Ion (LiB)

Two Presidents Recognized the Contributions of the ANL Team

Argonne National Laboratory's Michael Thackeray Invited to the White House by President Bush

ARGONNE, Ill. (Feb. 23, 2007) — President Bush invited Michael Thackeray, of Argonne National Laboratory, to the White House on February 23, 2007 for a round table discussion on the role of lithium ion batteries for transportation, including plug-in hybrid electric vehicles. As a battery expert, Thackeray provided an overview on advanced batteries, addressed the challenges of advanced battery research and development, and showed the path forward to achieving commercially-viable lithium-ion battery-powered vehicles.

Two decades ago, scientists at Argonne, led by Mike Thackeray, who's here today -- where is Mike? There he is right here. (Applause.) Mike started work on a rechargeable lithium battery for cars. And some folks at the time said the idea wasn't worth the effort. They said that even if you had the technology, the car would cost too much, it wouldn't go far enough.

But Mike and his team knew better. They knew you could do better. And America, our government, our federal government made it a priority, and we funded those efforts. And Mike went to work. And when others gave up, the team kept on at it. And when development hit a snag, the team found solutions. And a few years ago, all of this hard work paid off, and scientists here at Argonne helped create a lithium ion battery that costs less, lasts longer than any that had come before.

Key People who have enabled practical Li-Ion and practical EV Li-Ion

Michael Thackeray (l), John Goodenough (r)

Stan Whittingham (l), Martin Winter (c)

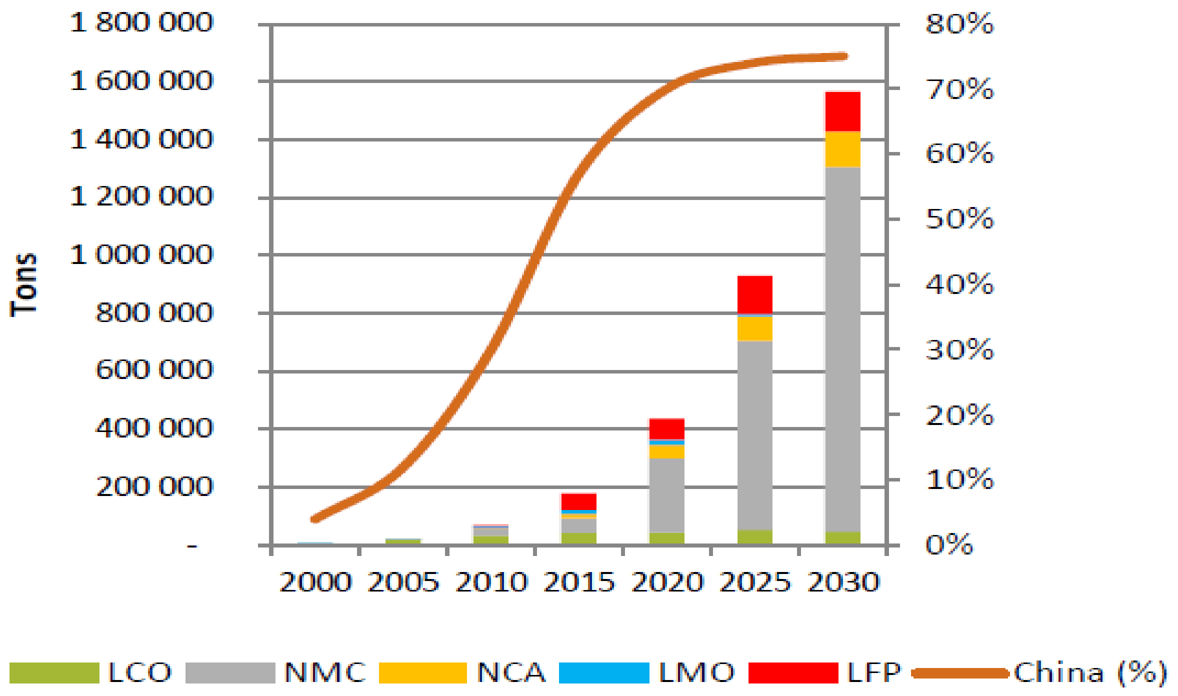
Michael Thackeray (c), Martin Winter (r)

Would Lithium – Ion inventors have been recognized with Nobel Prize if LiB was limited to consumer only? Lithium Ion for EV was enabled by practical low cost NCM cathode invented by Michael Thackeray, Khalil Amine, Chris Johnson and the Argonne National Laboratory team.

CATHODE ACTIVE MATERIAL FORECASTS 2000-2030

Realistic scenario

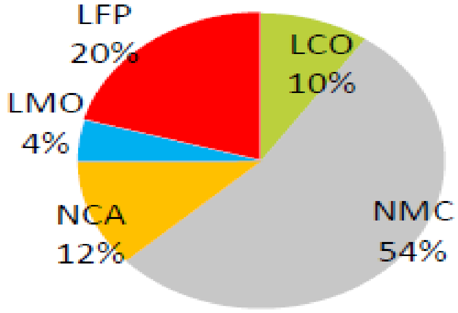
Cathode active materials 2000-2030 - Tons



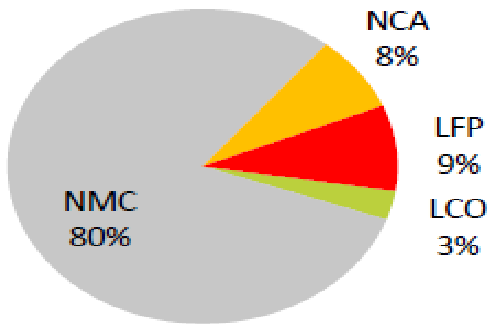
ASSUMPTIONS:

- Portable devices: 2019-2030: +4% per year in volume
- HEV: 3,4 M HEV/year in 2020, 9,3 M HEV in 2025 & 18,3 M in 2030
- P-HEV: 0,5 M P-HEV/year in 2020, 0,9 M in 2025 & 1,3 M in 2030
- EV: 2 M EV/year in 2020 (1 M in China) / 5,2 M/year in 2025 (2 M in China) 100% LIB, 11,3 M EV in 2030 (3,3 M in China)
- Industrial, stationary & other applications 2019-2030: +15% per year in volume

Cathode active materials in 2019 390 000 Tons



Cathode active materials in 2030 1 570 000 Tons



Assumption: Tesla keep NCA chemistry and have a relative success (+900 000 EV sold per year in 2030 – TESLA forecast +650 000 in 2025)

Sources: AVICENNE ENERGY 2020

Problems with Prior Lithium-Ion Batteries

Argonne NATIONAL LABORATORY

Prior art positive electrode materials are expensive & degrade quickly

teries. The best-known electrode material is $LiCoO_2$, which has a layered-type structure and is relatively expensive compared to the isostructural nickel and manganese-based compounds. Efforts are therefore being made to develop less

JX-1 at 1:47-50

trolyte or release oxygen. These electrode materials can, therefore, suffer from structural instability in charged cells when, for example, more than 50% of the lithium is extracted from their structures; they require stabilization to combat such chemical degradation.

JX-1 at 2:1-5

5

Patents Address These Problems

’082 and ’143 patents describe using two-component material, with $Li_2M'O_3$ stabilizing $LiMO_2$

Therefore, further improvements must be made to $LiMO_2$ electrodes, particularly $LiMnO_2$, to impart greater structural stability to these electrode materials during electrochemical cycling in lithium cells and batteries. This invention addresses the stability of $LiMO_2$ electrode structures, particularly $LiMnO_2$, and makes use of a $Li_2M'O_3$ component to improve their stability.

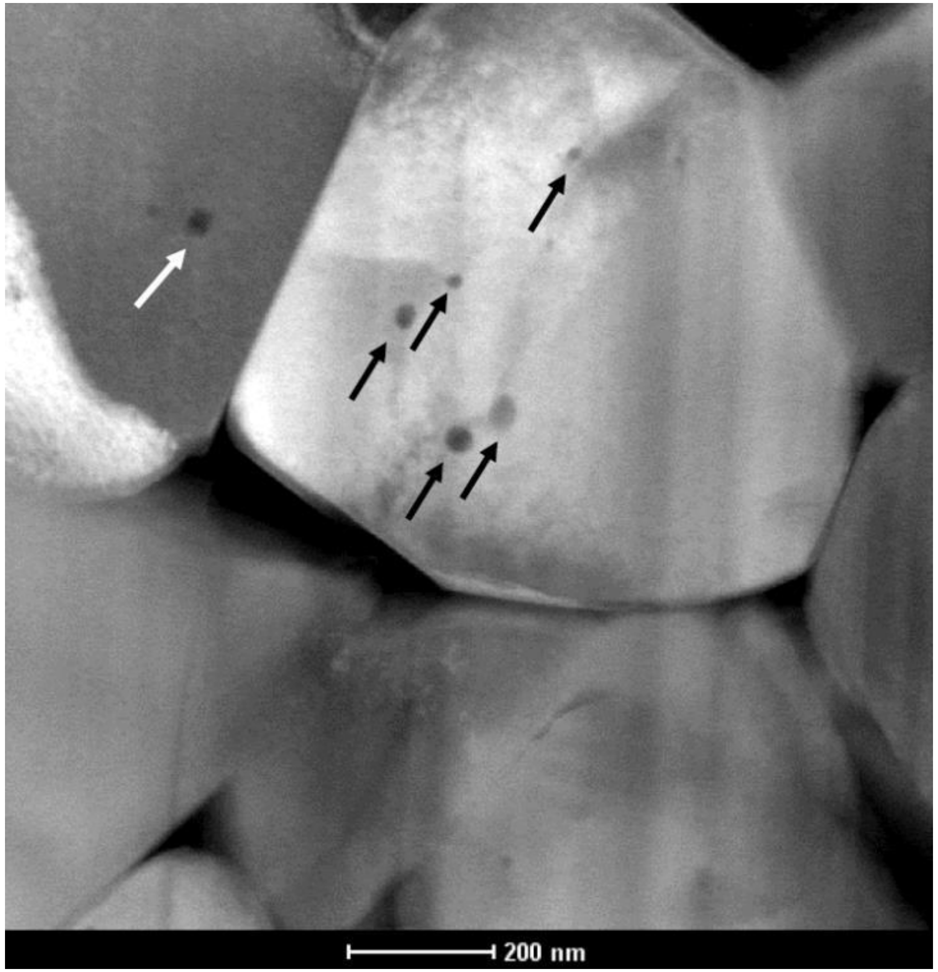
JX-1 at 2:23-29

6

Argonne NATIONAL LABORATORY

Commercial NCM Cathode Material

Dual Phase, Overlithiated NCM



- TEM examination clearly shows evidence of multiple phases.
- Evidence shows presence of both $LiMO_2$ and $Li_2M'O_3$ domains.

NCM cathode materials are the industry standard for EVs

BASF - ANL NCM Licensees

BASF We create chemistry
Argonne NATIONAL LABORATORY

BASF The Chemical Company
TODA KOGYO CORP
umicore

User Licenses

Pulead
瑞翔新材 RESHINE NEW MATERIAL 品 质 创 新 动 力
LF
LG Chem

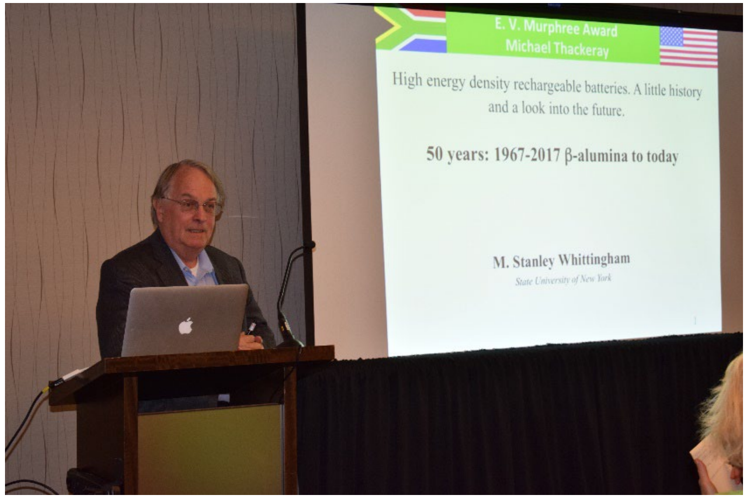
邦普 BRUNP
邦普循环 BRUNP RECYCLING
宁波容百新能源科技股份有限公司 Ningbo Ronbay New Energy Technology Co., Ltd.
GM

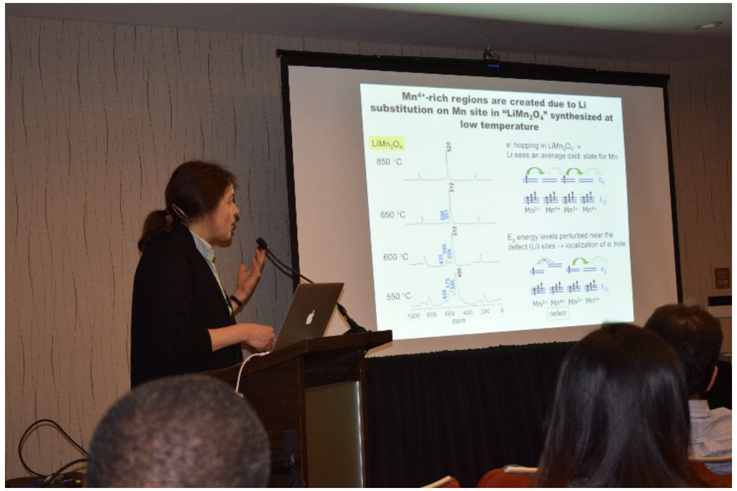
EcoPro BM
LG Chem

XTC 厦门钨业股份有限公司 XIAMEN TUNGSTEN CO.,LTD.
posco

https://www.catalysts.basf.com/products-and-industries/battery-materials/licensing-agreements

2016 ACS EV Murphree Award Symposium for Michael Thackeray





Michael Thackeray, John Goodenough, Stan Whittingham, Clare Grey, Martin Winter, Michael Fetcenko

How do we translate this success in NiMH and ANL NCM Licensing to Emerging Technologies?

Commercialization of ANL NCM Technology by BASF

ANL NCM available to all global cathode and battery producers

Joint Development
Capital Investment
Joint Patent Enforcement
Licensing

Cooperation
Aligned Strategy
Complimentary Strengths

- Licensed patents-in-suit from Argonne in 2009
- Opened plant in Elyria, OH in 2012 to produce lithium-ion NCM positive electrode active materials

Lessons Learned – NiMH and NCM Licensing

Invention must be real, must be commercial, must have enforceable patents

- Strong, enforceable patents are critical
  - Composition of matter and processing
  - Global, not just United States
  - Early adopter licensees
  - Patents will be challenged, plan for it
- Collaboration between National Laboratory and Industry needed at early stage
  - Partner selection is important, compatible and each brings strengths
  - R&D direction commercially may be quite different than early stage incubator
  - Patent improvements
  - Revenue and risk sharing

Thank you for your attention!