What’s New in Materials, Applications and Patents

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A Disclaimer

Obviously written by a Physicist who is baffled by phase diagrams!

METALLURGIST

A pseudo scientist, who uses undetermined suppositions, indefinite theories, and inexpressible hypotheses; which are based on unreliable information, uncertain quantities, and incomplete data; derived from non-reproducible experiments and incomplete investigations; using equipment and instruments of questionable accuracy, insufficient resolution, and inadequate sensitivity, to arrive at timid, tentative cloudy, abstruse, and non-committed conclusions prefaced by the phrase, “IT DEPENDS.”
What’s New in Permanent Magnets?

- AM/3D printing
- Nanocomposite magnets
- Fe16N2 magnets
- Hitachi Metals Patent Litigation
- Aerospace electrical drives
- GBD Dy-diffused magnets
- High Br Sm2Co17
- MnBi magnets
- Hyperloop
- Anisotropic bonded magnets
- Rare earth magnet recycling
- Daido Steel low Dy magnet
- Marine electrical drives
- Magnetic Refrigeration
- Aerospace electrical drives
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Presentation Outline

• Introduction to Magnet Applications, Inc..

• Patents - Hitachi Metals NdFeB patent litigation update

• Materials - Additive Manufacturing/3D printing of permanent magnets

• Applications - Magnetic Refrigeration Systems
Introduction: Magnet Applications, Inc..

• Visit the new website at: http://magnetapplications.com.
• A Bunting Magnetics Company: https://buntingmagnetics.com/.
• Largest North American manufacturer of compression bonded NdFeB and injection molded ferrite, NdFeB and hybrid magnets.
• Supply full range of engineered magnets and magnetic assemblies.
• Located in DuBois, PA – Originally established in UK over 50 years ago – sister company located in Berkhamsted, UK.
• Primary applications are BLDC motors and sensors in the automotive, medical and industrial markets.
Introduction: Magnet Applications, Inc..

- Pre-production magnetic design services including 3D magnetic modeling.
- Industry leading technical services to optimize the material for the application.
- Investing in R & D for next generation of magnetic materials.
- The backing of strong family ownership – in business for over 55 years.
- ISO-9001 Certified Quality System with a strong continuous improvement culture.
- Very strong international supply chain for the complete range of permanent magnet materials.
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At the start of the decade the industry was eagerly anticipating the expiration of the compositional/tetragonal structure HML NdFe(Co)B US patent 5,645,651 in July 2014.

August 2012 HML filed a complaint with the USITC against 29 manufacturers and importers of RE magnets and products containing RE magnets.

4 US patents cited; 6,461,565, 6,491,765, 6,527,874 and 6,537,385.
Hitachi Metals NdFeB Patent Litigation Update
History Part 1 - Key Claims of Cited Patents

- **6,461,565** – Method of pressing a RE alloy magnetic powder in a controlled environment from 5°C to 30°C and RH from 40% to 65%.
- **6,527,874** – RE magnetic alloy containing 0.1 to 1.0 At % Nb.
- **6,491,765** and **6,537,385** – Removal of RE-rich particles less than 1 micron from RE alloy magnetic powder.
Hitachi Metals NdFeB Patent Litigation Update
History Part 1 – USITC Phase

• USITC instituted a section 337 investigation in September 2012; multiple law firms and dozens of attorneys were involved.

• During the ensuing months the 5 original licensed Chinese manufacturers (plus 3 others) agreed to new terms under the cited patents.

• A matter of days before the July 2013 trial HML announced that settlement agreements had been reached with all parties and withdraw the petition to the USITC i.e. no day in court to determine validity of the cited patents.
Hitachi Metals NdFeB Patent Litigation Update
History Part 2 - Alliance of Rare-Earth Permanent Magnet Industry

- August 2013 - It was announced that “a dozen Chinese rare earth magnet companies have formed an industrial alliance to sue Japan’s Hitachi Metals for holding invalid patents and infringing patent rights of Chinese companies”.

- Petition for Inter Partes Review (IPR) of certain claims of 6,491,765 and 6,537,385 filed with USPTO August 11, 2014.

- IPR’s granted by Patent Trial and Appeal Board on February 2015
<table>
<thead>
<tr>
<th>USPN 6,537,385 (IPR2014-01265)</th>
<th>USPN 6,491,765 (IPR2014-01265)</th>
</tr>
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<tbody>
<tr>
<td>a first pulverization step of coarsely pulverizing an R--Fe--B alloy for rare earth magnets <strong>produced by a rapid cooling method</strong> and</td>
<td>a first pulverization step of coarsely pulverizing a material alloy for rare earth magnets and</td>
</tr>
<tr>
<td>a second pulverization step of finely pulverizing the material alloy,</td>
<td>a second pulverization step of finely pulverizing the material alloy,</td>
</tr>
<tr>
<td>wherein said second pulverization step comprises a step of <strong>removing at least part of the powder in which the concentration of rare earth element is greater than the average concentration of rare earth element contained in the entire powder.</strong></td>
<td>wherein said first pulverization step comprises a step of pulverizing the material alloy by a <strong>hydrogen pulverization method</strong>, and</td>
</tr>
<tr>
<td>said second pulverization step comprises a step of <strong>removing at least part of fine powder having a particle size of 1.0 µm or less to adjust the particle quantity of the fine powder having a particle size of 1.0 µm or less to 10% or loss of the particle quantity of the entire powder.</strong></td>
<td></td>
</tr>
</tbody>
</table>
On February 8, 2016 the PTAB issued their Final Written Decision for Patents 6,537,385 and 6,491,765 as follows:

“ORDERED that claims 1, 5, and 6 of the ’385 patent have been shown by a preponderance of the evidence to be unpatentable.”

“ORDERED that claims 1–4, 11, 12, and 14–16 of the ’765 patent have been shown by a preponderance of the evidence to be unpatentable.”
Hitachi Metals NdFeB Patent Litigation Update

History Part 2- Alliance of Rare-Earth Permanent Magnet Industry

• Case closed – not quite!

• April 8, 2016 HML files notice of appeal.

• September 16, HML files appeal brief of PTAB’s decision to Federal Court of Appeals.

• October 26, 2016 Alliance files their Appellee Brief.

• December 21, 2016 HML files their reply brief.

• If you are suffering from insomnia the briefs are available at http://www.jocllc.com/news.html.

• Probably another 6 to 9 months before the Appeals Court rules.
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MAI and ORNL were awarded a Cooperative Research and Development award to study the application of additive manufacturing to bonded magnets and systems.
Additive Manufacturing refers to a process by which digital 3D design data is used to build up a component in layers by depositing material. The term "3D printing" is increasingly used as a synonym for Additive Manufacturing.

AM can form complex shapes requiring little or no tooling and post-processing thus reducing the amount of waste generated.
AM is an Industrial Manufacturing Technology

Press Release

TRUMPF presents process chain for industrial 3D printing

Powerful medium format machines with tool change cylinder concept for industrial-scale LMF production – industry-ready periphery for external part and powder management – TruConnect solution range and monitoring for connected manufacturing includes additive manufacturing as well.

Ditzingen, November 15, 2016 – TRUMPF, the laser systems manufacturer and Industry 4.0 pioneer, is at the Formnext trade fair in Frankfurt to present its new 3D printers – TruPrint 3000 and TruPrint 5000. These medium format machines are based on laser metal fusion (LMF) technology, using lasers to generate complete parts layer by layer in a powder bed. These parts can measure up to
Types of Additive Manufacturing/3D Printing

ORNL Additive Manufacturing Capabilities:

- Electron Beam Melting
- Laser Sintering
- Laser Blown Powder Deposition
- Ultrasonic Consolidation
- Binder Jetting
- Fused Deposition Modeling
- Multi-head Photopolymer
- Large-Scale Polymer Deposition
Types of Additive Manufacturing

ASTM International: Technical Committee F42 on Additive Manufacturing

- Vat Photopolymerization
- Material Jetting
- Binder Jetting
- Material Extrusion
- Powder Bed Fusion
- Directed Energy Deposition
- Sheet Lamination
Indirect 3D Printing - ExOne Binder Jet Process
Bonded NdFeB Magnets Produced by Binder Jetting

Binderjet MQP-resin

$H_C = 9 \text{kOe}$
Binder Jetting of NdFeB Bonded Magnets
Types of Additive Manufacturing

ASTM International: Technical Committee F42 on Additive Manufacturing

- Vat Photopolymerization
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- Sheet Lamination
Big Area Additive Manufacturing (BAAM) of NdFeB Bonded Magnets

BAAM is an industry scale material extrusion additive manufacturing system that enables rapid and cost effective production of large scale components
Big Area Additive Manufacturing of NdFeB Bonded Magnets

MQP isotropic powder + Nylon-12 → Mix, melt and extrude → BAAM 3D printing → Additively printed NdFeB bonded magnets
Big Area Additive Manufacturing of NdFeB Bonded Magnets

Nozzle: Melt and Extrude

ID: 3 inches
OD: 4.5 inches
Big Area Additive Manufacturing (BAAM) of NdFeB Bonded Magnets
Surprise – you can make big magnets!
Big Area Additive Manufacturing (BAAM) of NdFeB Bonded Magnets
Scientific Reports, October 2016 (www.nature.com/scientificreports)
Can we “3D print” an Electric Motor?
University of Nottingham, UK – Blog/INNOVATE April 2015

August 10, 2015, by Michele Garibaldi

Can we “3D-Print” an Electric Motor?

The well-established success of the Rapid Prototyping technologies derives from the possibility of creating parts with almost any shape at no added costs. However, in order for a part to be functional (i.e., with good mechanical properties), high density and tailored material properties are desired. In the past few years, Additive Manufacturing (AM) technologies such as Selective Laser Melting (SLM, shown in Fig. 1) have been proving more valuable than Rapid Prototyping in that they can achieve densities comparable to those obtained through classical subtractive and formative processes. Thus, AM is showing great potential for moving from Rapid Prototyping to Rapid Manufacturing. For this reason, SLM is emerging across a broad range of sectors, including automotive, medical and aerospace, for the creation of functional parts. It is of public domain that one of the most prominent aerospace names regularly associated with AM is GE Aviation, which already in 2013 was leading the way with its plans to produce a fuel nozzle using SLM. A little more than two years have gone by, and GE best-selling engine of all times (the LEAP engine) is set to enter into production by end 2015. Indeed, it will feature the 3D-Printed fuel nozzles that have been making the headlines in 2013.
“Until now the design of standard magnetic devices has not gone much beyond the two-dimensions, especially due to constraints imposed by the (mainly subtractive and formative) manufacturing processes employed.”

“The possibility offered by AM to extend the design of components to three-dimensional space without the constraints of traditional manufacturing introduces new opportunities towards the production of highly power-dense electrical machines, where the core magnetic material is added only where it is actually needed. The impact of such innovative devices would be highly beneficial especially for transport applications, where weight is the primary determinant of vehicle efficiency”
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Magnetic Refrigeration Systems
Acknowledgements and Credits

• Timothy Lorkin – MoveOnn Inside
• Cooltech Applications - http://www.cooltech-applications.com/
Magnetic Refrigeration Systems
The Next Big Application for Magnets?

- Some classes of materials, called Magnetocaloric Materials (MCM), heat up when immersed in a magnetic field and cool down when removed from it, almost instantaneously. The phenomenon, known as Magnetocaloric Effect (MCE), was discovered by E. Warburg in 1881 and is derived from the ordering and disordering of magnetic domains by an applied field.
Magnetic Refrigeration Systems

• In 1997, the Ames Laboratory implemented a proof of principle using Gadolinium. Reacting at ambient temperature (~20°C), the use of Gadolinium was a milestone for all developments of magnetic refrigeration systems for commercial applications.

• All else being equal, the degree of temperature change depends on the strength of the magnetic field.
Magnetic Refrigeration Systems

- The cycle is performed as a refrigeration cycle that is analogous to the Carnot refrigeration cycle, but with increases and decreases in magnetic field strength instead of increases and decreases in pressure.

- Magnetic refrigeration is the only alternative technology which would simultaneously eliminate the need for harmful refrigerant gases and reduce the energy requirements, and hence carbon dioxide emissions.
Magnetic Refrigeration Systems
Giant Magnetocaloric Materials

- Strong temperature dependence of magnetization, large entropy jump at $T_c$.
- Large $\Delta T/\Delta H$ driven by moderate magnetic field level.
- Small thermal and magnetic hysteresis
- Low material cost (e.g. Gd)
- Non-Hazardous (e.g. As)
- High thermal and low electrical conductivity
- Mechanical and chemical stability, high ductility
Magnetic Refrigeration Systems
Key Players (OEM and MCM suppliers)

• Cooltech Applications (France)
• Camfridge Ltd. (UK)
• Astronautics Corporation of America (US)
• Whirlpool Corporation (US)
• NexTpac (France)
• Vacuumscmelze (Germany)
• IFW/IFAM Fraunhofer institutes (Germany)
• General Electric Co /Qingdao Haier Co. Ltd. (US/China)
• BASF SE (Germany)
• Eramet SA (France)
• Samsung Electronics Co Ltd. (Korea)
• Toshiba Corporation (Japan)
General functioning of the Cooltech’s Magnetic Refrigeration System
CoolTech’s Magnetic Refrigeration System
Magnetic Refrigeration Systems
Challenges – It’s been known since 1881

Even though some products have come to market, there are still challenges that need to be addressed before there is large scale deployment of the technology.

• The main issue is the supply of magnetocaloric materials, which are scarce. Reducing the material content, or identifying new materials, would increase viability.

• Low cost, high (BH)\text{max} magnets are needed e.g. Fe16N2.

• According to magnetic refrigeration engineers Cooltech Applications, the fabrication process is not yet optimized and production costs are still high.

• Interface optimizations (for example, heat exchangers) between the devices and the equipment to be refrigerated also need to be modified for maximum efficiency.

• Cooltech, Camfridge and Astronautics all have demonstration systems in the field
Summary - IT DEPENDS

• **NdFeB patent dispute** – what will happen? - IT DEPENDS on the Federal Court of Appeals ruling plus there maybe more challenges in 2017.

• **3D printing of magnets** - will this be a viable option for manufacturing permanent magnets? – IT DEPENDS on feasibility of combining multiple processes to produce a complete magnetic circuit.

• **Magnetic Refrigeration** – will it become a major market for permanent magnets? - IT DEPENDS on Governmental energy efficiency and environmental policies and resulting regulations.
Apologies - I’m guilty as anyone inflicting PowerPoint poisoning

Thank you for your kind attention