Hangzhou Vector Magnets Co., LTD
杭州矢量磁铁有限公司
Add: 6-1A, 88 Jiangling Rd, Binjiang, Hangzhou, Zhejiang, China
Tel: +86-571-5666-8956
Fax: +86-571-5666-8957
Url: www.vectormagnets.com

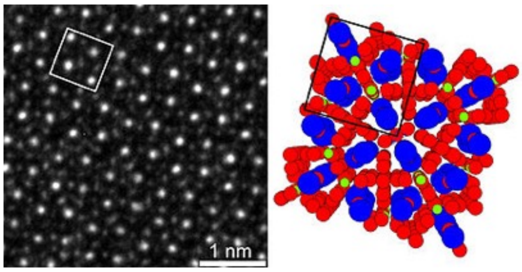
Neodymium Magnet

A neodymium magnet (also known as NdFeB, NIB or Neo magnet), the most widely used type of rare-earth magnet, is a permanent magnet made from an alloy of neodymium, iron and boron to form the $Nd_2Fe_{14}B$ tetragonal crystalline structure. Developed in 1982 by General Motors and Sumitomo Special Metals, neodymium magnets are the strongest type of permanent magnet commercially available. They have replaced other types of magnets in the many applications in modern products that require strong permanent magnets, such as motors in cordless tools, hard disk drives and magnetic fasteners.

Nickel-plated neodymium magnet cubes

Description

The tetragonal $Nd_2Fe_{14}B$ crystal structure has exceptionally high uniaxial magnetocrystalline anisotropy (HA~7 teslas – magnetic field strength H in A/m versus magnetic moment in A.m2). This gives the compound the potential to have high coercivity (i.e., resistance to being demagnetized). The compound also has a high saturation magnetization (Js ~1.6 T or 16 kG) and typically 1.3 teslas. Therefore, as the maximum energy density is proportional to Js2, this magnetic phase has the potential for storing large amounts of magnetic energy (BHmax ~ 512 kJ/m3 or 64 MG·Oe). This magnetic energy value is about 18 times greater than "ordinary" magnets by volume. This property is considerably higher in NdFeB alloys than in samarium cobalt (SmCo) magnets, which were the first type of rare-earth magnet to be commercialized. In practice, the magnetic properties of neodymium magnets depend on the alloy composition, microstructure, and manufacturing technique employed.



Left: High-resolution transmission electron microscopy image of Nd2Fe14B;
right: crystal structure with unit cell marked

History

In 1982, General Motors (GM) and Sumitomo Special Metals discovered the $Nd_2Fe_{14}B$ compound. The research was initially driven by the high raw materials cost of SmCo permanent magnets, which had been developed earlier. GM focused on the development of melt-spun nanocrystalline $Nd_2Fe_{14}B$ magnets, while Sumitomo developed full-density sintered $Nd_2Fe_{14}B$ magnets.

GM commercialized its inventions of isotropic Neo powder, bonded Neo magnets, and the related production processes by founding Magnequench in 1986 (Magnequench has since become part of Neo Materials Technology, Inc., which later merged into Molycorp). The company supplied melt-spun $Nd_2Fe_{14}B$ powder to bonded magnet manufacturers.

The Sumitomo facility became part of the Hitachi Corporation, and currently manufactures and licenses other companies to produce sintered $Nd_2Fe_{14}B$ magnets. Hitachi holds more than 600 patents covering neodymium magnets.

Chinese manufacturers have become a dominant force in neodymium magnet production, based on their control of much of the world's sources of rare earth mines.

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The United States Department of Energy has identified a need to find substitutes for rare earth metals in permanent magnet technology, and has begun funding such research. The Advanced Research Projects Agency-Energy has sponsored a Rare Earth Alternatives in Critical Technologies (REACT) program, to develop alternative materials. In 2011, ARPA-E awarded 31.6 million dollars to fund Rare-Earth Substitute projects.

Production

There are two principal neodymium magnet manufacturing methods:

- Classical powder metallurgy or sintered magnet process
- Rapid solidification or bonded magnet process

Sintered Nd-magnets are prepared by the raw materials being melted in a furnace, cast into a mold and cooled to form ingots. The ingots are pulverized and milled; the powder is then sintered into dense blocks. The blocks are then heat-treated, cut to shape, surface treated and magnetized.

In 2015, Nitto Denko Corporation of Japan announced their development of a new method of sintering neodymium magnet material. The method exploits an "organic/inorganic hybrid technology" to form a clay-like mixture that can be fashioned into various shapes for sintering. Most importantly, it is said to be possible to control a non-uniform orientation of the magnetic field in the sintered material to locally concentrate the field to, e.g., improve the performance of electric motors. Mass production is planned for 2017.

As of 2012, 50,000 tons of neodymium magnets are produced officially each year in China, and 80,000 tons in a "company-by-company" build-up done in 2013. China produces more than 95% of rare earth elements, and produces about 76% of the world's total rare-earth magnets.

Bonded Nd-magnets are prepared by melt spinning a thin ribbon of the NdFeB alloy. The ribbon contains randomly oriented $Nd_2Fe_{14}B$ nano-scale grains. This ribbon is then pulverized into particles, mixed with a polymer, and either compression- or injection-molded into bonded magnets. Bonded magnets offer less flux intensity than sintered magnets, but can be net-shape formed into intricately shaped parts, as is typical with Halbach arrays or arcs, trapezoids and other shapes and assemblies (e.g. Pot Magnets, Separator Grids, etc.) There are approximately 5,500 tons of Neo bonded magnets produced each year. In addition, it is possible to hot-press the melt spun nanocrystalline particles into fully dense isotropic magnets, and then upset-forge or back-extrude these into high-energy anisotropic magnets.

Properties

Neodymium magnets (small cylinders) lifting steel spheres. Such magnets can easily lift thousands of times their own weight.

Ferrofluid can be used to disclose a powerful neodymium magnet's field

Grades

Neodymium magnets are graded according to their maximum energy product, which relates to the magnetic flux output per unit volume. Higher values indicate stronger magnets and range from N35 up to N52. Letters following the grade indicate maximum operating temperatures (often the Curie temperature), which range from M (up to 100 degrees Celsius) to EH (200 degrees Celsius).

Grades of Neodymium magnets:

N35-N52
N33M-N48M
N30H-N45H
N30SH-N42SH
N30UH-N35UH
N28EH-N35EH

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Magnetic properties

Some important properties used to compare permanent magnets are:

remanence (Br)

which measures the strength of the magnetic field

coercivity (Hci)

the material's resistance to becoming demagnetized

energy product (BHmax)

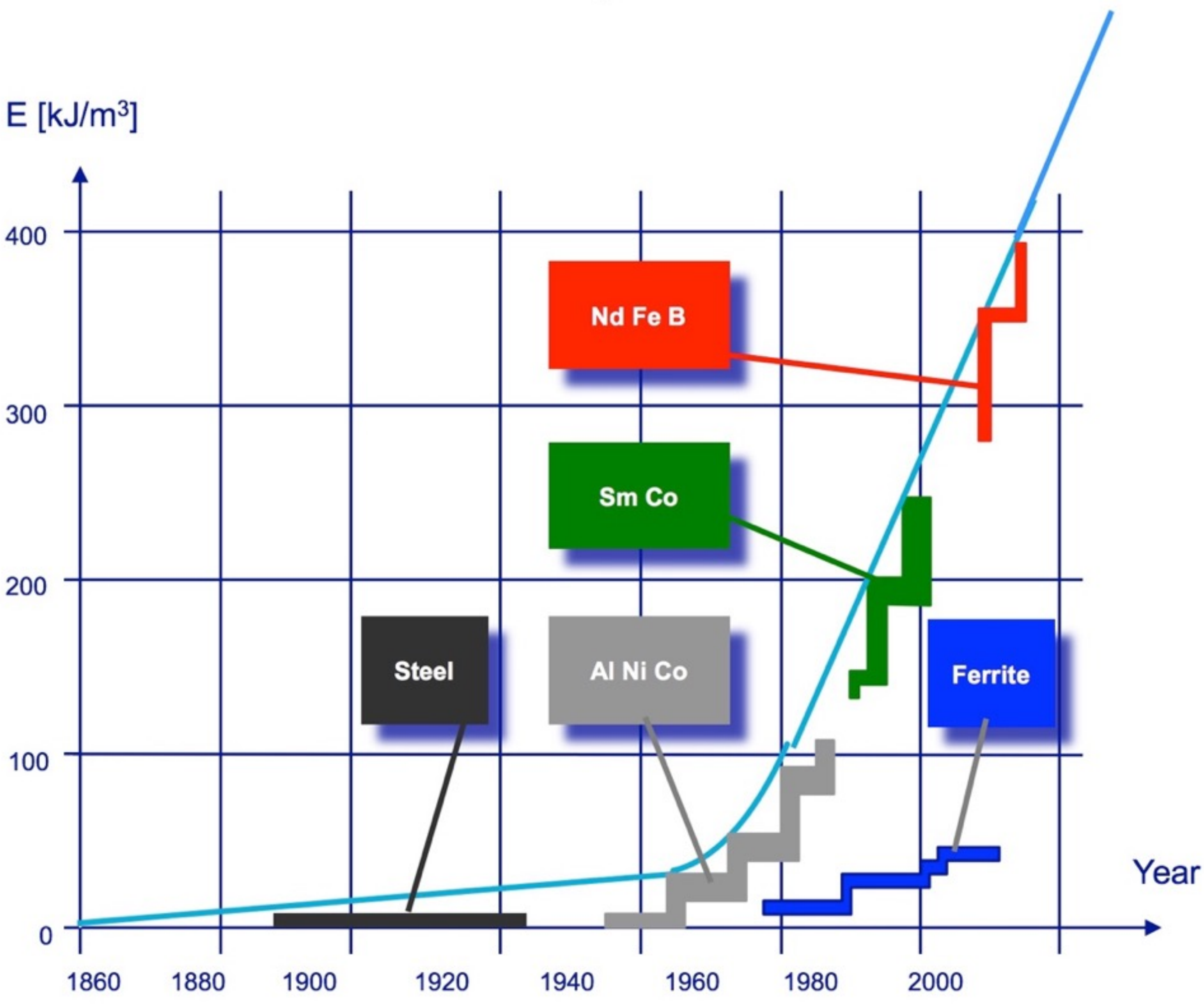
the density of magnetic energy

Curie temperature (TC)

the temperature at which the material loses its magnetism

Neodymium magnets have higher remanence, much higher coercivity and energy product, but often lower Curie temperature than other types. Neodymium is alloyed with terbium and dysprosium in order to preserve its magnetic properties at high temperatures. The table below compares the magnetic performance of neodymium magnets with other types of permanent magnets.

Magnet	Br (T)	Hci (kA/m)	BHmax (kJ/m3)	TC (°C)	TC (°F)
$Nd_2Fe_{14}B$ (sintered)	1.0–1.4	750–2000	200–440	310–400	590–752
$Nd_2Fe_{14}B$ (bonded)	0.6–0.7	600–1200	60–100	310–400	590–752
SmCo5 (sintered)	0.8–1.1	600–2000	120–200	720	1328
Sm(Co, Fe, Cu, Zr)7 (sintered)	0.9–1.15	450–1300	150–240	800	1472
Alnico (sintered)	0.6–1.4	275	10–88	700–860	1292–1580
Sr-ferrite (sintered)	0.2–0.78	100–300	10–40	450	842



Physical and mechanical properties

Comparison of physical properties of sintered neodymium and Sm-Co magnets

Property	Neodymium	Sm-Co
Remanence (T)	1–1.3	0.82–1.16
Coercivity (MA/m)	0.875–1.99	0.493–1.59
Relative permeability	1.05	1.05
Temperature coefficient of remanence (%/K)	−0.12	−0.03
Temperature coefficient of coercivity (%/K)	−0.55..−0.65	−0.15..−0.30
Curie temperature (°C)	320	800
Density (g/cm3)	7.3–7.5	8.2–8.4
CTE, magnetizing direction (1/K)	5.2×10−6	5.2×10−6
CTE, normal to magnetizing direction (1/K)	−0.8×10−6	11×10−6
Flexural strength (N/mm2)	250	150
Compressive strength (N/mm2)	1100	800
Tensile strength (N/mm2)	75	35
Vickers hardness (HV)	550–650	500–650
Electrical resistivity (Ω·cm)	(110–170)×10−6	86×10−6

Corrosion problems

These neodymium magnets corroded severely after 5 months of weather exposure

Sintered $Nd_2Fe_{14}B$ tends to be vulnerable to corrosion, especially along grain boundaries of a sintered magnet. This type of corrosion can cause serious deterioration, including crumbling of a magnet into a powder of small magnetic particles, or spalling of a surface layer.

This vulnerability is addressed in many commercial products by adding a protective coating to prevent exposure to the atmosphere. Nickel plating or two-layered copper-nickel plating are the standard methods, although plating with other metals, or polymer and lacquer protective coatings are also in use.

These neodymium magnets corroded severely after 5 months of weather exposure

Hazards

The greater forces exerted by rare-earth magnets create hazards that may not occur with other types of magnet. Neodymium magnets larger than a few cubic centimeters are strong enough to cause injuries to body parts pinched between two magnets, or a magnet and a metal surface, even causing broken bones.

Magnets allowed to get too near each other can strike each other with enough force to chip and shatter the brittle material, and the flying chips can cause various injuries, especially eye injuries. There have even been cases where young children who have swallowed several magnets have had sections of the digestive tract pinched between two magnets, causing injury or death. The stronger magnetic fields can be hazardous to mechanical and electronic devices, as they can erase magnetic media such as floppy disks and credit cards, and magnetize watches and the shadow masks of CRT type monitors at a greater distance than other types of magnet.

Applications

Existing magnet applications

This manually-powered flashlight uses a neodymium magnet to generate electricity

Neodymium magnets have replaced alnico and ferrite magnets in many of the myriad applications in modern technology where strong permanent magnets are required, because their greater strength allows the use of smaller, lighter magnets for a given application. Some examples are[citation needed]

- Head actuators for computer hard disks
- Erase heads for cheap cassette recorders
- Magnetic resonance imaging (MRI)
- Techanical e-cigarette firing switches
- Locks for doors
- Loudspeakers and headphones
- Magnetic bearings and couplings
- Benchtop NMR spectrometers
    - Electric motors:
    - Cordless tools
    - Servomotors
    - Lifting and compressor motors
    - Synchronous motors
    - Spindle and stepper motors
    - Electrical power steering
    - Drive motors for hybrid and electric vehicles. The electric motors of each Toyota Prius require 1 kilogram (2.2 pounds) of neodymium.
    - Actuators
- Electric generators for wind turbines (only those with permanent magnet excitation)
    - direct-drive wind turbines require c. 600 kg of PM material per megawatt
    - turbines using gears require less PM material per megawatt
- Toys

Neodymium content is estimated to be 31% of magnet weight

New applications

Neodymium magnet spheres assembled in the shape of a cube

In addition, the greater strength of neodymium magnets has inspired new applications in areas where magnets were not used before, such as magnetic jewelry clasps, children's magnetic building sets (and other neodymium magnet toys) and as part of the closing mechanism of modern sport parachute equipment. They also are the main metal in the formerly popular desk-toy magnets, "Buckyballs", though some US retailers have chosen not to sell them due to child-safety concerns.

Neodymium magnet spheres assembled in the shape of a cube

The strength and magnetic field homogeneity on neodymium magnets has also opened new applications in the medical field with the introduction of open magnetic resonance imaging (MRI) scanners used to image the body in radiology departments as an alternative to superconducting magnets that use a coil of superconducting wire to produce the magnetic field.

Neodymium magnets are used as a surgically placed anti-reflux system which is a band of magnets surgically implanted around the lower esophageal sphincter to treat gastro esophageal reflux disease (GERD).