



Rare-earth Information Center **INSIGHT**

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Improved Nd-Fe-B Permanent Magnets

Recently Arnold Engineering Co., Marengo, Illinois and its parent company, SPS Technologies, Newtown, Pennsylvania announced the development of a proprietary manufacturing process that greatly enhances the corrosion resistance of Nd-Fe-B permanent magnets while increasing the Curie temperature by more than 100°C. The process, which is called AQUANIDE, consists of milling the Nd-Fe-B alloy in an attritor in water, vacuum drying between 40 and 90°C, and then passivating the powder at a temperature between 125 and 300°C in a N₂ and/or CO₂ atmosphere. During the passivation process, a protective layer consisting of nitride and/or carbide phases is formed on the surface of the powder. The resultant powder is not pyrophoric and can be stored for prolonged periods of time in normal atmospheres without degradation. Furthermore, since it is also magnetically stable it is suitable for use in bonded magnets. The best magnet properties of the sintered AQUANIDE processed Nd-Fe-B alloys were: a (BH)_{max} energy product of 33.4 MGOe, a remanence of 11.8 kG, a coercivity of 14.1 kOe, and a Curie temperature of 440°C. The word AQUANIDE has been trademarked, and patent applications have been filed worldwide on this process. Arnold Engineering has received notice of allowance of the U.S. patent claims, and intends to license the AQUANIDE process technology.

Corrosion Resistance of Nd-Fe-B Permanent Magnets

The influence of interstitial impurities (carbon, nitrogen and oxygen) on the corrosion resistance of Nd-Fe-B permanent magnets has been studied by A. S. Kim and F. E. Camp [*J. Mater. Eng.* **13**, 175 (1991)]. They find that the carbon content should be >0.06 wt.%, up to a maximum of 0.14% for the best corrosion resistance. Similarly the oxygen content must be >0.6 wt.%, but no upper limit up to 1.0 wt.% was found, while the optimum nitrogen content was found to be 0.04 to 0.08 wt.%. The precise role which carbon plays was not discussed, but the authors thought that this impurity might have some influence on the microstructure of the Nd-Fe-B alloy which reduces the corrosion rate. The carbon is reported to dissolve in the "pure" neodymium metal phase in the grain boundaries, up to 0.14 wt.%. Beyond this concentration, the carbon exceeds its solid solubility in Nd and forms a second phase, probably a NdC_x phase (with x ~ 1.5), which is readily oxidized or corroded by the moisture and oxygen in the atmosphere. The authors noted that when the oxygen content was low the Nd-rich phase is thick in both the grain boundaries and the junctions of grain boundaries. When the oxygen content increases the Nd-rich phase becomes thinner in the grain boundaries and agglomerates in the triple junctions of the grain boundaries, while at the same time the Nd-rich phase (α -Nd) oxidizes to form a neodymium suboxide, NdO_x, phase. The nitrogen is thought to improve the corrosion resistance by assisting the oxidation of NdO_x to Nd₂O₃.

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The authors proposed a model for the corrosion of Nd-Fe-B permanent magnets, which is based on galvanic reaction between the more reactive Nd-rich phase (Nd or NdO_x) and the Nd₂Fe₁₄B phase when there is enough moisture in the air. If the Nd-rich phase in the grain boundaries is thick the reaction takes place rather rapidly in the boundary area and the formation of Nd(OH)₃ is accompanied by a volume expansion which causes intergranular fracture, thus exposing fresh uncorroded surfaces to the ambient moist atmosphere allowing the corrosion process to continue. When the Nd-rich phase in the grain boundaries is thin the reaction seems to be restricted to the triple junctions of the grain boundaries and the corrosion does not seem to propagate in the thin grain boundaries, at least during the time interval the experiment was carried out.

Superfluorescent Pr Fluoride Laser

Scientists at Nippon Telegraph and Telephone Corporation, NTT Opto-Electronics Laboratories, Ibaraki-Ken, Japan have developed a Pr³⁺-doped superfluorescent fluoride fiber laser operating at 1.306 μm with an output power of 0.166 mW. The Pr³⁺ ion was doped at a 0.1 wt.% level into a complex fluoride glass composed of ZrF₄-BaF₄-LaF₃-YF₃-AlF₃-LiF-NaF. The Pr³⁺-doped glass fiber, 4.5 μm in diameter, was clad with another fluoride glass which had a 0.6% refractive-index difference. The ³H₄-¹G₄ transition in Pr³⁺ was excited at 1.017 μm using a Ti-sapphire laser pumped by an Ar-ion laser. The output of the fluoride glass laser is low, but by changing the glass composition an improvement is expected.

This Pr³⁺-doped fluoride single-mode fiber has a peak wavelength of 1.3 μm which corresponds well with the central wavelength used in conventional telecommunication systems. These characteristics make it an ideal candidate for a broad-band light source in some signal-processing fiber systems as a low temporal coherent source. Currently superluminescent diodes (SLDs) are used for these applications. But because of their short lifetimes, poor wavelength stability, low output power, and low coupling power into a single-mode fiber, a great deal of effort is being concentrated on replacing the SLDs by rare earth doped superfluorescent fiber lasers (SFLs). Prior to this study by Y. Ohishi *et al.* [*Jap. J. Appl. Phys.* **30**, L1282 (1991)] the prime rare earth candidates were Nd³⁺-doped and Er³⁺-doped SFLs, with outputs at 1.06 and 1.5 μm, respectively. However, both of these SFLs operated on either side of central wavelength of optical telecommunication trunk line systems (1.3 μm), while the Pr³⁺ doped fluoride SFL sits right in the middle of it. The Pr³⁺-doped fluoride SFL is also useful for sensor applications, such as fiber gyroscopes.



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