Need for new magnet materials drives ORNL research

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Demand for rare earth elements used in magnets for wind turbines and other green energy applications is the force behind an effort to develop economical substitutes.

Increasing demand and a shrinking supply of rare earth elements for magnets creates a perfect opportunity for a research team from Oak Ridge National Laboratory and the University of Minnesota. The goal is to create a recipe for a replacement that doesn't use scarce ingredients.

"Worldwide demand for rare earths is expected to exceed supply by some 40,000 tons annually by the end of this decade," said Larry Allard, a researcher in ORNL's Materials Science and Technology Division. "In the past, 95 percent of that material has been supplied to the world by China, but in recent years China has begun limiting exports and by 2015 is expected to become a net importer."

The prospect of not having enough rare earth elements such as neodymium and dysprosium for magnets looms large for industries that need them for products we count on every day.

Most people never give it a second thought, but magnets are used in everything from the motors that power hybrid vehicles and electric windows to windmills, computers and hundreds of items that touch our lives every day. The traction drive components of a Toyota Prius, for example, use about 2 pounds of magnet materials while a 3-megawatt windmill uses 550 pounds. Today's automobiles and light trucks each use between 70 and 150 magnets to operate the speedometer, odometer, gas gauge, antilock brake systems, air bag sensors, fuel pumps and dozens of other systems.

In the home, magnets are even more common as they are found in door chimes, security systems, personal computers, printers, telephones, furnaces and air conditioning systems, garage door openers, refrigerators, freezers, workshop tools, hair dryers and electric shavers. It's difficult to imagine a world with no magnets. From an economics and national security perspective, it would be catastrophic.

That's why researchers like Allard, Edgar Lara-Curzio and Mike Brady of ORNL and Jian-Ping Wang of the University of Minnesota are focused on developing magnets made from abundant and inexpensive materials. Of specific interest is an iron nitride compound with a specific phase that potentially exhibits the highest saturation magnetization ever reported for a material.

"This is a critical parameter related to the highest degree to which a material can be magnetized," said Allard, who noted that this particular iteration of the iron-nitrogen compound has values up to 18 percent higher than the best commercial alloy, iron cobalt. The problem is that this material is metastable and exhibits relatively low coercivity, which means it can be demagnetized easily. The best permanent magnets - such as those made of neodymium-iron-boride - score high in these areas.

Working with Wang, Allard, Lara-Curzio and Brady will devise a method of producing this pure phase iron nitride compound and use specialized modeling methods to better understand the role of alloying additions that might stabilize the material so it retains its magnetic properties. Through their efforts, the researchers hope to better understand the magnetic behavior of the "alpha double prime" phase by correlating microstructure at the atomic level to processing and magnetic behavior.

Once researchers have answered these questions, their goal is to make bulk quantities of the material and move toward their ultimate goal of replacing neodymium-iron-boride magnets for automotive and other energy technology uses. This work with the University of Minnesota builds on previous work with Wang in which ORNL researchers were able to characterize iron nitride films with demonstrated potential. Allard noted that the Spallation Neutron Source made it possible to perform polarized neutron reflectometry, a test performed by Valeria Lauter to determine magnetic property.

In a separate effort, ORNL's David Parker hopes to computationally screen dozens of materials and then mix elements that emerge as promising candidates in a way to create a compound that will behave like rare earth elements. This material must also be scalable, retain its magnetic properties under varying conditions and meet cost-performance criteria. Parker noted that often the compounds identified as having desirable properties consist of elements with greatly differing melting points, stabilities and other traits and can prove very difficult to controllably manufacture. That's where ORNL's unique capabilities come into play.

"We have a suite of conventional and novel processing approaches to try to make the computationally predicted compounds, including a range of powder consolidation and gas reaction approaches," said Parker, who noted that there's nothing "sacred" about rare earth elements.

"Their main advantage is that due to their large nuclear charge, spin-orbit coupling is very strong and serves to fix the magnetization direction of the unpaired electrons," Parker said. "Other heavy elements may play the same role."

By employing strategic computational screening and ORNL's specialized microscopy and characterization skills, Allard and Parker believe they can make great strides toward solving a problem of national importance.

Provided by Oak Ridge National Laboratory

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