Scientists spy Galfenol's inner beauty mark

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Magnetostrictors are a critical element in sound detection equipment including the sonar used in submarines. Scientists working at NIST solved the structure of the magnetostrictor Galfenol, which could improve sonar's capabilities in the future. Credit: U.S. Navy photo

(PhysOrg.com) -- The sonar on submarines may get far more sensitive ears in the near future thanks to a mysterious compound developed by the military. Developed over a decade ago, it took a collaboration of scientists from the Virginia Polytechnic Institute and State University and the National Institute of Standards and Technology to determine why the material works. Surprisingly, the critical factor is a sprinkling of useful imperfections within an otherwise regular crystal.

The scientific team solved the internal structure of Galfenol, a compound of iron and gallium that changes shape when exposed to a magnetic field. Because the effect also works in reverse—a tiny bit of pressure that distorts its shape slightly and induces detectable magnetism—such “magnetostrictors” are the key ingredients in sound detection equipment.

Iron alone has some talent as a magnetostrictor, but U.S. Navy researchers discovered in 1998 that doping iron with gallium amplifies iron’s magnetostrictive capability tenfold. They dubbed their creation Galfenol, but the basis for the material’s behavior went unexplained.

“It’s important to know why a material works the way it does,” says Peter Gehring of the NIST Center for Neutron Research (NCNR). “If you can relate its atomic structure to its behavior, you might be able to improve the recipe.”

The scientists used neutron beams to determine Galfenol’s structure, settling a running debate over which model of its innards was correct. The investigation showed that the added gallium changes the structure of the iron, which on the atomic level forms a lattice of regular cubic cells. When the gallium combines with the iron, the faces of some cells become rectangular rather than square. These elongated gallium-iron cells then congregate into tiny clumps within the lattice, resembling “something like raisins within a cake,” as Gehring describes it.

The study also showed that these clusters of distorted cells respond to a magnetic field by rotating their magnetic moments, like tiny compass needles, to align with the field; it is this rotation that changes the exterior dimensions of the crystal. The clusters are thus responsible for Galfenol’s performance—it changes in size by 400 parts per million compared to iron’s 30—even though it seems surprising that imperfections in iron’s otherwise orderly lattice should improve its magnetostrictive talents.

“These irregularities give the iron more complex and richer properties,” Gehring says. “We see this theme repeated frequently in nature, where similar kinds of disorder lead to improved performance in high-temperature superconductors, giant magnetoresistive oxides, and other exotic new materials. It’s like the supermodel with a beauty mark on her cheek—we don’t know why it’s so appealing, but it is.

More information: * H. Cao, P.M. Gehring, C.P. Devreugd, J.A. Rodriguez-Rivera, J. Li and D. Viehland. The role of nano-scale precipitates on the enhanced magnetostriction of heat-treated Galfenol (Fe1-xGax) alloys. *Physical Review Letters*, forthcoming.

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