Magnets warm up to get stronger

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Physicists in the US have developed a warm compaction technique to make small, powerful bulk permanent magnets. The exchange-spring magnets consist of two magnetic phases - both "soft" and "hard" - and have exchange coupling between them, which makes the magnets stronger than ordinary magnets containing just a single phase. If perfected, the magnets could find use in a wide range of applications, from cell phones and data storage devices to hybrid cars, and could revolutionize our daily lives, say the researchers.

"Nanotechnology is not only good for creating novel materials like graphene but also for improving and re-birthing traditional materials like permanent magnets," team leader J Ping Liu of the University of Texas at Arlington told nanotechweb.org. Indeed, theory predicts that the energy product, or $\mathcal{B}H_{\text{max}}$ (the figure of merit for a magnet's strength) for exchange-coupled nanocomposite magnets could reach 100 MJ/m$^3$. This is double the current highest value for single-phase magnets.

A high $\mathcal{B}H_{\text{max}}$ requires the material to have a large magnetization and a large coercivity - the magnetic field needed to reduce the magnetization of a ferromagnetic material to zero. Exchange-spring magnets contain a magnetically hard phase, which has a high coercivity, and a soft phase with low coercivity and high magnetization. These two phases interact by exchange coupling. For the exchange coupling to be effective, however, the grain size of the hard and soft phases must be homogeneously controlled at the nanoscale, which can be difficult using conventional top-down fabrication methods.

Researchers are therefore looking for alternative bottom-up approaches to overcome this problem. Recently, they have become interested in iron-platinum (FePt) nanoparticles made by chemical methods, because of the very small particle size (a few nanometres) and very narrow size distribution in these materials.

However, the biggest challenge here is turning these particles into bulk magnets. Conventional compaction techniques do not work for nanoparticles because these methods require extensive heat treatment at high temperatures, which causes excessive grain growth. Moreover, the smaller the nanoparticles, the more difficult it is to compact them.

Now, Liu and colleagues have developed a high-pressure, warm compaction method, inspired by a special technique routinely used for making car parts. Unlike hot pressing, warm compaction takes place at modest temperatures, where metallic powders are chemically stable and no excessive grain growth occurs.

The researchers mix together FePt and iron oxide nanoparticles in a ratio of 8:1 and then compact them under pressures of up to 3.6 GPa for 10 minutes at various temperatures. They then characterise the compacted samples using electron microscopy and X-ray diffraction. Magnetic measurements are made with a superconducting quantum interference device (SQUID) magnetometer with a maximum applied field of 70 kOe.

The team says that the best magnets are produced at temperatures of about 600°C. A $\mathcal{B}H_{\text{max}}$ of up to 16.3 MGy has been reached, which is 25% higher than the value for conventional single-phase isotropic FePt magnets. Moreover, the samples have a density that is 95% of the theoretical density allowed for these materials, which makes them the densest bulk FePt magnets ever made with a nanoscale grain size.

"We also observed very interesting phenomena, like the pressure expedited phase transition from disordered face-centred-cubic to the so-called L1_0 structure in the material, at temperatures 100°C lower than usual," explained Liu. This phase transition also makes consolidating the magnets easier.

The team is now working hard on solving a key issue in fabricating these nanocomposites — orienting the hard magnetic component, which would further increase the $\mathcal{B}H_{\text{max}}$ of the material.

The researchers reported their work in J. Appl. Phys.

About the author

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