Magnetic materials increase energy density in power transformation

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Power transformation. Electrification of vehicles. Creating motors that are efficient. Some of the biggest technologies of the future rest on finding ways to efficiently transform energy. And the backbone that enables the development of these technologies is the field of advanced materials.

At Carnegie Mellon University, Materials Science and Engineering Professor Mike McHenry and his research group are developing metal amorphous nanocomposite materials (MANC), or magnetic materials whose nanocrystals have been grown out of an amorphous matrix to create a two phase magnetic material that exploits both the attractive magnetic inductions of the nanocrystals and the large electrical resistance of a metallic glass. When operated at high frequencies, these MANC materials offer very high energy efficiency, due to their low losses of energy—an essential component for transforming energy.

Different MANC compositions can be applied to various applications but have most recently been adopted in power transformers that will be used to bring renewable energy to the grid. These transformers need magnetic materials to harvest solar or wind energy, then transform it to a power that can be stored and fed to the grid.

Typically, silicon steels used to transform energy are lossy at high frequencies, meaning they lose energy when excited with high frequency alternating current fields. But McHenry's material doesn't suffer from this problem. It is highly efficient and loses little energy, even at frequencies reaching tens of kHz. The lossless nature of the material allows for high power density applications such as power grid inductors and transformers, electric vehicle motors, and even potentially for motors that propel aircraft and rockets in space.

To synthesize these materials, McHenry's team weighs alloy components combining iron, cobalt, and nickel, mixed with glass formers in ratios optimized to achieve desirable magnetic, electrical and mechanical properties. Next, they use a crucible to melt the material and cast the molten metal onto a rotating copper wheel using a technique called planar flow casting. The molten alloy forms a melt pool on the copper alloy casting wheel. The large thermal mass of the wheel quickly extracts heat out of the material, cooling the liquid metal at about 1 million degrees per second. At those solidification rates, atoms do not have time to find positions in a crystalline lattice. The resulting metastable material is a metallic glass—a material whose isotropic structure makes it easy to switch the magnetization without losing energy, perfect for use in high power applications.

"In every one of the projects we work on, we learn something more," said McHenry.

McHenry's lab is strong in this method of synthesis, called rapid solidification, which is part of the synthesis stage of the materials science paradigm (synthesis, structure, properties, and performance). His lab is able to create these materials, or discover the best method for creating these materials, then works with others at national laboratories and industry to scale it up for use in real-world applications.

Currently, McHenry and his team are collaborating with the National Energy Technology Laboratory (NETL), NASA Glenn Research Center, North Carolina State University, and Eaton Corporation on a Department of Energy-funded project to create high-density transformers to bring renewable energy to the power grid. The project, a three-port photovoltaic converter, increases power density and enables the photovoltaic energy source to connect directly to the transformer that connects to the storage device.

"We work on a myriad of geometries," said McHenry. "Our job is to create materials, then hand it off to the people who will use it in their products. It's really the materials that are enabling power and energy applications; everyone is riding the materials' development horse."

Provided by Carnegie Mellon University Materials Science and Engineering

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