Magnetic or superconducting

Argovia Professor Martino Poggio uses special cantilevers to study a broad range of materials

For the first time ever, the team led by Argovia Professor Martino Poggio recently succeeded in examining the magnetic properties of tiny magnetic crystals consisting of magnetic nanoparticles. The ability to measure these very faint magnetic forces using cantilever magnetometry opens the door to an array of potential applications. A very different kind of cantilever is at the heart of a European Horizon 2020 project approved in 2020, to be coordinated by Martino Poggio over the next four years. The international project team plans to use focused ion beam technology to manufacture sensors directly on the cantilever tip that can also be used to examine superconducting materials.

Materials with novel properties

Numerous materials with special properties occur in nature. Researchers around the world are busy adding to this list in the lab, creating new substances with optical, electrical or magnetic properties not found in the natural world.

For example, nanoparticles that self-assemble as if by magic can be used to create crystal superstructures. If researchers use magnetic nanoparticles in this process, under the right conditions they will come together to form magnetic mesocrystals that can reach a size of up to several micrometres. Examining the magnetic properties of these mesocrystals has so far not been possible, as their total magnetic moment is very small, and their orientation on a surface is random rather than orderly.

Cantilevers are key

In collaboration with researchers from Germany, Belgium and Sweden, however, the team led by Argovia professor Martino Poggio has now succeeded in precisely measuring the magnetic properties of these mesocrystals. A paper recently published in the scientific journal *Physical Review B* describes how Poggio's team used highly sensitive dynamic cantilever magnetometry to analyze the magnetic forces at work in mesocrystals.

To this end, postdoc Dr. Boris Gross and doctoral researcher Simon Philipp of Poggio's team applied individual mesocrystals of maghemite (γ-Fe_2O_3) to a cantilever. The cantilever was then exposed to a magnetic field in order to observe the magnetic behavior of the crystals.

Simon Philipp was able to optimize the procedure in such a way that individual maghemite mesocrystals on the surface – on which they are arranged at random following self-organization – can be selected, imaged and examined in different orientations. As a result, the researchers were able to study not just the magnetism of the crystal superstructure, but also that of the minute nanoparticles themselves.

Magnetization with a preferred orientation

The measurements revealed that the magnetization of the mesocrystals exhibits a cubic preferred orientation. Known in expert circles as anisotropy, this orientation is dependent on the shape of the mesocrystal, and results from the fact that the individual nanoparticles are themselves tiny cubic crystals arranged in a lattice.

The ability to examine the magnetism of mesocrystals opens up a broad range of potential applications. "Biologists, for instance, are discussing the possibility of using magnetic mesocrystals as transporters for a cargo that could be guided to the intended destination with the help of magnets," Martino Poggio remarks. "Before the magnetic properties of mesocrystals can be adjusted and altered for applications of this sort, we need a precise method with which to analyze their magnetism."

In charge of a FET OPEN project

Another highlight of 2020 for Martino Poggio was the approval of a project under the EU Horizon 2020 program.

Working with researchers from IBM Zurich, Germany and Spain, over the next four years the Poggio team will develop a new production method for exceptionally sensitive and precise probes for scanning probe microscopy that can be used to examine current, magnetization, dissipation, and topography on the nanometer-scale.

Under the FET OPEN funding program, established to support European cooperations developing radically innovative technologies, the researchers will receive almost three million euros for the creation of the groundbreaking sensors.

The interdisciplinary team began the project, which revolves around the use of focused ion beam (FIB) technology, in October 2020. Using this technology, available to the researchers in the SNI's Nano Imaging Lab, Poggio's team will manufacture tiny, highly sensitive sensors directly on the tip of cantilevers that can be used to image new and poorly understood condensed matter phenomena, including, for example, superconductivity, highly insulating states, and magnetism in 2D materials. The probes, which will contain nanometer-sized Josephson junctions (JJs) and superconducting quantum interference devices (SQUIDs), will serve to image magnetic fields and susceptibility, besides enabling measurement of electrical currents and their losses.

A productive start

For the first few months of the project, the team focused primarily on the design of the new cantilevers, which the experts at IBM have already begun manufacturing. Meanwhile, Martino Poggio's group in Basel began creating an initial protoype from commercially available cantilevers, using FIB technology to cut the cantilevers to size and coating them with the superconducting material niobium.

A new era for scanning probe microscopy

At a later stage, the cantilevers will be created especially for different fields of application, and fitted with the appropriate probe at the tip.

The application focus will initially be on studying magnetic fields in two-dimensional van der Waals materials. The researchers are especially interested in mapping the transport of charges and imaging edge states and correlated electronic states. The examinations can be performed at comparatively high temperatures of up to 80 Kelvin (-193°C), with a spatial resolution of up to 10 nanometers.

"With this project, we hope to usher in a new era for the already highly successful field of scanning probe microscopy. This will allow us to tackle poorly understood phenomena in physics, chemistry and materials science that can't be studied using current technology," said Poggio.

For more information about this and other projects from Poggio's lab, visit https://poggiolab.unibas.ch

Over the next few years, Argovia Professor Martino Poggio will lead a project in the EU Horizon program. The project will use focused ion beam technology to produce sensors directly at the tip of a cantilever that can also be used to study superconducting materials.