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IBM researchers develop new way to explore and control atom-scale magnetism

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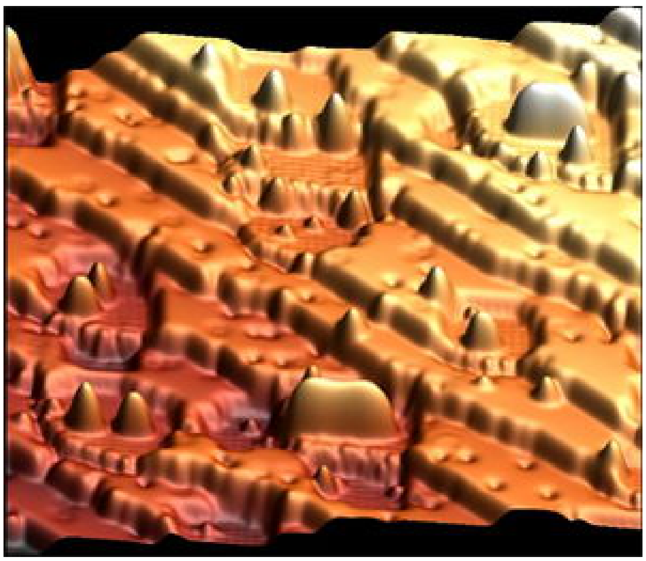


STM image of 28nm by 28nm area of the terraced copper and copper nitride surface where the IBM experiments were performed. The smooth flat surfaces are copper metal; the cross-hatched, slightly depressed areas are patches of insulating CuN, which were created by implanting a sub-monolayer amount of nitrogen and heating the surface. The scientists wanted both sufaces close to each other so they could easy test magnanese-atom structures on both the conducting and insulating surfaces. The visible humps on the surfaces are the manganese structures (1-10 atoms long). Credit: IBM

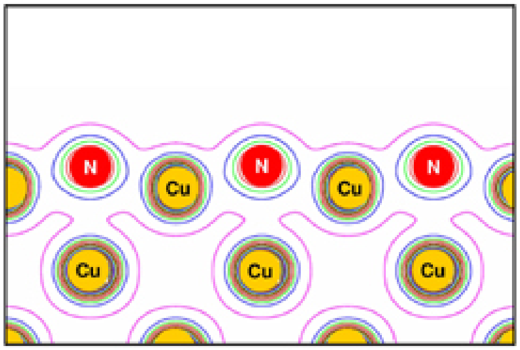
IBM scientists have developed a powerful new technique for exploring and controlling magnetism at its fundamental atomic level. The new method promises to be an important tool in the quest not only to understand the operation of future computer circuit and data-storage elements as they shrink toward atomic dimensions, but also to lay the foundation for new materials and computing devices that leverage atom-scale magnetic phenomena.

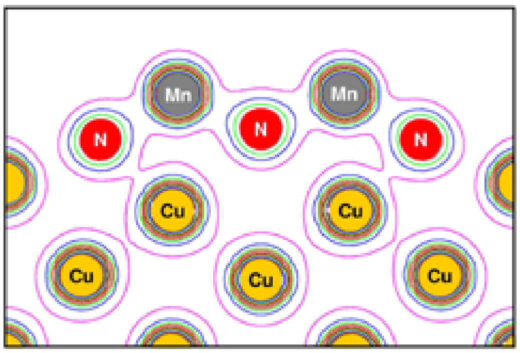
"We have developed a window into the atomic heart of magnetism," said Andreas Heinrich, research staff member at IBM's Almaden Research Center in San Jose, California. "We can now position atoms and then measure and control their magnetic interactions within precisely designed structures."

The new method, called spin-excitation spectroscopy, uses IBM's special low-temperature scanning tunneling microscope designed for use with a broad range of magnetic fields up to 140,000 times stronger than the earth's. The researchers first move atoms into position and then measure the interactions between their atomic spins, which are the fundamental sources of magnetism.

In their experiments, the IBM researchers created chains of up to 10 manganese atoms atop an extremely thin electrically insulating surface and measured how the magnetic properties changed as each new atom was added. They found that chains with an even number of atoms had no net magnetism, while chains with an odd number of atoms showed net magnetism.

"This kind of exploratory research is essential for the long-term future of the computer industry," said Gian-Luca Bona, manager of science and technology at IBM Almaden. "Sometime in the next couple of decades, it will be impossibly difficult to continue improving transistors and other traditional microelectronic circuit elements by simply shrinking them. We will then need alternative structures and, perhaps, altogether different ways of computing. Techniques like this can help us gain the knowledge needed to create those alternatives."





This image shows a calculated cross-section of the CuN surface layer before (top) and after Mn atoms are placed on the surface. (This calculation is not part of the Science Express paper itself; it was done for another paper by colleague Chiung-Yuan Lin.) Credit: IBM

These new experimental results are published in today's issue of Science Express, Science magazine's online advance publication of reports judged by the journal's editors to be especially timely and important. The report's authors are Cyrus Hirjibehedin, Christopher Lutz and Heinrich.

In addition to exploring the basic properties of magnetic materials, the IBM researchers expect to use this new technique in the future to:

-- Explore the limits of magnetic data storage, by engineering the energy required to flip the collective orientation of a small number of magnetically coupled atoms.
-- Determine the feasibility of spin-based wires and a spin version of the molecular-motion cascade, the group's 2002 achievement that included an arrangement of molecules that formed a working computer circuit some 260,000 times smaller than its conventional design in silicon (or about 50 years of circuit-shrinking at Moore's Law pace).
-- Investigate how engineered spin interactions could be applied to quantum information systems, such as quantum computers.

The new technique builds upon the IBM team’s development in late 2004 of spin-flip spectroscopy – a method for measuring magnetic properties of single atoms. Those experiments were done using an aluminum oxide insulating surface, but it was impossible to move atoms around on that surface. Indeed, while the IBM team first showed how to use the STM to move and position individual atoms atop metal surfaces back in 1990, until now no one has been able to move and position atoms on insulating surfaces because those surfaces tend to be atomically complex, rough, easily damaged and/or have varying attractive forces with the atoms. Experiments measuring atomic magnetic properties require an insulating surface because the large numbers of available conducting electrons within a metal would overwhelm and cancel out any spin variations from individual atoms being studied.

For their spin-excitation spectroscopy experiments, the IBM scientists were successful when they converted sections of a smooth copper metal surface into a one-atom-thick coating of copper nitride, an insulator.

Spintronics is an emerging class of new electronic circuits that exploit the magnetic orientations of electrons and atoms -- the quantum property called "spin" – in addition to or instead of the traditional flow of electrical charges. Electron spins can be either "up" or "down." Aligning spins in a material creates magnetism. Most materials are non-magnetic because they have equal numbers of up and down electron spins, which cancel each other. But materials such as iron and cobalt have an unequal numbers of electron spins and thus are magnetic.

Household magnets are made of ferromagnetic materials, such as iron or cobalt. Their spins tend to align in the same direction and thus produce the external magnetic field that we can see or feel. Other magnetic materials, such as manganese, are called antiferromagnetic because their atomic spins tend to align in the opposite direction from their neighbors, which yields no external magnetic field but interesting spintronic properties.

This new result is the latest in a series of achievements in nanoscale science at IBM Research. Two IBM scientists in Switzerland won the 1986 Nobel Prize in Physics for their early 1980s invention of the scanning tunneling microscope (STM). Over the past 16 years, IBM Almaden researchers have pioneered the use of STMs for positioning atoms into precisely designed structures that reveal fundamental atomic-scale properties and may have potential uses in information technology. The group's results include:

-- Positioning individual atoms on surfaces,
-- Inventing an electrical switch with a single atom as the active element,
-- Inventing a new kind of electron trap called a "quantum corral,"
-- Discovering the "quantum mirage" effect, in which an electron's quantum wave pattern is used to project information,
-- Demonstrating a complete functional computational circuit based on the "molecule cascade" motion of individual molecules that is 260,000 times smaller than that which could be made by the best contemporary chip-making methods, and
-- Demonstrating spin-flip spectroscopy: using an STM to probe the spin-state of a single atom and measure the energy required to flip a single

spin.

Source: IBM