IBM Brings Single-Atom Data Storage, Molecular Computers Closer to Reality

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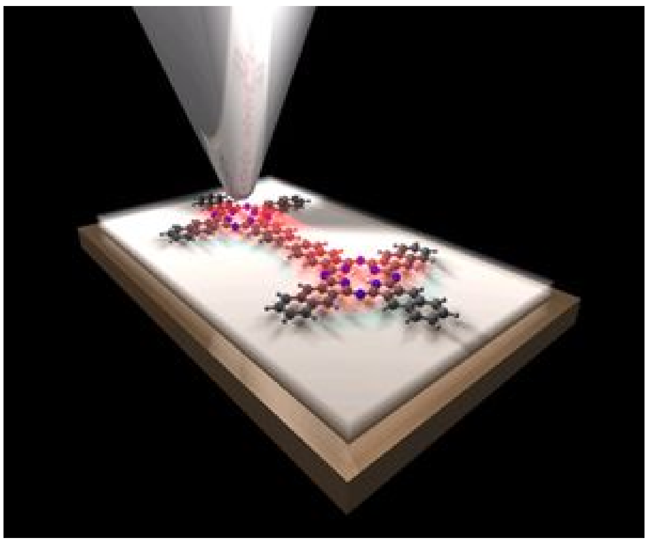

Schematic three-dimensional image of a molecular "logic gate" of two naphthalocyanine molecules, which are probed by the tip of the low-temperature scanning tunneling microscope. By inducing a voltage pulse through the tip to the molecule underneath the tip (shown in the back), the two hydrogen atoms in the adjacent molecule (in white at the center of the molecule in front) change position and electrically switch the entire molecule from "on" to "off". This represents a rudimentary logic-gate, an essential component of computer chips and could be the building block for computers built from molecular components. Credit: IBM

IBM today announced two major scientific achievements in the field of nanotechnology that could one day lead to new kinds of devices and structures built from a few atoms or molecules.

Although still far from making their way into products, these breakthroughs will enable scientists at IBM and elsewhere to continue driving the field of nanotechnology, the exploration of building structures and devices out of ultra-tiny, atomic-scale components. Such devices might be used as future computer chips, storage devices, sensors and for applications nobody has imagined yet.

The work will be unveiled tomorrow in two reports being published by the journal *Science*.

In the first report, IBM scientists describe major progress in probing a property called magnetic anisotropy in individual atoms. This fundamental measurement has important technological consequences because it determines an atom's ability to store information. Previously, nobody had been able to measure the magnetic anisotropy of a single atom.

With further work it may be possible to build structures consisting of small clusters of atoms, or even individual atoms, that could reliably store magnetic information. Such a storage capability would enable nearly 30,000 feature length movies or the entire contents of YouTube – millions of videos estimated to be more than 1,000 trillion bits of data – to fit in a device the size of an iPod. Perhaps more importantly, the breakthrough could lead to new kinds of structures and devices that are so small they could be applied to entire new fields and disciplines beyond traditional computing.

In the second report, IBM researchers unveiled the first single-molecule switch that can operate flawlessly without disrupting the molecule's outer frame -- a significant step toward building computing elements at the molecular scale that are vastly smaller, faster and use less energy than today's computer chips and memory devices.

In addition to switching within a single molecule, the researchers also demonstrated that atoms inside one molecule can be used to switch atoms in an adjacent molecule, representing a rudimentary logic element. This is made possible partly because the molecular framework is not disturbed.

The Science of The Small: Understanding the Magnetic Properties of Atoms

In the paper titled “Large Magnetic Anisotropy of a Single Atomic Spin Embedded in a Surface Molecular Network,” the researchers used IBM’s special scanning tunneling microscope (STM) to manipulate individual iron atoms and arranged them with atomic precision on a specially prepared copper surface. They then determined the orientation and strength of the magnetic anisotropy of the individual iron atoms.

Anisotropy is an important property for data storage because it determines whether or not a magnet can maintain a specific orientation. This in turn allows the magnet to represent either a “1” or “0,” which is the basis for storing data in computers.

“One of the major challenges for the IT industry today is shrinking the bit size used for data storage to the smallest possible features, while increasing the capacity,” said Gian-Luca Bona, manager of science and technology at the IBM Almaden Research Center in San Jose, California. “We are working at the ultimate edge of what is possible – and we are now one step closer to figuring out how to store data at the atomic level. Understanding the specific magnetic properties of atoms is the cornerstone of progressing toward new, more efficient ways to store data.”

Lilliputian Scale Devices: Single Molecule Logic Switching

In the paper titled "Current-Induced Hydrogen Tautomerization and Conductance Switching of Naphthalocyanine Molecules," IBM researchers describe the ability to switch a single molecule "on" and "off," a basic element of computer logic, using two hydrogen atoms within a naphthalocyanine organic molecule. Previously, researchers at IBM and elsewhere have demonstrated switching within single molecules, but the molecules would change their shape when switching, making them unsuitable for building logic gates for computer chips or memory elements.

Switches inside computer chips act like a light switch to turn the flow of electrons on and off and, when put together, make up the logic gates, which in turn make up electrical circuits. Having ever smaller switches allows the circuits to be shrunk to ever smaller sizes, making it possible to pack more circuits into a processor and boosting speed and performance.

These molecular switches could one day lead to computer chips with speeds as fast as today's fastest supercomputers, but much smaller in size; with some speculating even building computer chips so small they could be the size of a speck of dust or fit on the tip of a needle.

Development of conventional silicon-based CMOS chips is approaching its physical limits, and the IT industry is exploring new, truly disruptive technologies to achieve further increases in computer performance. Modular molecular logic is a possible candidate, though still several years from reality. The next step for the Research team is to build a series of these molecules into a circuit, then figure out how to network those together into a molecular chip.

The concept of using molecules as electronic components is still in its infancy. Only a few examples of individual molecules serving as switches or memory elements have been demonstrated to date. Most of these molecules are complex, three-dimensional structures and change their shape when switching. Placing them on a surface while maintaining their function is extremely difficult, making them unsuitable as building blocks for computer logic.

The switching within the molecule used by the IBM researchers is well-defined, highly-localized, reversible, intrinsic to the molecule, and does not involve changes in the molecular frame. Therefore, this molecule could be used as a building block for more complex molecular devices that serve as logic elements. As the shape of the molecule does not change during switching, single switches can be coupled in a controlled way. The switching process should also work with molecules embedded in more complex structures.

"Accidental" Science

Although the IBM Research team had been screening various molecules to discover if they would be suitable for molecular switches, in the case of naphthalocyanine, the tests being performed were not to observe switching but rather to examine molecular vibrations, since understanding vibrations of molecules is important for devices operating at the atomic level. During those tests, team members were surprised to observe results that were intriguing for switching at the molecular scale, and they shifted their focus from studying vibrations to studying switching, leading to this breakthrough.

“One of the beauties of doing exploratory science is that by researching one area, you sometimes stumble upon other areas of major significance,” said Gerhard Meyer, senior researcher in the nanoscale science group at the IBM Zurich lab. “Although the discovery of this breakthrough was accidental, it may prove to be significant for building the computers of the future."

Source: IBM

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