Scientists First To Measure Force Required To Move Individual Atoms

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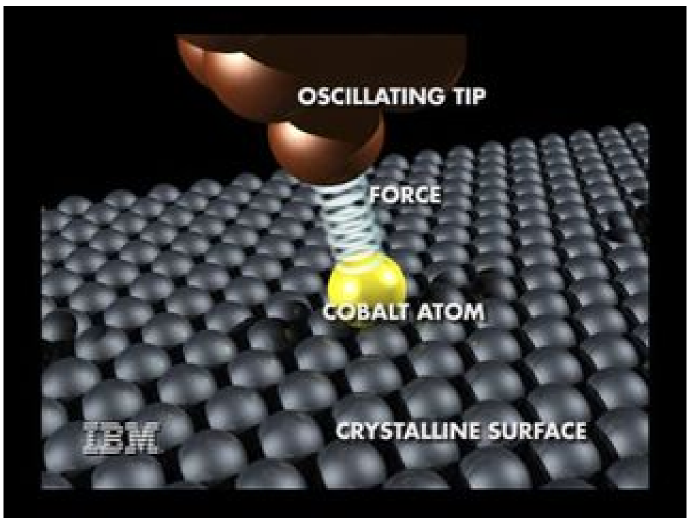

Illustration of an Atomic Force Microscope (AFM) tip measuring the force it takes to move a cobalt atom on a crystalline surface. The ability to measure the exact force it takes to move individual atoms is one of the keys to designing and constructing the small structures that will enable future nanotechnologies. Credit: IBM

IBM scientists, in collaboration with the University of Regensburg in Germany, are the first ever to measure the force it takes to move individual atoms on a surface. This fundamental measurement provides important information for designing future atomic-scale devices: computer chips, miniaturized storage devices, and more.

Some twenty years ago at IBM's Almaden Research Center in San Jose, in a small lab packed with high-tech equipment in the hills of Silicon Valley, IBM Fellow Don Eigler achieved a landmark in mankind's ability to build small structures. On September 29, 1989 he demonstrated the ability to manipulate individual atoms with atomic-scale precision, and went on to write I-B-M with individual Xenon atoms, an event likened to the Wright brothers' first flight at Kitty Hawk.

View video: www.youtube.com/watch?v=BUq2bQkL1zo

Now, a new crop of researchers in that same lab – with help from the University of Regensburg –have taken the extraordinary step of measuring the tiny forces needed to manipulate the atoms. These findings will be published in the February 22 issue of *Science* magazine.

Understanding the force necessary to move specific atoms on specific surfaces is one of the keys to designing and constructing the small structures that will enable future nanotechnologies. The problem is akin to what scientists and engineers needed to learn about construction at macroscopic sizes many decades ago. For example, building a modern bridge would be impossible without first measuring the strength of different materials, understanding the relevant forces, and comprehending how everything interacts. In the nanotechnology realm, to make structures that you want to remain rigidly in place you would use strongly bonded ("sticky") atoms while for groups of atoms that need to move you would use atoms held in place only by weak chemical bonds.

"This result provides fundamental information about atomic scale fabrication and could pave the way for new data storage and memory devices," said Andreas Heinrich, lead scientist in the scanning tunneling microscopy lab at the IBM Almaden Research Center. "Our mission is to create the foundation for what could someday be called the IBM nanoconstruction company."

In the paper, "The Force Needed to Move an Atom on a Surface," the scientists show that the force required to move a cobalt atom over a smooth platinum surface is 210 piconewtons, while moving a cobalt atom over a copper surface takes only 17 piconewtons. To put this in perspective, the force required to lift a copper penny that weighs just three grams is nearly 30 billion piconewtons – 2 billion times greater than the force to move a single cobalt atom over a copper surface.

This knowledge will enable a deeper understanding of the atomic-scale processes at the heart of future nanotechnology endeavors, furthering progress toward nanoscale computing and medical devices. The well-known trend in computer hardware – the exponentially increasing number of ever-shrinking transistors that can be placed on an integrated circuit – is commonly known as Moore's Law. Shrinking the transistors allows them to use less power while having higher speed and lower cost. One of the IT industry's most pressing challenges is to find designs and manufacturing methods that will allow the industry to continue making these devices smaller and smaller.

Miniaturizing these devices to the ultimate limit – the scale of just a few atoms – requires radically new designs and manufacturing methods. The ability to measure the force it takes to move an atom provides a new window into the workings of atom-by-atom construction and operation for future nanodevices.

UNDERSTANDING THE FORCE TO MOVE AN ATOM

Half a century ago, Nobel Laureate Richard Feynman asked what would happen if we could precisely position individual atoms at will. This dream has since become reality and nowadays "atom manipulation" is used widely in research to build, probe and manipulate objects at the scale of individual atoms. However, the fundamental question – "how much force does it take to move an atom on a surface?" – had eluded experimental access until now.

In the paper, the researchers describe their use of a sensitive atomic force microscope (AFM) to measure both the strength and direction of the force exerted on an atom or molecule on a surface using a sharp metal tip to move the atom. The team discovered that the force varies dramatically depending on the material used for the surface. The amount of force also changes greatly when a small molecule is used instead of a single atom.

This latest milestone combines an incredibly sensitive force measurement with the extreme precision and stability needed to move atoms. This work builds on IBM's long history in atomic force microscopy: the AFM was introduced by Nobel Laureate and IBM Fellow Gerd Binnig, IBM scientist Christoph Gerber and Stanford Professor Calvin Quate over 20 years ago.

The AFM uses a sharp tip mounted on a flexible beam – akin to a tiny diving board – to measure the interaction between the tip and the atoms on a surface. In the present work, the flexible beam was actually a miniature quartz tuning fork of the type commonly found in clocks and wrist watches. When the tip is positioned close to an atom on the surface, the frequency of the tuning fork changes slightly. The frequency change can be analyzed to determine the force exerted on the atom. "It is amazing to see how this tool, which at its heart uses the tuning fork of an everyday wrist watch, can be used to measure forces between individual atoms," said Professor Franz Giessibl of the University of Regensburg.

Source: