

# Tech businesses see big future in nanoworld

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This may be remembered as the "Alice in Wonderland" decade for new technology.

More and more businesses are moving into the world of nanotechnology, where particles of common materials are shrunk to such a minuscule size that they behave in unexpected — and often useful — ways.

Entrepreneurs and multinationals alike are building on research from the 1980s and 1990s that led to relatively simple ways to fashion silicon, metals, plastics and even workaday substances like clay into particles of no more than a few molecules each.

Although the basic chemical structure of materials in this microscopic landscape remains unchanged, the materials often exhibit surprising properties shaped by the unfamiliar forces of quantum physics, which governs the behavior of individual atoms. Silicon, for example, becomes fluorescent. Other materials show unusual electrical qualities or become amazingly strong. Some, like silver, have medical effects, like fighting inflammation.

Nanotechnology derives its name from the fact that the nanometer — one billionth of a meter — is its basic measuring unit. In the nanoworld, the width of the average human hair (about 80,000 nanometers) is huge. One nanometer is roughly the width of five carbon atoms, or a simple sugar molecule. Most proteins, the chemical workhorses of all living things, are roughly 10 nanometers wide,

## In the nanoworld, the width of the average human hair (about 80,000 nanometers) is huge.

and a virus is about 100 nanometers long.

Primitive forms of nanoscale technology have been used for decades. For example, carbon fibers from 10 to several hundred nanometers long in length have long been mixed with rubber to strengthen tires. But the inventors of such processes had little understanding of what was happening at the molecular level.

Today, a growing number of companies specializing in nanomaterials are developing market niches creating customized molecules to embed in other materials. Take Hybrid Plastics, a 4-year-old company in Fountain Valley, Calif. The company works with a family of synthetic molecules that average less than 2 nanometers in diameter. The molecules add strength and heat resistance, or reduce inflammability, when blended with other materials.

The first product containing one of Hybrid Plastics' molecules was a material to bond caps to teeth; it was introduced in August by Pentron under the name NanoBond.

Another nanoscale segment that is beginning to mature commercially centers on quantum dots, the name given to nanoscale crystals that produce light when stimulated by light or other energy. The size of the dot determines the color of the light it emits.

Quantum Dot, based in Hay-

ward, Calif., introduced its first product to drug researchers in November: a metallic crystal bound to a protein called streptavidin.

The protein is strongly attracted to biotin, also called Vitamin H, which helps the body process fat and carbohydrates. The Quantum Dot product acts as a probe for researchers — it latches on to biotin in tissues and, in effect, becomes a lighthouse signaling the location and concentration.

The search for tools to tag and study genes, proteins and other biological agents has attracted other companies with nanoscale products.

For instance, Nanoprobes, based in Yaphank, N.Y., makes probes by attaching streptavidin and other substances to clusters of gold atoms about 1.4 nanometers in diameter. The probes are located by shining a stream of electrons on a sample — the gold clusters reflect the energy in a telltale pattern.

Nanoco, a spinoff of the University of Manchester in England, recently began shipping quantum-dot materials to other companies that want to build probes and sensors for applications outside biology. Iain Woolward, Nanoco's chief executive, said he expects quantum dots to be used this year to make multicolored atomic-scale labels for security applications and for sensing hydrogen flows in fuel

cells.

Nanoscale crystals with filtering properties are gaining a foothold in the \$20 billion display screen market.

Manufacturers like 3M have introduced paper-thin films for displays that are built up from as many as 100 layers of light-filtering and brightness-enhancing materials. Each layer's thickness is controlled to within a few nanometers.

Now, manufacturers are tweaking the molecules in the layers in optical films to a previously unimaginable degree, resulting in products like glare-reducing light polarizers from Optiva, a startup in South San Francisco, Calif. Optiva produces stacks of dye crystals 3-4 nanometers high. Because of quantum forces, they assemble themselves into precise rows.

Optiva's thin polarizing film can reduce the thickness of liquid crystal displays by 20 percent to 40 percent and cut costs, according to Greg King, the company's executive vice president for operations. He said customers were planning to use the company's thin films next year in displays for products like screens for handheld computers.

Despite all the advances, many researchers say they are just the prelude to the main event: the development of nanoscale computers.

The only hope for continuing the trend to faster, smaller and cheaper computers appears to be inventing a way for molecular-size components to assemble themselves into useful devices. Such computers would be ruled by quantum forces, the hallmark of nanotechnology.

1,000,000,000 = 1 billion

mm  $\frac{1}{1000}$  of meter

50 nanometer is  $\frac{1}{1,000,000}$  of mm

1 millionth of mm

# Smile, Electron! Fast 'Camera' Captures Action Around Atom

By KENNETH CHANG

Using a form of ultrafast flash photography, scientists have for the first time tracked the motion of electrons deep within atoms.

The experiment enables a deeper look at the fundamental building blocks of matter, resolving the swirling blur of electrons into a stop-action movie. Scientists hope that directly studying the electronic behavior of atoms could lead to compact and efficient X-ray lasers.

In the current issue of the journal *Nature*, scientists at the Vienna University of Technology in Austria and the University of Bielefeld in Germany describe how they knock electrons out of krypton atoms with a short X-ray pulse and measure how long it takes other electrons to fill those holes.

"It's the opening, hopefully, to a whole series of experiments that will study electron motion directly," said Dr. Louis F. DiMauro, a senior scientist at the Brookhaven National Laboratory in Upton, N.Y., who wrote an accompanying commentary.

Although the motion of the electron within the lightest atom, a hydrogen atom, can be solved exactly from basic equations of quantum mechanics, the motion of electrons within more complex atoms remains inexactly known. If scientists understood that behavior, they might be able to alter it.

"You can possibly think of generating new states of matter," Dr. DiMauro said.

To capture the action, "what you need is a camera with a very high shutter speed," said Dr. Ferenc

Krausz, director of the Center for Advanced Light Sources at the Vienna University of Technology and the senior author of the *Nature* paper.

Take a photograph of a fast-moving car with a slow shutter speed of one-hundredth of a second, and the image will be a blur. Accelerate the shutter to one-thousandth of a second, and the car will appear frozen.

Scientists use the same strategy, with flashes of light as their shutter to freeze the motion of atoms and molecules. As the pulses become shorter, more becomes clear.

Dr. Ronald G. W. Norrish and Dr. George Porter pioneered the technique in the late 1940's. They used a light pulse about a thousandth of a second long that shattered chemical bonds of molecules in a gas. A second flash of light identified the fragments before they recombined into new molecules.

Dr. Norrish and Dr. Porter, who was knighted in 1972 and later elevated to Baron of Luddenham, won the 1967 Nobel Prize in Chemistry for the research.

By the 50's, new equipment shortened the flashes to millionths of a second, and the invention of the laser in 1960 enabled even shorter flashes.

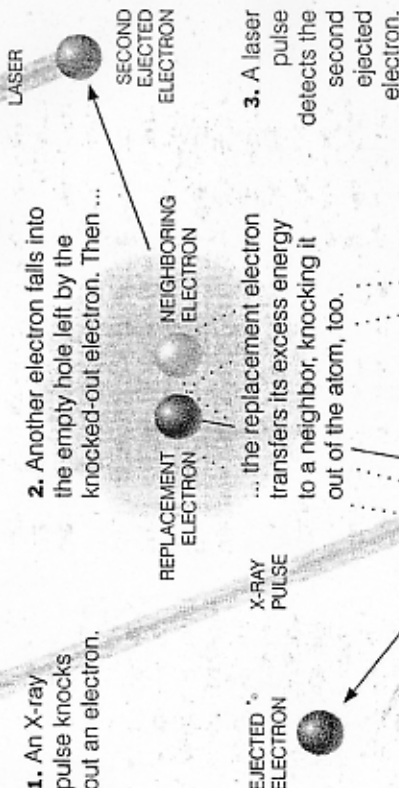
In 1999, Dr. Ahmed H. Zewail of the California Institute of Technology received the Nobel Prize in Chemistry for his study of chemical reactions with laser pulses that lasted less than a trillionth of a second.

"The next question is what is going on inside atoms," Dr. Krausz said.

Fundamental physical barriers limit making yet briefer pulses of visible light. So researchers have turned to shorter wavelengths like X-rays. In the new experiment, a short intense laser pulse hits a gas of neon

## Chasing Electrons

For the first time, scientists have measured the motion of electrons deep inside an atom, in this case krypton.



1. An X-ray pulse knocks out an electron.

2. Another electron falls into the empty hole left by the knocked-out electron. Then ...

... the replacement electron transfers its excess energy to a neighbor, knocking it out of the atom, too.

3. A laser pulse detects the second ejected electron.

atoms. The jolt excites the neon atoms, causing them to emit a pulse of X-rays that last less than a thousandth of a trillionth of a second and that speeds along with the original laser pulse.

By bouncing the pulses off a two-part mirror, the researchers open up a slight gap between the X-ray pulse and the laser pulse. The X-ray pulse then hits krypton atoms, knocking out some of their electrons. The laser pulse, arriving a fraction of a moment later, allows the researchers to view other electrons tumbling into the spaces left by the knocked-out electrons.

The researchers still cannot directly detect an electron's jumping into an empty space. But when that electron drops, it gives extra energy to a neighbor, kicking it out of the atom, too. The laser pulse illuminates this second ejected electron.

The experiment does not violate Heisenberg's uncertainty principle, which prohibits the exact measurement of both the position and velocity of a particle. The laser pulse does not reveal the position of the electron, just its velocity.

The researchers repeated the experiment, varying the time between the X-ray and laser pulses, producing, in effect, a stop-action movie. "You can reconstruct the process from the series of snapshots," Dr. Krausz said.

The experiments show that it takes about eight one-thousandths of a trillionth of a second for an electron to fill the empty space. That agrees with what physicists had previously deduced indirectly.

"This is, of course," Dr. Krausz said, "just a proof of principle experiment."

Source: *Nature*

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