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## In the World of the Very Small, Companies Make Big Plans

By BARNABY J. FEDER

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 1980's and 1990's 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 apiece.

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 unseen 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, and a virus is about 100 nanometers long.

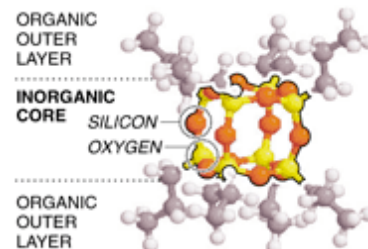
Primitive forms of nanoscale technology have been used for decades. For example, carbon fibers from 10 to several hundred nanometers in length have long been mixed with rubber to strengthen tires. But the inventors of such processes had little understanding of what was happening at the

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### Mighty Molecules

A molecule, below, created by Hybrid Plastics, a company specializing in the microscopic particles of basic materials known as nanomaterials, combines organic and inorganic elements to create a hybrid plastic that is lighter, stronger and less flammable than other plastics.



Source: Department of Chemical Engineering, University of Michigan

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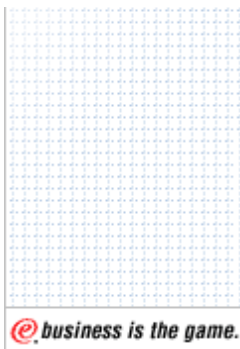
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molecular level.

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 four-year-old company in Fountain Valley, Calif. The company works with a family of synthetic molecules that average less than two 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 Hayward, Calif., introduced its first product to drug researchers in November: a metallic crystal that is 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, expects quantum dots to be used next 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 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-

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reducing light polarizers from Optiva, a start-up in South San Francisco, Calif. Optiva produces stacks of dye crystals three to four 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 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 hand-held 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.

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