Rainer Nies of Siemens Corporate Technology uses ropes to demonstrate advances in materials research. Each one can hold three tons. Yet their cross sections vary from 22 millimeters in the case of the hemp rope to six millimeters for the high-performance polymer cord.

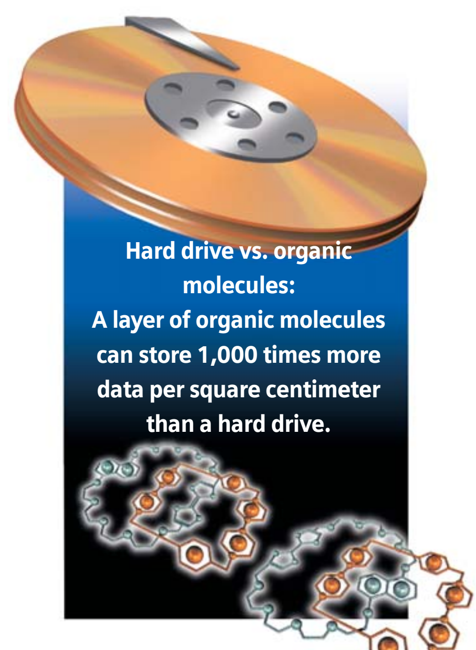
Invisible Revolutions

Wood, stone, ceramics — for thousands of years people have made use of all kinds of naturally available materials. But things are changing in a big way. Researchers are now customizing materials for a variety of purposes, and they're even doing it at the atomic level. The future belongs to intelligent materials.

For thousands of years people had to make do with the materials that nature provided them with — things like wood and stone, and metals such as gold, lead and copper. Even after the advent of iron forging, clay furnaces and glass-making, it was nearly two thousand years before any great leap in materials science occurred. "Materials research as an independent discipline didn't even exist 50 years ago," says Dr. Peter Paul Schepp, Managing Director of the German Society for Materials Research (DGM). Development scientists basically used the materials they could find in a catalog, he adds.

This situation has changed dramatically. "Our knowledge of materials has exploded over the last two decades," says Rainer Nies from Strategic Marketing at Siemens Corporate Technology (CT). Nies, a physicist, headed a study of new materials. The study found that although researchers in the past refined known materials for use with new applications, today's materials scientists, chemists, physicists and even biologists and computer scientists create customized new materials. And the future will bring further advances. "We're on the verge of a new era — an age of intelligent materials," says Nies.

The buzzwords of the future will be nanotechnology, bioengineering and adaptronics. Researchers in the latter field are attempting to create materials that can adapt to various environmental conditions — for example, construction support materials that can dampen oscillations by themselves (see p. 12). Biomaterials include biopolymers, artificial spider-silk fibers, biomorphic ceramics made from materials such as cardboard that maintain the source material's basic structures, and materials for medical applications, such as artificial tissue elements (see p. 15).



Hard drive vs. organic molecules: A layer of organic molecules can store 1,000 times more data per square centimeter than a hard drive.

Nanotechnology ultimately focuses on individual atoms that are maneuvered piece by piece in a completely controlled manner to create a material (see p. 18). Richard Smalley, an American Nobel Prize laureate in chemistry, is convinced that nanotechnology in particular will dramatically change the world we live in (see interview on p. 23). German experts share Smalley's view. According to a study conducted by the Electronic Technology Association (VDE), microsystems technology and nanotechnology have the greatest innovation potential, ahead of even information technology and biotechnology.

Foamed Metal. Even without nanotechnology, however, the ability to combine known materials with new production methods means that the amount of materials used in industry will continue to increase. Foamed lightweight metals, for example, could be transformed into especially light, yet stable components for aerospace or automotive applications. Such materials are very rigid while weighing relatively little. Similar properties are exhibited by composite materials containing fibers made of high-strength or very rigid materials, such as glass or carbon, which are incorporated into plastics.

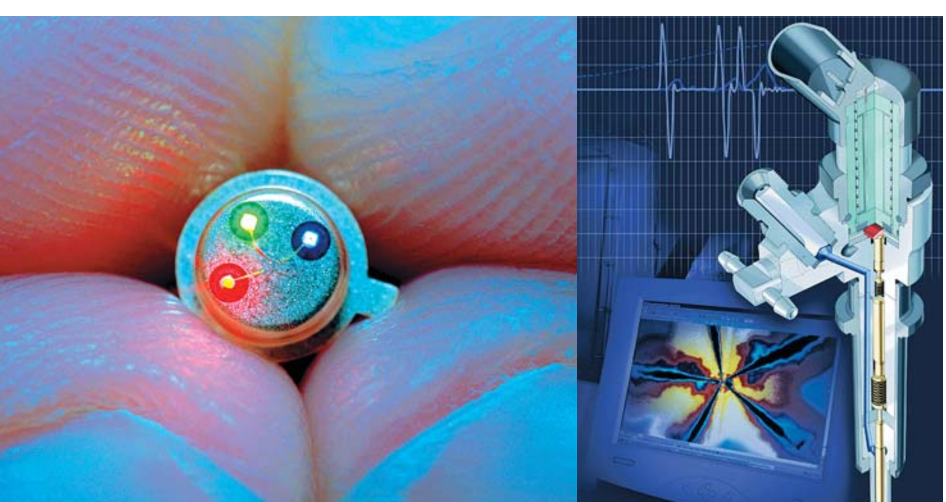
The variety of materials can also be increased through improved manufacturing processes. For instance, DGM's Schepp points to superplastic forming, a process that makes it possible to significantly reduce the cost of manufacturing components. "The final contours are created in virtually one step — casting is the only conventional technique that can accomplish anything similar to this," says Schepp. "Turning and milling are necessary only for fine detail work." Definitely required, however, is thermo-mechanical pretreatment of the material in a manner that's precisely tailored to its properties. This treatment refines the grain structure of the material to such a degree that the grains flow like sand into the form, which they then completely fill, requiring only a maximum of ten percent of the pressure needed with conventional methods. Superplastic forming is a particularly suitable technique for manufacturing medical implants. An artificial thigh bone, for example, consists of titanium alloys, which are very expensive and difficult to machine. But when such implants are produced on a large scale, substantial savings can be achieved because milling-related waste can be significantly reduced.

Light bulbs vs. LEDs: Red LEDs are three times more efficient than conventional incandescent light bulbs.

Experts agree that successful materials development today depends on achieving a new dimension in interdisciplinary approaches. Not only do researchers from various fields have to work closely together during every stage of development; but the individual components of a part must interact in an optimized manner as well. It is also very important that future users be integrated into the process early on.

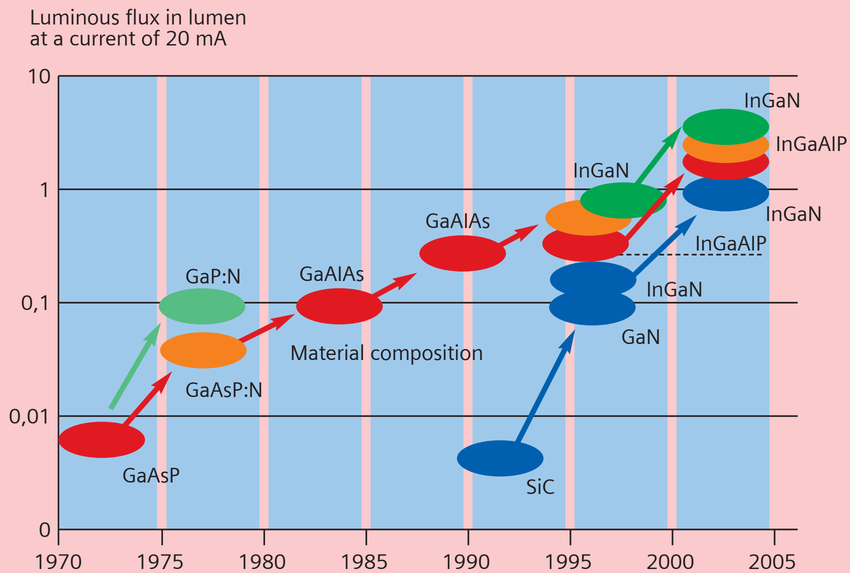
Ceramics Under Stress. A good example of the successes that have been achieved in modern materials research is a diesel injection system from Siemens that is controlled by piezo crystals (bottom right). In piezoelectric applications, a ceramic expands when a voltage is applied. "The injector exploits this effect to open and close a valve," explains Dr. Karl Lubitz from Siemens Corporate Technology's Materials Research department. Lubitz developed the key component for the piezo injector for automotive supplier Siemens VDO. More than ten years of research went into the piezo injector, which can pump a cubic millimeter of diesel fuel at a pressure of 1,600 bars into an engine combustion chamber in less than a millisecond. Such targeted injection not only causes the engine to run more smoothly and quietly; it also cuts fuel consumption and emissions.

The injection component, which is coated with a plastic, is extremely complex — it has 360 ceramic layers. Nevertheless, it is only a small part of a system in which each component is critically important for the proper functioning of the whole.



LEDs (left) and piezo injectors for diesel vehicles (right) are two shining examples of successful materials development at Siemens. But it's not just better materials that count — improved processing also plays a vital role.

LED LUMINOSITY HAS INCREASED BY LEAPS AND BOUNDS



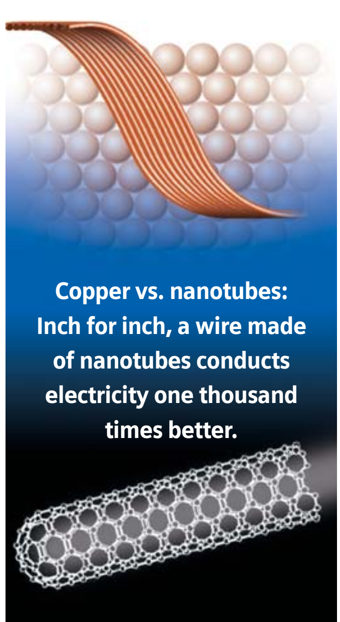
Ga: Gallium, As:Arsenic, P: Phosphorous, N: Nitrogen, Al: Aluminum, In: Indium

Scientists have boosted the efficiency of LEDs by a factor of 30 every decade since 1970. The graph shows the amount of light emitted by LEDs at a specified current consumption, the colors that could be achieved at the time, and the range of materials used. Source: Osram.

"When we started this project, hardly anyone believed we would be able to control fuel injection using piezo ceramics," says Dr. Andreas Kappel from Corporate Technology's Microsystems department. But Kappel gradually succeeded in convincing everyone that the technology would work. And it's a good thing he did. "Siemens VDO is going to post billions of euros in sales in the next few years with this development," he adds proudly. "The technology's potential isn't even close to having been exhausted." Kappel and his team are now able not only to simulate a functioning injector all the way down to its microstructure, but can also observe it in operation. This enables them to run numerous tests to improve injection in a very short period of time, without having to install the actual component in an engine.

From Simulations to Promising Mixtures. Such computer simulations have become an important tool in all areas of materials research. They make it possible to predict how materials will behave at various temperatures, under load, and at different times throughout their life cycles — on the atomic level and as a complete component. Furthermore, when it comes to finding the best material for a particular application, mathematical models are rapidly replacing trial-and-error techniques. Researchers can use combination methods to study — in one process step — a variety of mixtures of chemical elements with regard to their suitability, and they can then extract the most promising mixture from the vast amounts of resulting data (see p. 26).

But even the best supercomputer cannot replace the experience of a scientist. "To be successful, you need a team that has a commitment to continuity in its research," says Dr. Bernhard Stapp, Head of Research at Osram Opto Semiconductors. And he knows what he's talking about, since his team of researchers is mainly responsible for the increases that have been achieved in the efficiency of light-emitting diodes (LEDs). LEDs offer significant advantages in converting electric current into light (see graphic). Depending on the conditions in which they are used, they can run for up to 100,000 hours. If left on ten hours a day, they will continue to operate for nearly 30 years. They are also extremely robust, and their efficiency rating is many times higher than that of a normal light bulb. LEDs have already replaced conventional technologies in certain areas, such as interior lighting for automobiles, and are set to take over vehicle taillights as well.



Copper vs. nanotubes: Inch for inch, a wire made of nanotubes conducts electricity one thousand times better.

LEDs, which have a chip-edge length of less than half a millimeter, have benefitted not only from dramatic improvements in materials, but also from special surface structures. LED production involves depositing several crystalline layers onto semiconductor disks at temperatures of between 600 and 1,000 degrees Celsius. Every single parameter — whether temperature, pressure, wafer rotation speed, or gas composition — is critical for achieving an optimal product that can also be profitably mass produced. A big problem with the materials used in LEDs (gallium-indium-aluminum-phosphide or gallium-indium-nitride) is their extremely high refractive index. That is, most of the light produced is reflected inward at the edge where the crystal meets the air. Researchers have gotten around this total internal reflection problem by producing a surface with specially shaped profiles that significantly improve the degree of light emitted. Improvements of this sort, along with constant material refinement, have increased efficiency by a factor of 30 each decade since 1970.

"We have to do more than just find the best phosphor," says Stapp. "We also have to be able to recognize and control the complex relationships between materials, processes and applications." Adds Karl Lubitz: "This is a team effort. A researcher working in isolation would have no chance of succeeding with new materials." ■ *Norbert Aschenbrenner*