Hot Technologies Here are three that are changing production, inventory keeping, and the design of new products

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(FORTUNE Magazine) – SUPERGLASS FOR TOMORROW'S CHIPMAKING

What goes on in the furnaces at Corning's calcium fluoride plant in Canton, N.Y., is a fiercely guarded secret. Corning won't even reveal how many people work at the facility.

Corning isn't alone in its efforts to keep calcium fluoride production under wraps. Once the glasslike material was identified as critical for next-generation chipmaking machines, growing it turned into an extremely competitive race. Other major producers include a U.S. division of France's Saint-Gobain and Germany's Schott Lithotech. "There's tremendous demand for this product," says Jim Steiner, Corning's vice president for specialty materials, "more than with any product I've ever worked with."

In chipmaking, machines called scanners, also known as steppers, employ photolithography to send light from a laser through a series of lenses to project tiny circuit patterns onto silicon wafers. Each wafer is then sliced into scores of chips or more. According to Moore's law, named for the Intel co-founder who formulated it, computing power--measured by storage density and speed--doubles every 18 months to two years, and its costs drop as chipmakers keep doubling the number of transistors per unit area of a chip. One way they do that is to project with ever shorter wavelengths of light to print ever smaller "line widths."

As the size of circuits shrinks, standard glass lenses no longer suffice. Chipmakers have already begun using scanners that project ultraviolet light at a wavelength of 193 nanometers, far outside the range of visible light, and produce line widths of 0.13 microns or less. (A nanometer and a micron are, respectively, a billionth and a millionth of a meter.) Some of the lenses on these machines are made of calcium fluoride. Scanners slated to be ready in 2005 will need to use shorter, 157-nanometer wavelengths to project line widths of 0.07 microns or less. Until the late '90s, chipmakers believed that 193 nanometers was the shortest practical wavelength using optical lithography. When they learned that a subsequent technology would not be ready in time, they decided to develop 157-nanometer optical equipment, and glass producers scrambled to make major investments.

Calcium fluoride is the only optical material transparent enough to transmit light at such low wavelengths to achieve such tiny line widths. It also holds up better under intense, repetitive beams of light than fused silica, the glass used for most lensmaking today. Unless it is used for all the lenses of 157-nanometer machines, smaller line widths--and the continued validity of Moore's law--would be in doubt. "Calcium fluoride is the linchpin for 157," says Tony Yen, co-director of lithography at International Sematech, a research consortium. "There's nothing to replace it in the time frame you need."

To the naked eye, calcium fluoride looks like a piece of glass. It's been used for years in television-camera lenses. But it's a lot more difficult and time-consuming to make than fused silica. It starts out as a powderlike material but must be grown as a large cylindrical crystal at temperatures ranging from 1,800[degrees] to 3,600[degrees] F. When cooled and processed, it becomes transparent. The quality needed for 157-nanometer systems, which some say is about four times better than that needed for 193 scanners, is extremely difficult to achieve. While glass for lenses can be made in a matter of days, a calcium fluoride crystal takes up to four months to form and can be ruined if even the tiniest particle slips into the mix. Millisecond power outages in furnaces are capable of destroying an entire batch. Once formed, the crystals are sliced like salami into lens blanks.

"It's probably the most challenging crystalline material that we've ever had to grow," says Tom Kinisky, president of the crystals and detectors division at Saint-Gobain. When it was discovered last year that calcium fluoride has a quality called intrinsic birefringence, which creates a double-vision effect, things got even more complicated. Equipment makers that had to compensate for this quality in lens design found they needed blanks that met even more stringent criteria.

None of the crystal growers is willing to reveal its yields of usable product, but scrappage is high. Dan Hutcheson, CEO of chip manufacturing research firm VLSI Research, estimates that only about 10% to 20% of the calcium fluoride grown today is usable. "Once you get a good piece of glass," says Phillip Ware, a senior fellow in lithography strategy at Canon, "it's way more precious than gold." It costs more too. Hutcheson estimates that the lenses in a 157-nanometer scanner could cost up to $5 million. That would bring the total cost of the tool to about $20 million, he adds, which is almost double the price of a state-of-the-art 193 machine.

Those prices are so high because tens of millions of dollars have already been spent on research and on equipment needed to make calcium fluoride. According to Bob Sell, a marketing and strategy manager for Corning's specialty-materials division, his company has spent $30 million on expansion at the Canton plant alone. Even lens and scanner makers like Nikon and Canon have made investments in growing calcium fluoride. "We need such a large quantity, and it needs to be such a high grade, that it's dangerous to depend totally on external suppliers," says Ware, explaining why Canon built its own plant last July in Japan.

The industry is growing more confident that the lenses will be ready by 2005, but headaches remain. Last December, ASML, a Dutch equipment maker, had to delay the launch of a preliminary 157 scanner when it failed because of the poor quality of the calcium fluoride. Still, Yan Borodovsky, the director of lithography at Intel, doesn't seem too worried. He's been working on ways to extend the current technology, just in case 157 isn't perfected in time. Moore's law is still in force, says Borodovsky. "It isn't slowing down, and neither are we." --S.K.

THE BIG NEW WIRELESS MOVEMENT IN FACTORIES

Forklift operator James Lesniak used to find himself driving big distances at the General Motors' Cadillac and Buick assembly plant that straddles the border between Detroit and Hamtramck, Mich., just to make a single delivery of parts. Because of the time required to pick up his assignment at a central computer terminal, locate the appropriate parts, deliver them to the right location, and drive back to get his next assignment, Lesniak typically made only 30 deliveries a day.

Now, with wireless technology, Lesniak averages 60 to 70 parts deliveries a day. A wireless terminal attached to his forklift saves the 30-year veteran the time that he used to spend returning to a central location after each delivery. It also helps that the new system has been programmed to keep Lesniak within a 60,000-square-foot zone in the plant's "general assembly" area. Previously he got haphazard assignments that could take him anywhere in an area more than seven times as large. These days, he says, "I know right where I'm going."

In the nine months since the plant adopted the terminals, it has seen forklift traffic decline 200 miles per shift, or 400 miles a day. "A lot of unnecessary work is being eliminated," says materials manager Dan Larabell. He estimates that the system, which uses terminals made by Symbol Technologies of Holtsville, N.Y., will save the plant more than $1 million this year.

Wireless technology isn't new in factories. It's been around for years in the form of radios, wireless bar-code scanners, cellphones, and even walkie-talkies. Yet as wireless technology becomes more affordable and systems become more compatible with one another, companies are using them to transmit ever-growing amounts of mission-critical data. Until the introduction in September 1999 of a standard called IEEE 802.11b, or Wi-Fi, wireless systems were mainly proprietary and couldn't talk to one another. "Companies used to purchase the technology as an island," says analyst Ken Dulaney of the Gartner Group, a computer research firm in Stamford, Conn. "Now wireless is starting to blend into the entire framework of what they're doing." According to Forrester Research in Cambridge, Mass., some 15% of manufacturers now have wireless networks in their plants, up from 6% a year ago.

Wireless doesn't change the way companies do business. But in many cases it allows greater mobility, faster communication, and a huge amount of flexibility. Without the constraint of wires, plant managers can keep better track of employee utilization and material flow and can more easily reconfigure assembly lines.

Take, for example, Goodrich's plant in Chula Vista, Calif., that makes engine nacelles and other aircraft body parts. A team headed by Gary McCune and Greg Smith installed a wireless grid at the same time that they replaced Goodrich's customized material resource planning system with SAP enterprise resource planning software.

When plant workers at Chula Vista start a new job, they now put the necessary information into a wireless terminal made by Intelligent Instrumentation, a Texas Instruments company, and it's fed into Goodrich's central network. When employees receive parts deliveries, they scan a bar code with a Symbol handheld computer, and the information is centrally recorded. In real time, coordinators and supervisors throughout the plant can check the status of a part that has been received or is being worked on.

Because the system has been in place only since January, McCune hasn't calculated the return on investment, but he's already seen improvements. It used to take months to reconfigure the shop floor when customers' orders changed. Now, instead of running new cables to every computer in the plant, which costs money and causes downtime, Goodrich can simply move the terminals at will. "With wireless, you basically need a power cord, and you're ready to go," says McCune.

Wireless has other advantages. It can be used at a construction site where installing temporary wiring is too costly. At GM, Larabell's wireless system also has helped boost plant-floor safety. The drop in forklift traffic has reduced the risk of accidents. And the screens on the Symbol terminals go black ten seconds after a driver acknowledges receipt of his assignment. That allows drivers to look where they are going instead of being tempted to keep their eyes on directions printed on a piece of paper.

It's not the answer to everything, though. "I wouldn't go into somebody who had a completely wired operation today and suggest that they should cut the wires just for the sake of becoming wireless," says Barry Issberner, vice president of vertical marketing at Symbol. There has to be a business rationale for making an investment in a wireless network. Despite all the advances made in the technology's reliability, most companies still use it in conjunction with a wired network. Even futurists don't envision a completely wireless factory.

Wireless has drawbacks. It can't handle as much data as a wired system, and interference is a limitation, especially in industrial environments. "There are devices or materials out there that will drown out the radio frequency signal," says networking manager Matt Doidge, a key player in the installation of Goodrich's wireless grid. Anything, from steel machinery and concrete building structures to a chain-link fence or certain electromagnetic noise like that from motors and sparks, can disrupt data transmission. Such problems can be solved, but it takes an expert to help place the correct number of antennas in the right spots.

Security is another worry that some experts believe has limited the adoption of wireless. But, says wireless expert Wayne Manges of the Oak Ridge National Laboratory, "most security problems with wireless are the same ones you have with wired." Many people don't take advantage of security features that are built into the technology, such as encryption and an ability to identify users and receivers of information. In recent months a few vendors, such as Ecutel of Alexandria, Va., have launched products that provide extra security for wireless networks.

So far wireless has made the most headway in inventory tracking. But industry experts predict that remote monitoring--keeping tabs on machine diagnostics--will bring the next wave of growth. Professor Jay Lee is collaborating with companies to develop expertise in that area. Lee is a fellow at the Society of Manufacturing Engineers and director of the Center for Intelligent Maintenance Systems (IMS), a cooperative at the University of Wisconsin in Milwaukee that's working on the advancement of machine intelligence through different technologies, such as wireless. Eaton Corp., an IMS member, just launched a product that will eliminate the need for maintenance personnel to be in front of a machine or to sit at a computer to keep track of performance. With this kind of technology, says Lee, "people can focus more on how to prevent things rather than how to react to them." --S.K.

VIRTUAL PEOPLE THAT HELP DESIGN PRODUCTS

Jack, Jill, Ramsis, Sammie, Safework Pro, Ergo Dude, and a score of cohorts are industrial workers of a new kind: digital manikins on a computer screen. They cut the expense of product development in the early stages and help industry come up with new offerings, from cars to industrial floor-cleaning machines, that are better designed for human use. When employed in the simulation of new production lines, the manikins also cut down on potential injuries to workers. Enthusiastic industrial users are helping the $100-million-a-year digital-manikin market grow at a brisk 20% to 30% annual pace, according to Alan Christman, vice president of CIMdata, an Ann Arbor, Mich., data keeper on computerized manufacturing.

The manikins--and the engineers who run them--perform seemingly magical tricks. At the International Truck and Engine plant in Fort Wayne, senior human-factors engineer Darrell Bowman clicks a mouse and "flies" the manikin named Jill from somewhere in cyberspace onto the driver's seat in a truck cabin under design. One of Jill's tasks is to help place side mirrors in a perfect position for a truck driver. From his keyboard, Bowman manipulates Jill's onscreen movements. What especially appeals to Bowman is his ability to see what Jill's eyes see, allowing him to place mirrors according to designers' specifications.

Like most digital manikins, Jill has a body whose skeleton consists of 70 interconnected joints, in imitation of humans, who have over 100. Clever software that prescribes proper interaction between the joints allows Bowman to move Jill's torso, head, hands, arms, and legs to ensure the proper fit for a female truck driver of a selected size and shape, and to measure her ability to reach the foot pedals, steering wheel, and instrument panel. If Jill bumps into part of the truck cabin, she doesn't say "Ouch." Instead, the portion of her body in contact with an obstruction lights up red to alert Bowman that the cabin design needs tweaking.

Unlike the physical crash-test dummies that are their distant relatives, Jill and her companion Jack can be instantly shrunk or enlarged to represent the different segments of the population. Companies can also customize their human-like figures to match different people. International Truck has created a library of male and female drivers that, like real truck drivers, are bulkier than the population at large. When the company designs school buses, its designers call on a population of digital kids (who bear no names) created in a flash of electronic cloning.

Only about five years old as commercial products, digital manikins are produced principally by three companies, originated in university computer labs at approximately the same time, and have many overlapping features. In addition to EDS, which produces Jack and Jill software, the other major players are Delmia, a subsidiary of the French CAD/CAM powerhouse Dassault Systemes, and Tecmath, a German company. All three companies run their manikin business from offices in the Detroit area. Delmia's manikins are Safework Pro, which is just as sophisticated as Jack and Jill, and Ergo Dude, which is less complex. Tecmath sells Ramsis, which is heavily oriented toward the auto industry. Sammie, created at a British university lab, isn't as widely used as manikins from the three main vendors.

Jack, Jill, and their buddies can now be found moving in, around, and under virtual cars at GM, Ford, DaimlerChrysler, and most other automakers; helping design better agricultural and earthmoving machines at Deere and Caterpillar; putting out simulated fires in the U.S. Navy's virtual-reality submarines; helping design airplane interiors at Boeing; and riding motorcycles and snowmobiles at other companies. In manufacturing settings, digital manikins are helping in the design of assembly layouts and in determining if repetitive assembly is safe enough to avoid causing wrist injuries. At an automaker's new plant in the Midwest, which for competitive reasons can't be named, Jack and Jill recently helped set up 250 workstations, determining the best height of the assembly lines for workers of various sizes.

Ergonomic issues are one reason the use of digital manikins is expanding. According to government data, companies paid $20 billion in workers' compensation for job-related injuries in 2000 alone. Digital manikins, whose software is stuffed with equations on posture measurements, the weight of objects to be lifted, low-back injury assessment, and many other variables, open huge new opportunities for preventing worker injury.

Before digital manikins arrived, manufacturers used cumbersome two-dimensional paper or plastic cutouts of human figures for both product design and ergonomic studies. "The problem with those models was that their joints weren't connected," says Kyle Nebel, a senior mechanical engineer at the U.S. Army's Tank-Automotive and Armaments Command (TACOM) in Warren, Mich. "You'd move the upper leg, and you'd have to attach the lower leg again. So you could spend days just positioning that model of a human."

The new ability to produce any number of manikins of different sizes is made possible by data on real people, collected by the U.S. Army and other sources and now part of the manikin software. The programs enable manufacturers to better tailor their products to the needs of customers ranging from a 4-foot-6 woman in the fifth percentile of the population (where only 5% of women would be smaller) to a 6-foot-6 male in the 95th percentile (where only 5% of males would be taller).

When Tennant Co., a Minneapolis maker of industrial floor-cleaning machines, was recently investigating whether smaller workers could easily replace the big batteries on its new NexGen 2.0 machine, which sweeps, scrubs, and burnishes in one pass, project engineer Joseph K. Krueger called forth the shortest possible versions of Jack and Jill, both in the fifth percentile. People that size, he learned, could do the job without injuring themselves, provided the handles to remove the batteries were properly placed.

Using the manikins, Krueger got down to such details as the impact on the manikins' right and left elbows, shoulders, trunk, hips, knees, and ankles when they were lifting the heavy battery and turning and flexing their torsos. Reassured about the safety of the design, Tennant engineers incorporated the findings into the machine's final hardware prototype, skipping the building of intermediate designs. "The confidence level of doing it right the first time is so much higher now," says Krueger. In the past Tennant would have had to build costly intermediate prototypes and test them with real people. The task would have taken two to three weeks. Using digital manikins, Krueger did his analysis in one day.

The use of digital manikins is spreading because advances in software and hardware are making it affordable even to small and medium-sized companies. "Not too many years ago," says Mark Fleigle, chief engineer for technology and testing at $450-million-a-year Tennant, "only giant companies like GM could afford this software." Tennant started using Jack and Jill late last year, purchasing a set of the basic software from EDS for $25,000. Additional software packages come at $10,000 apiece. The other vendors' software is in the same price range. How quickly does the use of manikins pay off? Says Fleigle: "If you can eliminate one ergonomic goof when you're still in the virtual world, and don't have to build an extra prototype, you pay for the manikin software on your very first project."

Manikins are being constantly improved to take on new jobs. New software developed this year by Tecmath for an automakers' consortium will allow its Ramsis manikin to measure how a digital manikin gradually alters the shape of a seat cushion in a car or truck. Ramsis would be taking over that job from half-sized solid dummies known as Oscars--torsos with buttocks and legs made of plastic with metal weights attached. Digital manikins could also push aside widely used crash dummies made of plastics and metal. TNO Automotive, a Dutch contract R&D company, has developed digital crash dummies that contain a rib cage, spine, pelvis, thorax, and other structures. These digital dummies supply more accurate information than "dumb" crash dummies, and like other digital manikins can be easily produced to match a wide range of driver and passenger body types.

Manikin users eagerly await further advances. They would like, for example, to order a manikin to climb into a car or a truck cabin. Today a manikin can only be "flown" directly onto a car or truck seat, already in a sitting position. To walk up the steps into a truck cab, a manikin has to be instructed as tediously as a toddler on how to get up the steps. The manikin user must spell out in excruciating detail such instructions as "move your right foot, step on the step," etc., in a process that can take up to eight hours of programming and must be repeated for each different set of steps. Another way is to use a motion-capture tool kit that records a real human's motions stepping into a truck and then transfers the information to manikin software.

The users would also like to have the manikins display a modicum of intelligence--or what would appear to an outsider to be intelligence--as they react to unexpected situations. This illusion of intelligence would be created by cleverly written software algorithms interacting at lightning speeds in new contexts. It's no easy task to spell out such independent decision-making in software, but smarter manikins can already be seen at Norman I. Badler's center for human modeling and simulation at the University of Pennsylvania.

Badler's lab is where Jack, the first digital manikin with functioning joints and the first to become a commercial product, was born. The manikin was later sold to a small company, since acquired by EDS. Continuing their pioneering in a project for the military, Badler and his students have created a virtual checkpoint at a military base where onscreen cars are stopped by military "trainees"--four Jacks in uniform. In somewhat stilted English, a trainee asks the driver for his ID. Instead the driver pulls out a gun and with a distinct "pop" shoots the trainee, who has failed to hide behind a big metal drum placed there for that purpose. To correct the error, the trainees are instructed in plain English: "When you draw your weapon at the driver, take cover behind your drum."

When the next terrorist drives up, the manikins execute the new instructions with appropriately angry faces, programmed with special software, as they draw their guns and arrest him. This kind of manikin capability, says Badler, could be used to train workers on assembly lines and instruct crew members aboard ships, and it could be applied in other working and training situations. Predicts Badler: "Within five years, virtual humans will have individual personalities, emotional states, and live conversations. The idea is to make Jack smart enough to be a participant in a real-time situation." Even without that kind of intelligence, Jack and his pals are having quite an impact. --G.B.

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