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DynamicSilicon

Published by
Gilder Publishing, LLC

Vol. 2, No. 6 | The Investor's Guide to Breakthrough Micro Devices | June 2002

Digital Everything, Silicon Everywhere

"Don't invest in tech." "Semiconductors are down and can't come back." "We had a great run with the PC, but what's next?" There's plenty of gloom and doom about technology in general and about semiconductors in particular. Semiconductors are down, the larger economy is down, and there's a dot-com backlash. If you listen to popular advice about technology and semiconductors, you'd sooner have your money in a mattress. The PC market is saturated, Internet traffic growth is slowing, and cell phone sales are down. I'm not going to tell you that that's all wrong and that you should be investing in tech stocks today—that requires market timing and financial analysis and I don't do that.

Instead, *Dynamic Silicon* builds a picture of technology's long-term future. In each issue I state where I see the industry going and why and I list "Dynamic Silicon" companies whose strategies align with that vision. It's a guide, but it's your decision about whether or when to invest in a particular company.

Today's semiconductor pessimists remind me of Charles H. Duell, commissioner of the U.S. Office of Patents. In 1899, about six million patents ago, Duell advocated closing the patent office because "Everything that can be invented has been invented." The thesis was ridiculous then and it's ridiculous now.

One argument goes like this. We already have the PC and we have been through an escalating range of applications. The PC market is saturated. So is the market for switches, routers, and servers. So what's next? Then came cell phones, MP3 players, digital cameras, PDAs, and smart cards. Well, those opportunities have been exploited too, so what's next? The implication is that there is nothing left on which to build the future for semiconductor electronics.

This is silly. Before the PC, there was thought to be no market for PCs. After the PC, we now somehow know that there's no next opportunity? The same is true for MP3 players, cell phones, and smart cards? We think all the stuff that needs electronics has been found and we think that what's there is good enough? In a few years this will look as foolish as DEC CEO Ken Olsen's 1977 statement: "There's no reason anyone would want a computer in their home."

New markets and growing markets represent huge opportunities for electronics in the near future. Automobile (drive train, engine, cockpit, entertainment, driving aids), photography (image capture, viewfinders, printing, storage), voice applications, last mile connection, smart buildings and bridges (that actively counter earthquake movement, for example), smart toys, smart appliances, smart clothing, and smart tools. In addition, requirements are changing. Power efficiency is becoming important, non-volatile memory is on the way, adaptive systems will displace fixed-response ones, system-on-chip designs will displace multiple-chip designs, and "always on" systems will displace manually controlled systems. The smart sensors and MEMS field is getting off the ground and will revolutionize industries. Behind these revolutions, nanomaterials will invade with waves of innovation in new applications and in size, function, and efficiency.

The PC and cell phone markets in the U.S. may be saturating, but there's a whole globe of potential customers for electronics that has barely been tapped.

Gilder Publishing's *Gilder Biotech Report* is dedicated to biotechnology. There's a staggering array of advances on the way in biomedical/chemical applications. New opportunities are emerging in medical diagnostics, testing, characterization, surgery, instrumentation, drug development, drug delivery, drug discovery,

In This Issue: This issue is about the semiconductor industry's boom and bust cycles and how these cycles run apart from the economy. These cycles occur in the semiconductor industry whether the economy is up or down. That's because the cycles are caused by periodic supply-chain wrecks induced by large middlemen (distributors) who are allowed to keep their huge orders in until the last possible moment. Meanwhile, technology marches on under this cloud, transforming industries. Photography is a representative industry—semiconductors will change every aspect of it. The change that has occurred is that semiconductors are enabling innovation in many more places and in many more fields. This is because the PC has already pushed semiconductor development beyond what's needed to put advanced circuitry in everything.

Semiconductor Boom and Bust Cycles

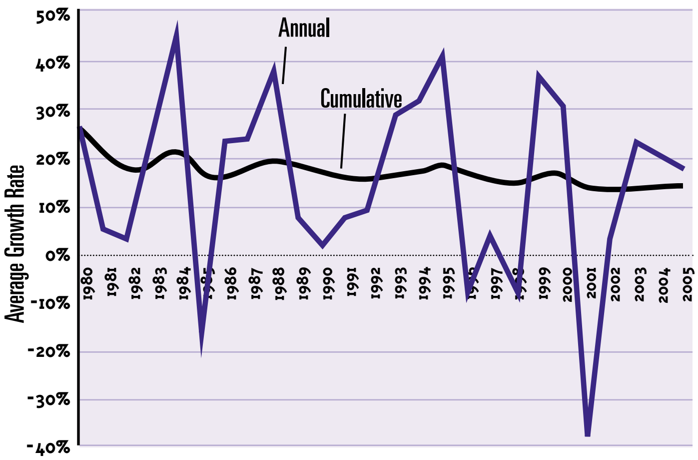

Fig. 1. The semiconductor industry's boom and bust cycles and the running average.

and patient monitoring. Progress in semiconductor manufacturing has brought us to feature sizes found in biological systems. We'll soon be adapting efficient, low-power solutions copied from biological systems.

The whole cathode-ray tube business will be going solid state. Electronic noses and tongues are just becoming feasible. Radio-frequency identification will revolutionize inventory, distribution, and tracking. Robotics for tank and pipe inspection, dangerous environments, home security, and a zillion other applications are on the way. Need I go on?

The semiconductor industry is notorious for its boom and bust cycles. *The industry's organization causes these cycles, so the dives and recoveries aren't closely tied to emerging applications or to broader economic cycles.* In 2001, deflation in the broader economy and a down cycle in the semiconductor industry coincided, but they are not strongly connected.

The cycle that won't die. Ron Wilson named it in an 8 January 2001 *EETimes* editorial. He's right. Here's how it works. Original equipment manufacturers (OEMs) buy through distributors who get their chips from suppliers. Suppose it's a boom year, growing at, say, 30%. This is an average. Industry-leading segments may be growing at twice this rate. Chip suppliers in a leading segment grow with their segment or forfeit market share. They compete for chips from leading-edge suppliers. OEMs build inventory for the growing market. OEMs stockpile chips to build systems and they double and triple order from their distributors to be assured of chips. Everyone is production limited. Chip suppliers struggle to increase production, but the lead-time for adding production capacity is two years.

Demand for systems slows. Is it real? Is it just a dip? Accumulate a little inventory, but don't lose your place in line for chips by canceling chip orders. Chip suppliers continue to accelerate production. When the time comes to buy the chips or cancel the order, the order is canceled. Cancel all *three* orders. Some time after the OEMs cancel their orders with the distributors, the distributors cancel their orders with the supplier. The chip supplier, who's still *accelerating* production, sees the order backlog vaporize. Poof! Inventories accumulate at the chip suppliers, the distributors, and the OEMs (chips *and* systems accumulate at the OEM). The OEM's weaker customers fail, defaulting on the OEM's loans and returning systems or selling them on eBay. The OEM's bloated inventory now competes in this declining market with systems the OEM has subsidized. With six-month product cycles for chips and systems, these inventories age rapidly. It means huge write-downs for everyone and a long time to work through accumulated inventory. And all this just as the suppliers' new production capacity is coming online!

The semiconductor industry has always been cyclical. Are we now to believe that it will not recover? That would be an important change in its behavior. What has changed to make us believe that the cycles are over and that the industry is moribund? Some analysts think we've run out of applications to drive the industry forward. When the computer was invented, its success was a surprise. The PC's success was a surprise. The Internet's success was a surprise. Now, because analysts can't imagine the next "surprise," they assume there won't be one. There's nothing new in the analysts' position, but by now we should have learned not to believe them.

DynamicSilicon

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Dynamic Silicon is published monthly by Gilder Publishing, LLC. Editorial and business address: 291A Main Street, Great Barrington, MA 01230. Editorial inquiries can be sent to: bozo@gilder.com.

Semiconductors aren't regular products like steel, carpet, shoes, refrigerators, and automobiles. Regular products follow broad economic cycles: in good times, they sell well; in bad times, they sell poorly. As we explained in "The Tech Sector Rocks" (*Dynamic Silicon*, Vol. 1, No. 8), however, semiconductors are different. In good times, semiconductors invade systems to add features and to increase performance. In bad times, semiconductors invade systems to save power and to lower cost.

There's a popular misconception that Moore's law, which says the number of transistors on a chip doubles every eighteen months, drives the semiconductor industry. Moore's law isn't a driver; it's an enabler (*Dynamic Silicon*, Vol. 2, No. 1). The notion that Moore's law drives the industry came from the PC's quest for speed. PC microprocessors rode the leading edge of semiconductor process development and this connected market growth and Moore's law progress in peoples' minds.

Semiconductor chips don't just displace themselves each cycle with a chip that's cheaper or that has better performance. That's the way the PC industry grew and we think of the PC industry as the prototype because it dominated the semiconductor market for twenty years. The PC market has made it seem as if there are only two choices: more performance for the same money or lower cost for the same performance. There are many alternatives. Chips continually go into new applications and they continually displace old designs with low-power or cheaper versions. Think of how your garage-door's remote control has shrunk from bath-soap size to keychain trinket.

The industry doesn't live only on the leading edge of Moore's law progress. At TSMC, the largest of the foundries, the leading-edge semiconductor process accounted for only 5% of TMSC's wafer starts in 2000. By 2004, TSMC expects that the three most recent process generations (130, 107, and 90 nanometers) will account for only 20% of its wafer starts. TSMC expects that 80% of its business will come from making chips that are three or more process generations behind the leading edge!

Choose an industry and examine it. You will see that every semiconductor inside that industry is in transition. Photography is a great example of an industry where this is happening.

Digital Cameras

According to the EPA, the photographic equipment and supplies business, mainly manufacturing and processing film, generates the most chemical waste in the U.S.—six times that of the second-place medical instruments business. Digital image capture and processing, by contrast, is almost pollution free. Almost, because we use batteries. Film-based photography advances slowly in comparison. Image-capture chips for digital cameras improve with Moore's law. Processing and storage for digital images pace improvements in the semiconductor process. The latest MEMS-based ink-jet nozzles eject ink droplets smaller than your eye can resolve, which enables printing with resolution equivalent to chemical film prints. With digital images, there's little waste; if you don't like the picture, shoot it again. With film, you don't know what you've got until it's been developed. Digital cameras have lots of advantages but digital cameras are harder to use and they face an entrenched competitor.

The North American market for low-end digital cameras is growing; from forecast sales of 9.5 million units in 2002, the number will grow to 18.7 million in 2007. By contrast, the number of film cameras sold in 2002 (excluding disposable cameras) will be 19 million. Film camera sales may decrease to 17 million in 2007. I'm not including disposable cameras, which sell about 100 million units a year, because they created a new market. In 2002, the revenue from digital camera sales, forecast to be $1.9 billion, will exceed the revenue from film cameras for the first time. It seems as if digital cameras compete to displace conventional cameras in photography; it may turn out that digital cameras, like disposable cameras, are creating a new market. Don't think of the digital camera as a camera, think of it as a mobile scanner for the Internet.

The Internet enables information access and sharing. Before the Net, information access was a high-cost business (e.g., library collection and maintenance, research services) and information sharing was limited to storing and distributing physical copies. The rise of the Internet is the rise of information access and of information sharing. The digital camera is a mobile information collector for the Internet—a fundamental function not shared with the film camera. Already, the installed base of digital cameras creates *tens of billions* of images each year.

There's plenty of room for innovation in digital cameras and digital photography. Semiconductors have invaded and will continue to improve viewfinders, image capture, storage, communication, image processing, printing, and even batteries.

Micro displays

The back of a typical digital camera sports a miniature flat-panel display. It is typically a low-resolution, color liquid crystal display (LCD) and it's a problem.

The display is hard to view in bright light, it's small, and it eats batteries.

About a hundred companies are working to improve flat-panel micro displays. Several candidates are emerging. The most important improvements are in cost, in screen resolution, in contrast ratio, and in power consumption. Contrast ratio is the brightness of the white in the image divided by the brightness of the black. Printing on good paper shows a contrast ratio of 20 to 1; newspapers, 10 to 1. Displays are active or passive. Active displays emit light (and can, therefore, achieve contrast ratios higher than paper), while passive displays rely on reflecting light. For passive displays, reflectivity is the measure of image quality. For printing on good paper, reflectivity is 80% (it reflects 80% of the light hitting the paper).

Liquid-crystal display. The LCD is the incumbent. It benefits from 25 years of product development and it enjoys an entrenched position in digital cameras. There are active and passive LCDs. The typical laptop's LCD is active, while the typical cell phone's display is passive. Passive LCD contrast ratios may be as low as 5 to 1. The LCD has deep-pocket backers, known costs, and a track record of high-volume manufacturing. Displaytech, Kopin, MicroDisplay, Philips, Sharp Microelectronics, Samsung, Three-Five Systems, and a host of other companies make small liquid-crystal-based displays.

Cholesteric liquid-crystal display. Kent Displays, Inc. (www.kentdisplays.com) makes passive displays called "cholesteric LCDs" (liquid crystal derived from animal cholesterol—even cholesterol has redeeming traits). It sounds like magic. Imagine display images that look good in direct sunlight and are viewable from any angle. Reflectivity of the display can be 70%, so the cholesteric LCD works better in brighter light (the opposite of a typical laptop LCD). Its contrast ratio is 20 to 1. Its display elements exhibit memory, so displaying a static image doesn't use power. It does take energy to change the display, but once the image is there, it will stay for years even if the power is turned off. Cholesteric LCDs are available in 320x240 pixels, 240x160 pixels, and 128x32 pixels. The manufacturing process for cholesteric LCDs is similar to that for laptop LCDs—an advantage. The display requires up to 40 volts and between 30 and 100 milliseconds to change an image. This is too slow for video, but is great for signage and for informational displays.

Organic light-emitting-diode display. OLED displays are built of red, green, and blue light-emitting polymers. Polymers are large semiconducting molecules. Recently, the OLED display has gotten press attention for the stunning images it produces. Though relatively new, the market for OLED displays should reach $112 million this year, primarily in car stereos and cell phones. The OLED display market is expected to grow to $2.8 billion by 2007. Because they emit photons (rather than relying on reflected light), OLEDs can achieve a contrast ratio of 250 to 1. OLED displays have better viewing angles and better contrast, operate faster, and dissipate less power than their LCD competitors. In addition, OLED displays are thin, lightweight, operate at low voltages, and can be built on flexible sheets of plastic. Plastic substrates allow high-volume manufacturing, which should make OLED displays cheaper than LCDs once the manufacturing process is optimized. Imagine giant rolls of flexible plastic displays coming off automated lines. Today OLED displays are more expensive to manufacture than LCDs.

About fifty companies are working on OLEDs, including Cambridge Display Technology, DuPont, Eastman Kodak, eMagin, Lite Array, NEC, Nippon Seki, Philips, Pioneer Electronics, Samsung, Sanyo Electric, Seiko Epson, Sony, TDK, and Toshiba. In spite of OLED's advantages over LCDs, its makers face challenges. The OLED's polymers readily absorb water and oxygen, causing performance degradation and early failure. The polymers are so sensitive to water and oxygen that sealing them requires special materials and special manufacturing expertise. The light-emitting diodes themselves are a challenge. The conversion efficiency and lifetime of the polymer diodes differs by color. Green polymer diodes are five times more efficient than red and blue polymer diodes. The lifetime of the green diodes is twice the lifetime of the red diodes and ten times the lifetime of the blue ones. Differences in lifetime mean that the display's color changes with time. The short lifetime of blue polymer diodes limits overall display life.

MEMS-based display. Yield is a problem for flat-panel displays. Your eye is good at detecting anomalies. I've got a laptop with a million-pixel display. It's got three bad pixels. That makes 99.9997% of the pixels good, but I see the bad ones instantly. If one pixel is bad, the display is bad. This problem gets worse as the number of pixels rises. Also, the back of a camera is only so big, so, increasing the resolution of the micro display means cramming more pixels into the same area. Even if a 2-inch display held 1600x1200 pixels, your eye couldn't resolve detail in the display's image.

Microvision (MVIS) has a solution to the flat panel's yield and scaling problems: build the display with a single pixel.

Microvision began with a head-worn display for military applications. I visited Microvision a little over a year ago. I spent the day talking with engineers and executives, I visited the labs, and I tried prototypes. Microvision's display is fundamentally different. There is no screen. Instead, Microvision's combination of optics and microelectromechanical systems (MEMS) uses a red laser as a source to send photons directly to your eye's sensors.

In a cathode-ray tube (CRT) display, the CRT beams electrons at the screen. Powerful electromagnetic fields bend the beam to hit a particular point. The screen is coated with phosphor material that glows when struck by electrons. To paint the image on the screen, the electron beam sweeps one horizontal row of pixels and then returns (the electron beam is off during the return) and moves to the next row. When all the rows have been scanned, the beam returns to the starting point and begins again. For a modern 1024x768 display, this "raster scan" sweeps the 1024 pixels in each of 768 rows 85 times a second. Each pixel is made up of a red, green, and blue phosphor. CRTs fire separate electron beams at the red, green, and blue phosphors. The CRT is a one-pixel system meaning that at any instant only one pixel is lit by the beam. The display seems to show a complete image instead of one rapidly moving pixel because the screen's phosphor glows for a while (persistence) after the electron beam passes and because the sensors in our eyes exhibit persistence (that's why spots persist after a camera's flash).

Microvison's display system mimics the CRT display. Replace the electron gun with a laser or with a light-emitting diode (LED). Bounce low-power light off a MEMS mirror directly into your eye, using the sensors in your eye as the screen. Electromagnetic fields move the gimbaled mirror in a raster scan to complete the image. Modulate the light beam to turn pixels off or on (or for any intensity in between). Red, green, and blue lasers or LEDs create a color image. It's a one-pixel system, which readily scales to higher resolution. Eliminating the screen between the source and your eye's sensors ups the efficiency. The low-power light from Microvision's system writes on top of any image that's there, creating a high-resolution "overlay." The effect recalls heads-up displays in fighter aircraft, but with higher resolution and with better contrast.

Microvision has contracts to develop MEMS-based vision systems for the Army in aviation and in medical applications. The Army is a great customer because it knows what it wants and is willing to pay development costs. Microvision retains patents and trade secrets from this development and Microvision is free to use what it develops in commercial products. The Army has been the early adopter that Microvision needed to develop its MEMS-based scanner for augmented-vision applications. In January, Microvision began shipping "Nomad," its commercial version of the MEMS-based head-worn display. The Army is now paying to cost-reduce and to improve the Army's system. Improvements made under the Army contract will benefit Microvision's commercial products.

The first-generation MEMS scanner chip, which is being delivered to commercial customers in today's Nomad systems, is 7x13 mm. The second-generation chip, in prototype, is 6x6 mm. It increases the system's energy efficiency by a factor of ten for the same display quality. The smaller size more than triples the number of chips per wafer, cutting both the cost of the chip and the energy needed to move the mirror. The third-generation chip is in development and promises similar improvements in size, efficiency, and cost. Microvision's chips are made on 100-mm wafers today, but it has already established high-volume production with foundry partner Walsin Lihwa Corp. of Taiwan, which also offers 150- and 200-mm wafers. Moving to larger wafers will further reduce the chip cost. By the third generation, Microvision believes the cost and power will be low enough to attract camera makers. It is already talking to all of them.

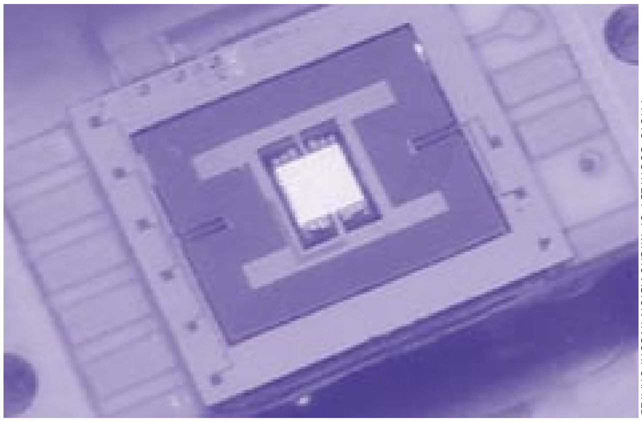

PHOTO COURTESY OF MICROVISION INCORPORATED

Fig. 2. Microvision's MEMS chip has a gimbaled mirror to draw the image directly into the eye.

Instead of looking at a miniature flat-panel display on the back, imagine looking into your camera's viewfinder at an image that looks better than the display on a typical laptop computer. It looks like there is a *15-inch screen* two feet in front of you. It shows you, in full color, exactly what the camera's image sensor sees. This is new; there's no way you can get this level of detail from a film camera's viewfinder. This points the way to future cameras that let you see the image at its print resolution as you take the picture.

Microvision's color LEDs come from partner Cree. Display contrast is 150 to 1 for SVGA (800x600) resolution. This March, Microvision announced an agreement with "an unnamed Asian corporation" to develop displays for consumer electronics applications. Microvision's display would enable viewing *unedited* web pages and email *attachments* from a cell phone, personal digital assistant, or camera. Today, cell phones and PDAs can only access the web through special servers that convert a limited selection of web pages to their tiny screen format.

The MEMS chip also functions as a scanner enabling cheap, portable scanners for difficult-to-read 2D bar codes (it could still read conventional 1D bar codes). It has the potential to scan the eye to authenticate the user of the display.

Microvision is a Dynamic Silicon company for its bar-code scanners, for its MEMS-based display, and for its Nomad display system.

Imagers

Charge-coupled-device imagers. The image chip is the eye of the digital camera. For the past 25 years, charge-coupled devices (CCDs) have dominated image capture. In a typical digital camera, the CCD imager is an array of millions of photo sensors that convert light into electric charge. Electronics in the camera figures out how much light each pixel captured by measuring the charge. For color images, each pixel is covered with a color filter so that it captures light of only one color. Imagine a checkerboard filter overlaying the array of light-sensitive pixels. Half of the checkerboard squares will be green filters, one quarter will be red, and one quarter will be blue. This checkerboard is called a "mosaic filter." The camera's microprocessor has to construct a full-color image from the red, green, and blue pixels collected.

CMOS imagers. About ten years ago, CMOS image sensors emerged for low-end applications. CMOS imagers have gotten better with semiconductor process improvements and they now challenge CCD imagers. CCD imagers are built in a custom process that is different from other semiconductors, so CCD imagers are more expensive and they improve slower (because they have lower manufacturing volumes and fewer applications than CMOS chips). CCD imagers require special clocking and special voltages and they are unable to integrate other electronic functions onto the same chip. CMOS imagers don't require special clocks or special voltages and they easily integrate other electronic functions. CMOS-based cameras, therefore, are cheaper, use one-third the power, and have fewer chips than CCD-based cameras. The CCD's advantages have been in the number of pixels and in pixel sensitivity. The CCD's advantage in number of pixels is disappearing. The CCD imager's pixel is more sensitive because all of its area collects light, while part of the CMOS imager's pixel is covered with circuits. The "fill factor," a measure of quality for a CMOS pixel, is the percent of the pixel area devoted to collecting light (as opposed to occupied by circuits). Almost all CMOS imagers use a mosaic filter.

Shipments of CCD imagers are growing slowly and will decline after 2003. Shipments of CMOS imagers are growing rapidly and will pass CCDs in 2003.

Foveon. Foveon is a Silicon Valley startup. Foveon's X3 imager is the Kodachrome of CMOS imagers; it does for digital imagers what Kodak's Kodachrome film did for color photography. Kodachrome film has three color-sensitive layers. Different colors of light penetrate to different depths, exposing red-, green-, and blue-sensitive layers. Foveon's X3 chip does the same thing. Instead of using a mosaic filter, Foveon stacks blue sensors on top of green sensors on top of red sensors. Red light, for example, penetrates the blue and green sensors to be captured by the red sensors. *Foveon's X3 imager captures all three colors at each pixel location*. Foveon's X3 chip uses a CMOS-compatible process and there's no mosaic filter, so the chip's cost may decline to a fifth the cost of its competitors. National Semiconductor, which owns 51% of Foveon, makes the chip.

As pixels proliferate, the conventional imager's mosaic filter gets more intricate, more expensive, and more difficult to align. Except for Foveon, digital cameras today capture only one color at each pixel, *throwing out two-thirds of the incoming light at every pixel*. The camera's digital signal processor may execute hundreds of millions of instructions to construct an image from physically separated red, green, and blue pixels. Having to construct the image introduces visual artifacts, it costs power, and it takes time. Foveon's X3 captures all the light at every point on the image, so there's no processing delay to construct an image that's been artificially checkerboarded through a mosaic filter. This reduces the camera's chip count, power dissipation, and cost while improving its response time. Foveon's X3 imager will displace its rivals and dominate the imager market.

Foveon's new imager isn't just for high-end cameras, consumer cameras should appear this Christmas. Foveon is a Dynamic Silicon company for its revolutionary X3 imager. National Semiconductor (NSM) is a Dynamic Silicon company for its part ownership of Foveon, for its production of Foveon's X3 imagers, for its x86-based Geode microcontrollers, and for its consumer-product orientation.

Storage

Digital cameras store images in flash memory modules or on small disks such as IBM's Microdrive. Both types of storage are expensive. Flash memory modules are slow, they lack capacity, and they wear out. Small disk drives are slow and they need too much power. There's help on the way. Denser memory chips are next, then fast, dense memory, then MEMS-based storage.

Startup Matrix Semiconductor (*Dynamic Silicon*, Vol. 2, No. 1) is building "write-once" memory modules (think electronic film) that will have the same capacity as flash modules at a quarter of the cost. That's not a satisfactory solution, but Matrix says read-write modules are on the way.

I covered memory chips in "Goldilocks and the Three Memory Chips" (*Dynamic Silicon*, Vol. 2, No. 5). The holy grail of memory chips combines the best characteristics of flash, SRAM, and DRAM. The ideal memory chip would be as dense and as cheap as DRAM, as fast as SRAM, and non-volatile like flash. The leading candidates are magnetoresistive RAM (MRAM), ferroelectric RAM (FRAM) and ovonic unified memory (OUM).

This month, Motorola announced a 1-Mb MRAM prototype. Motorola promises samples in 2003 and products in 2004. Motorola's 1-Mb MRAM follows its announcement of a 256-kb MRAM by sixteen months, so there's progress. Motorola recently signed an agreement to work with Philips and with STMicroelectronics on MRAM development. But Motorola's 1-Mb MRAM isn't as fast as SRAM; it's as slow as DRAM. It also isn't as dense as DRAM, which will have a thousand times the density of the 1-Mb MRAM when it ships.

Ovonic unified memory is my choice among the candidates for next-generation, non-volatile memory. Startup Ovonyx (www.ovonyx.com)—a joint venture among Intel, Tyler Lowrey, and Energy Conversion Devices, Inc.—works to commercialize OUM. Energy Conversion Devices (ENER, www.ovonic.com) is the original licensor of the technology and, as such, is a Dynamic Silicon company. Intel has a non-exclusive license to OUM from Energy Conversion Devices. Other licensees include Sony, Panasonic, Sanyo, Toshiba, Hitachi, STMicroelectronics, and BAE Systems.

I explained MEMS-based storage in two previous issues (*Dynamic Silicon*, Vol. 1, No. 2 & No. 5). In "MEMS-based Storage" (May 2001), I concluded that MEMS-based storage wasn't ready for production because there were too many unsolved problems. It's still true today, but there's progress. This month, IBM announced advances in its "Millipede" MEMS-based storage. IBM has achieved a storage density of 1,000 Gb/in^2, and says it can go higher. This compares with 50 Gb/in^2 in hard disks. IBM built a Millipede prototype with 1,024 read/write heads and says it will have four times as many read/write heads next year. IBM's MEMS-based storage could have ten times the capacity of a flash module with similar power dissipation in the same *physical* volume as a flash-compatible module.

Lessons

My example of the transition from film to digital photography shows that there's room for improvement in digital cameras. I talked about coming transitions in the display, in the imager, and in storage. There are similar advances in the camera's communication with the PC, in its microprocessors and other electronics, and in printing the images. Digital cameras are still too hard to use. Polaroid gave digital cameras to one hundred individuals and asked them to take pictures and then print them. Only eight were able to do so. There's improvement needed in user interfaces, application software, and peripheral components. Look at cell phones, MP3 players, GPS receivers, car stereos, or washing machines, and you'll see a similar story.

The semiconductor industry isn't finished now that the PC and the cell phone have been invented. There's market incentive to improve the PC, the cell phone, and a host of other digital systems. There will be other surprises like the PC and the MP3 player, too, even if we can't predict what they will be.

The semiconductor industry's boom and bust cycles *are not closely tied to broad national or global economic cycles*. The semiconductor industry might grow by 46% in one year and shrink by 17% the next, as it did in 1984 and 1985. The semiconductor industry is more volatile than broad economic cycles, but its twenty-year average growth is still above 14%. If you can separate leading-edge companies from the rest, you should do better on long-term investments. In 1999 and 2000, the semiconductor industry grew by 39% and 31%, respectively. Leading-edge companies grew *faster*. In 1999 and 2000, Xilinx grew total revenue by 54% and 63%, respectively. Given the semiconductor market's inherent volatility and given that the leading-edge companies were growing faster than the market, it shouldn't have been a surprise to see semiconductors overshoot and compensate. As bad as 2001 seems, it was still the fourth-largest year ever, in absolute terms, for the semiconductor industry!

Nick Tredennick and Brion Shimamoto
June 18, 2002

Dynamic Silicon Companies

The world will split into the tethered fibersphere (computing, access ports, data transport, and storage) and the mobile devices that collect and consume data. Dynamic logic and MEMS will emerge as important application enablers to mobile devices and to devices plugged into the power grid. We add to this list those companies whose products best position them for growth in the environment of our projections. We do not consider the financial position of the company in the market. Since dynamic logic and MEMS are just emerging, some companies on this list are startups.

Company (Symbol)	Technology Leadership	Reference Date	Reference Price	5/31/02 Price	52-Week Range	Market Cap.
Altera (ALTR)	General Programmable Logic Devices (PLDs)	12/29/00	26.31	18.03	14.66 - 33.60	6.8B
Analog Devices (ADI)	RF Analog Devices, MEMS, DSPs	12/29/00	51.19	36.62	29.00 - 52.74	13.4B
ARC Cores (ARK**)	Configurable Microprocessors	12/29/00	£3.34	£0.27	£0.25 - £1.06	£115.6M
ARM Limited (ARMHY***)	Microprocessor and System-On-Chip Cores	11/26/01	16.59	7.95	7.30 - 19.20	2.8B
Calient (none*)	Photonic Switches	3/31/01				
Celoxica (none*)	DKI Development Suite	5/31/01				
Cepheid, Inc. (CPHD)	MEMS and Microfluidic Technology	12/17/01	4.73	5.12	1.48 - 11.48	136.8M
Chartered Semiconductor (CHRT)	CMOS Semiconductor Foundry	7/31/01	26.55	22.40	16.06 - 30.36	3.1B
Coventor (none*)	MEMS IP and Development Systems	7/31/01				
Cypress (CY)	MEMS Foundry, Dynamic Logic	12/29/00	19.69	19.93	14.00 - 28.95	2.4B
Cyrano Sciences, Inc. (none*)	MEMS Sensors	12/17/01				
Energy Conversion Devices (ENER)	Ovonic Unified Memory	6/18/02	27.69		15.00 - 28.16	2.5B
Foveon (none*)	CMOS Imaging Chips	6/18/02				
Microvision (MVIS)	MEMS-based Micro Displays, Nomad Head-Worn Display, Scanners	6/18/02	6.80		6.21 - 22.57	92.0M
National Semiconductor (NSM)	Geode x86 Microcontrollers, Consumer Orientation, 51% Ownership of Foveon	6/18/02	32.30		19.70 - 37.30	5.8B
QuickSilver Technology, Inc. (none*)	Dynamic Logic for Mobile Devices	12/29/00				
SiRF (none*)	Silicon for Wireless RF, GPS	12/29/00				
Taiwan Semiconductor (TSM†)	CMOS Semiconductor Foundry	5/31/01	14.18 ††	16.58	8.39 - 20.99	55.8B
Tensilica (none*)	Design Environment Licensing for Configurable Soft Core Processors	5/31/01				
Transmeta (TMTA)	Microprocessor Instruction Sets	12/29/00	23.50	2.37	1.17 - 14.91	314.0M
Triscend (none*)	Configurable Microcontrollers (Peripherals)	2/28/01				
United Microelectronics (UMC†)	CMOS Semiconductor Foundry	5/31/01	10.16	8.50	4.25 - 11.52	22.5B
Wind River Systems (WIND)	Embedded Operating Systems	7/31/01	14.32	6.72	5.80 - 25.35	528.8M
Xilinx (XLNX)	General Programmable Logic Devices (PLDs)	2/28/01	38.88	35.26	19.52 - 49.54	11.8B

† Also listed on the Taiwan Stock Exchange

†† TSM reported a stock split on 6/29/01. The Reference Price has been adjusted for the split.

* Pre-IPO startup companies.

** ARK is currently traded on the London Stock Exchange

*** ARM is traded on the London Stock Exchange (ARM) and on NASDAQ (ARMHY)

NOTE: This list of Dynamic Silicon companies is not a model portfolio. It is a list of technologies in the Dynamic Silicon paradigm and of companies that lead in their application. Companies appear on this list only for their technology leadership, without consideration of their current share price or the appropriate timing of an investment decision. The presence of a company on the list is not a recommendation to buy shares at the current price. Reference Price is the company's closing share price on the Reference Date, the day the company was added to the table, typically the last trading day of the month prior to publication. The authors and other Gilder Publishing, LLC staff may hold positions in some or all of the companies listed or discussed in the issue.