20th Anniversary Issue

TWENTY YEARS REMOVED from its birth in 1983, with 211 issues and counting, *MICRO* continues its tradition of high-quality trade journalism. Hundreds of technical articles; thousands of news stories, product releases, and advertisements; and countless hours of labor have gone into the pages of this magazine over the past two decades. We've put together a special anniversary section, featuring musings from some old friends of the magazine, fascinating facts and reminiscences, and other commemorative nuggets. So turn the page and join in the celebration.

Twenty years for everything to change… or not

Keith Dillenbeck

I began my career in the semiconductor industry 21 years ago as a process engineer for Motorola, making 64-Kb DRAMs. Back then, moving from 4-in. to 5-in. wafers was considered leading edge. The only thing I owned in 1982 that was 300 mm was the steering wheel on my car. Since that time, I have been involved in many diverse aspects of semiconductor defect engineering and wafer cleaning, and the journey has been fun. While many things have changed, many have not.

Looking at the evolution from a 64-Kb DRAM to a 3.0-GHz microprocessor, one can certainly say that the integrated circuit fabrication process has grown significantly more sophisticated and much more complex. Back in the early 1980s, process engineers like me spent a great deal of time making killer contaminants—like copper—go completely away. Now, we all spend much of our time working feverishly to make copper work as a critical interconnect material.

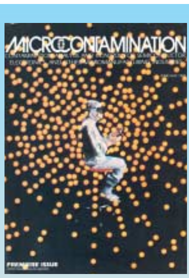
Keith Dillenbeck is a product line manager for Axcelis Technologies and a long-time member of *MICRO*'s editorial advisory board. (Inset) Keith 20 years ago.

I also remember a very old project at Motorola to eliminate the use of tweezers so that we would not scratch wafers. Nowadays, we use slurry, a very abrasive material not unlike sandpaper, to gently planarize critical circuit patterns.

The complexity of 90- and 65-nm semiconductor processes has driven the art and science of defect engineering to new levels. The incorporation of challenging new materials and structures such as copper interconnects, low-k dielectrics, high-k capacitors, and tantalum barrier layers has demanded new technical thinking about how we reduce process defects within the IC process. What we knew then, and what we routinely practice today, is that a low-defectivity process must be designed and integrated in from the beginning of the development cycle. Semiconductor devices are too complex to tolerate the practice of designing and verifying a workable process now, then working to enhance the yield later. The economic realities of modern semiconductor manufacturing dictate that devices must yield in the mid- to high-90% range. When I started in the business, we only dreamed of yields of this magnitude.

The semiconductor industry certainly has a great deal to be proud of during the past 20 years. We have continued to make revolutionary progress in how we detect circuit and pattern defects, remove contaminants from critical surfaces, and design process-integration schemes that are immune to common defect mechanisms. However, there are many significant common technical

MICRO and History– A timeline of the first 20 years



1983
Microcontamination launched, June-July issue distributed at Semicon West

IBM introduces first PC with a built-in hard drive

Motorola unveils first cellular phone

1984
Congress passes Chip Protection Act during trade dispute with Japan

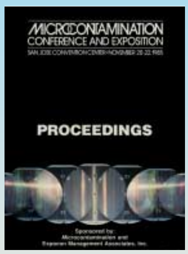
First Apple Macintosh introduced

IMEC created by Flemish government in Belgium

1985
First "facsimile" number appears in ad in *Microcontamination*

First *Microcontamination* conference and exposition held in San Jose

Toshiba invents flash memory



issues that we surely thought would change—but really haven't.

One major area in which we expected to make significant progress is the continued reliance on particle test wafers throughout the device fabrication

Tools are much cleaner than they were two decades ago, but defect excursions continue to plague most process engineers.

process. The practice of taking a process tool out of production to run relatively expensive particle monitor wafers continues. Tools are much cleaner than they were two decades ago, but defect excursions continue to plague most process engineers. As a result, we continue to run lots of non-value-added particle tests. It always bothered us when we had to ask the question, "Are we really seeing a particle or perhaps just haze on the wafer surface?" Surprisingly, we often find ourselves asking that same question, except that the defects are much smaller and are measured on significantly more expensive monitoring tools.

Several years ago we thought we had a chance to eliminate or significantly reduce the number of particle test wafers through the use of in situ particle and defect metrology tools. Although some progress has been made, it's still not enough. Reliable onboard monitoring systems to help ensure critical equipment and process performance are still critically needed.

The extensive use of wet wafer-cleaning processes is another major area where we expected revolutionary changes. Back in the mid-1970s, Werner Kern and his colleagues at RCA discovered a

Joe Monkowski, Advanced Energy

Being a visionary is tough business. Early in the process, the ideas are so new that people have a hard time accepting them. Later, once the ideas have been proven and well accepted, people take them for granted.

When *Microcontamination* first began publication in 1983, the far-reaching influence of contamination was not fully understood or appreciated. Although there was general awareness of the need to keep particles out of the cleanroom, the knowledge did not go much further. For example, there was little appreciation for the effect of particles in the chemicals associated with wafer processing. The idea that the process tool could be the largest source of contamination was quite radical—there was very little understanding of process-induced contamination. These were the topics, though, that were covered and explored by *Microcontamination* throughout the 1980s and early 1990s.

When *Microcontamination* began in 1983, the far-reaching influence of contamination was not fully understood or appreciated.

During this time, advances in microcontamination control were made on many fronts, to the point where much of it is now taken for granted. So much for granted, in fact, that *Microcontamination* became *MICRO*, and coverage expanded to include topics such as advanced process control (APC)—which today is as fresh and filled with unexplored opportunities as microcontamination was 20 years ago.

It is great to have a forum that embraces the coverage and exploration of these cutting-edge ideas. Congratulations to *MICRO*, and a big thank you for providing this visionary leadership.

Joe Monkowski is vice president of marketing for Advanced Energy Industries' control systems and instrumentation group and has been a contributor to MICRO *since its early days.*

1986
Chernobyl nuclear plant disaster occurs

First five-year U.S.-Japan Semiconductor Trade Agreement signed

Taiwan Semiconductor Manufacturing Corp. (TSMC) founded

1987
Sematech is incorporated with 13 charter members

Star Trek: The Next Generation debuts

Wall Street's "Black Monday" occurs, when Dow Jones lost 22.6% of its value

1988
Ohmi Papers debut in October issue of ***Microcontamination***

1989
Berlin Wall falls

Intel debuts 486 microprocessor

Sematech produces its first wafer lot

1990
Nelson Mandela released from South African prison

Ohmi series ends in July issue of ***Microcontamination;*** book-length collection of articles published shortly thereafter

Robert Noyce dies

ROBERT NOYCE photo courtesy of INTEL

wet-cleaning technology that became known as "the RCA process." Almost three decades later, we continue to use copious amounts of sulfuric acid, hydrogen peroxide, ammonium hydroxide, and other wet chemicals.

In 1987, while working as a Motorola assignee to Sematech, I hosted a group of distinguished industry experts at the consortium's first wafer-cleaning workshop. During this very enlightening three-day event, we talked ourselves into the belief that by 1993, leading semiconductor processes would use entirely gas-phase cleaning methods for removing contaminants and particles from critical FEOL device layers. Back then, emerging technologies like UV-ozone organic removal, UV-chlorine metal removal, and laser-assisted particle removal had a shining future.

While some of these gas-phase processes have found certain niche applications, liquid-based wafer-cleaning techniques continue to dominate our industry. Leading research institutions such as Tohoku University in Japan and IMEC in Belgium have helped us to better understand the chemistry and physics of contaminant removal and surface preparation. Nonetheless, we still rely heavily on wet wafer-cleaning and polymer removal technologies—and we probably will for the foreseeable future.

We still rely heavily on wet wafer-cleaning and polymer removal technologies.

One cannot reflect on the past two decades without discussing the impact that various downturns have had on our progress, especially since we are still emerging from perhaps the deepest and longest industry recession ever. The volatility and cyclical nature of the semiconductor business is a reality that may be painful to absorb, but one that forces us to find ways to make progress in spite of it all. The inability to buy all the equipment we want or to hire all the people we need may have slowed down our progress in certain technical areas, but it has also taught us how to carefully prioritize our programs and how to analyze the economic benefits of what we do.

The past 20 years have seen great changes and improvements in how we think of circuit defects and how to design contamination out of a process. For those of us who have worked in this technical arena, the voyage so far has certainly been memorable. We will face a growing number of even more daunting technical challenges as the technology evolves from the 130-nm to 90-nm to 65-nm process nodes. The incorporation of new materials and ever-more-complex integration schemes will necessitate the invention of new ways of measuring and removing contamination and other killer defects, as well as the design of process steps that are not defect sensitive. Our crystal ball may be cloudy, but we can rest assured that the journey in the years ahead will be as fun and exciting as the road we've traveled since the early 1980s. ■

The Star Trek connection

MICRO even has a place in Star Trek lore. The premise of *Contamination*, a *Star Trek: The Next Generation* novel published by Pocket Books in March 1991, was inspired by the earlier incarnation of the magazine. John Vornholt, the book's author and a friend of editor Tom Cheyney and his wife Cassandra, says in the foreword that "it was while perusing an issue of *Microcontamination* that the idea for this novel was born." The plot revolves around a murder that occurs in the Starship Enterprise's onboard cleanroom facilities. Here is a brief excerpt:

"Within this cleanroom were smaller cleanrooms of transparent aluminum, where robots moved with harmonic ease, shuffling wafers of microchips in and out of reactors and furnaces. Along the walls of the busy cleanroom, tanks, pumps, and piping stretched from floor to ceiling….'That is semiconductor research and development,' explained Saduk matter of factly. 'The developers have to duplicate manufacturing techniques that are common throughout the Federation.' "

1991
First Gulf War occurs

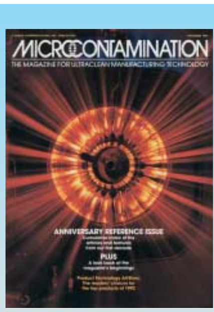
Microcontamination publishes yearlong series on in situ process monitoring

1992
Gordon Moore launches National Technology Roadmap plan

Microcontamination publishes article series by Sematech on cost of ownership

Semicon West moves from San Mateo to San Francisco

1993
First edition of *National Technology Roadmap for Semiconductors (NTRS)* published



Microcontamination turns 10

U.S. chip companies recapture lead in world semiconductor sales

1994
Last *Microcontamination* Conference and Exposition held in San Jose

Last episode of *Star Trek: The Next Generation*

Sony develops first PlayStation, example of trend toward system-on-a-chip technology

GORDON MOORE—INTEL; PLAYSTATION CPU—LSI LOGIC

Electrostatic charge control then and now

Arnold Steinman

In 1983, users of semiconductor devices made most of the efforts to reduce the impacts of electrostatic charge. Charge on personnel transferred to the devices in an electrostatic discharge (ESD) event, and the result was device destruction. Members of the military and telecommunications industries started the Electrostatic Discharge Association (ESDA) in the late 1970s to study and deal with the problems caused by ESD.

Semiconductor manufacturing was changing in 1983. Device geometries were going below 5 µm, particularly with the newer microprocessors and "large" memory devices exceeding 8 Kb. Killer particle size was well below 1 µm, and the new problem was contamination control. When particle sizes go below 1 µm, electrostatic forces surpass gravitational settling in attracting particles to wafer surfaces. Upgrading contamination control was not easy in the existing wafer fabs.

It suddenly became important to eliminate static charge to reduce contamination levels in front-end semiconductor manufacturing. Charge resided on insulators such as oxide-coated silicon wafers and their polycarbonate or PVC carriers. To neutralize this charge and reduce contamination, a cleanroom-compatible, ceiling-mounted air ionization system was introduced at Mostek in Carrollton, TX. The results were immediate—a 70–80% reduction in surface contamination of wafers. Intel, Texas Instruments, Motorola, Advanced Micro Devices, and other major manufacturers installed similar systems over the next few years. Some additional benefits of static control were also seen, including a decrease in equipment lockups and reduced damage to photomasks.

Arnold Steinman is chief technology officer for Ion Systems and a long-time member of *MICRO*'s editorial advisory board.

Over the past 20 years, semiconductor manufacturing has changed remarkably. Would manufacturers of 5-µm devices in 1983 have expected to be making 100-nm devices in 2003? Wafer fab designs evolved from ballrooms to today's bay-and-chase or ultraclean minienvironment styles. Have all of these changes eliminated the need to control static electricity? Quite the contrary, technological change makes the static problem worse.

Killer particle size has shrunk below 30 nm. More of these small particles exist in a cleanroom or minienvironment, and their minuscule size makes them easier to attract and bond to charged wafer or equipment surfaces. Once on a surface, their diminutive size requires liquid or chemical removal. Future lithography techniques, such as 157 nm or EUV, may require a nitrogen atmosphere and the elimination of pellicles. The static-charge levels and the resulting contamination will increase dramatically.

Equipment lockups continue to affect productivity. The increased processor speeds in equipment have made the problem even more serious. ESD events generating signals in the 100-MHz to 2-GHz frequency range did not affect microprocessors running at 1 MHz in 1983. Unfortunately, all current microprocessors run in the same frequency range as the signals generated by ESD. The result is more-frequent equipment

1995

Microcontamination* renamed *MICRO

MICRO awarded Ozzie Silver Award of Excellence for best use of photography in November/December issue

1996

U.S. National Medal of Technology awarded to Applied Materials' Jim Morgan

1997

Intel's Andy Grove (left) named *Time* magazine's "Man of the Year"

IBM adopts copper interconnect technology for volume manufacturing

KLA Instruments, Tencor Instruments merge

1998

MICRO turns 15 and adopts defect/yield focus

1999

AMD opens Fab 30 in Dresden, Germany

NTRS becomes *International Technology Roadmap for Semiconductors*

ANDREW GROVE, ROBERT NOYCE, GORDON MOORE—INTEL lockups, and bad data transmitted to factory management systems.

The ability of a device to survive an ESD event decreases with smaller device geometry. A discharge requires less energy to damage the smaller device. Devices in 1983 withstood thousands of volts. In 2003, most devices can withstand only about 250 V. Magnetoresistive heads used in disk drives are initially manufactured on wafers. Once singulated, their ESD sensitivity is already under 5 V. What will the sensitivity of 45-nm devices be in 10 years? ESD damage to small-dimension reticle features is already a serious problem.

Is anyone concerned about the future? Heeding the experiences of the disk drive industry, both the *International Technology Roadmap for Semiconductors (ITRS)* and SEMI are addressing static control. The Facilities Integration chapter of *ITRS* 2002 contains recommendations for static control. SEMI backs this up with several documents targeting static control in production equipment and a soon-to-be-released guide to controlling static charge in the entire semiconductor factory. Both the *ITRS* and SEMI make recommendations for static-charge levels correlated to device technology nodes.

Static control materials manufacturers have responded as well. There are many new methods for controlling charge on operating personnel, innovative cleanroom-compatible static control materials, and improved ionization methods for today's cleanroom and equipment designs.

There has been increased awareness of the importance of controlling static charge throughout the manufacturing process. Manufacturers understand the impact that static charge has on their quality and yield. End-users recognize that static charge can drastically affect the reliability of semiconductors in their products. Most importantly, everyone appreciates the effect of quality and reliability on their profitability. ■

Takeshi Hattori, Sony Semiconductor

The digital convergence of consumer, networking, and PC applications has been creating completely new broadband-networked consumer electronics markets where people's interests have become more diversified and whimsical. Accordingly, at least in Japan, the driving force of the semiconductor industry has shifted from DRAM chips for computer applications, which dominated the last quarter of the 20th century, to system-on-a-chip (SoC) devices for digital consumer electronics applications. The growing trend has also led to paradigm shifts in semiconductor manufacturing toward a combination of rapid-ramp-up, short-cycle-time, high-mix, and low- or variable-volume production to quickly meet the increased demand for high-end consumer products.

To achieve defect reduction and yield enhancement in this new chipmaking environment, short-loop feed-forward systems must be employed. Advanced process control and in situ monitoring will be much more important in the SoC era than the traditional approach of longer-loop feedback based on final test and inspection data, which worked well in the high-throughput DRAM era. Single-wafer processing will also be desired for high-mix, low-volume SoC production.

Advanced process control and in situ monitoring will be much more important in the SoC era.

MICRO magazine has made enormous contributions to the worldwide semiconductor industry for the past 20 years by publishing outstanding technical articles from distinguished authors on defect reduction and prevention and subsequent yield enhancement. I hope the magazine continues to contribute to the healthy growth of the semiconductor and related industries, showing guidelines for the best practices in manufacturing for the rapidly changing future. "It is not the strongest of the species to survive, nor the most intelligent, but rather the one most responsive to change" (Charles Darwin).

Takeshi Hattori is chief research officer and general manager of Sony Semiconductor Network's UCT Laboratories in Atsugi, Japan, and a long-time member of MICRO*'s editorial advisory board.*

2000

Jack Kilby wins Nobel Prize for Physics

SEMI turns 30 and throws party at Moffett Field, CA, blimp hanger

TSMC announces first 300-mm customer product wafer starts

2001

First EUV lithography tool prototype unveiled at Sandia National Labs

IBM successfully tests 210-GHz SiGe-based transistor

People's Republic of China admitted to World Trade Organization

2002

Intel ships microprocessors made on 300-mm wafers with 0.13-µm technology

Jan Hendrik Schon fired from Bell Labs for fabricating nanotech research results

MICRO publishes 200th issue in March

2003

Infineon, SMIC announce plan to build first 300-mm fab in China

MICRO celebrates 20th anniversary

JACK KILBY—TEXAS INSTRUMENTS

One man's strange journey from particles to patents

Bruce Huling

I was actually looking for a job in the forest service when I was offered a job at Intel in the late 1970s. The exciting new world of wafers and ICs was just too hard to pass up, and besides, I thought I could always go back to a comfy job with Smokey the Bear later.

Wrong.

During my formative years, these things called particles or defects attracted my attention, although they seemed difficult to pin down and there wasn't much to read up on to understand their sources, behaviors, and impacts. I can still see in my mind diffusion furnace sleds and hooks, and process tubes that had ruts ground into them from pulling wafers in sleds out with a glass rod formed in the shape of a hook. Those were the glory days of reducing defects by using your eyes and brainpower to simply point your finger and say, "A-ha, there is the problem!"

One of my friends started a company making soft-landing and cantilevered diffusion loaders and was a presto millionaire almost overnight. (This would be a continual pattern throughout my career—friends, not me, starting companies.)

I sold my measly thousand shares of Intel stock to buy a new 1979 Jeep. I try not to think about what that car cost me by not holding onto that damn stock. What heady times they were back then, so full of possibilities.

In those days, high-tech sleuthing sometimes involved the use of a scanning electron microscope. But most "detection" involved waving a wafer in front of a bright light or using one of many microscopes located in almost every bay by pulling a big 4-in. wafer out with your tweezers and placing it on the platen to take a look. Engineers who were cool had their own personalized tweezers, usually held onto their bunny suits with a roach clip.

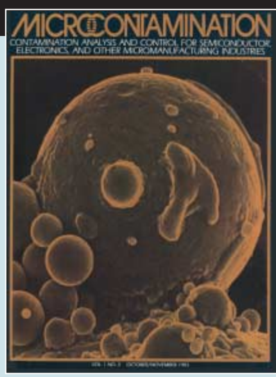
I left Intel on a Friday and started at Motorola the following Monday. My defect passion continued at Motorola for many years, with frequent diversions into spending money (installing and modifying process equipment), spending more money (building fabs), and spending even more money (transferring processes and shutting down factories). Yet none of the factories that I built or worked in over the past 20 years still operates today.

In the early 1980s, I had the opportunity to install and test the second getter-based gas purifier in the United States. The president of the purifier company couldn't believe there ever would be much of a market for gas purification in the semiconductor business. Two years later they had established a U.S. base of operations to support their burgeoning sales.

During this era I became a member of a new organization called the Semiconductor Safety Association (now the Semiconductor Environmental, Safety and Health Association, or SESHA), thanks to one of my earliest mentors, Ted Bielli. It has been special people like Ted who helped me to always challenge what is known, seek that which is not, and to generally buck the flow and have a lot of fun.

Bruce Huling is corporate IP portfolio manager for ON Semiconductor and a long-time member of *MICRO*'s editorial advisory board.

MICROflashback...20 years



'Many industry leaders in Japan and the United States believe that to attain true Class 10 environments, it will be necessary to eliminate people from cleanrooms; others maintain that operators will have to wear space suit–like outfits covering the face and the entire body.… Robots might pass wafers and wafer lots to each other from one staging area to the next, and some other sort of automatic mechanism might load the wafers into the various processing equipment and then remove them. Human operators would be situated in a remote area monitoring the equipment and controlling it with the aid of one or more host computers.' *(from "The Cleanroom of the Future," by Thomas Brandt, October/November 1983 issue of* Microcontamination*)*

Stanley T. Myers, SEMI

Stanley T. Myers, 1983

...and in 2003

Surviving two decades in the volatile semiconductor industry is no mean feat. That's why I'd like to congratulate *MICRO* on its 20th anniversary. I applaud the efforts of publications such as *MICRO* because they play a vital role in disseminating information about new semiconductor manufacturing technologies that enable our industry to continue its incredible pace of innovation. Further, I admire the quality and depth of *MICRO*'s coverage and look forward to being a reader for many more years to come.

Stanley T. Myers is president and CEO of SEMI.

Another person who greatly influenced my career early on was a "cleans guy" named Don Tolliver. Don is also a Dan Noble Fellow (Noble being the Motorola dude who started an operation in Phoenix making transistors, thus founding what would become Moto's Semiconductor Products Sector). Don spent a lot of his time cranking me up on many facets of defect reduction. He also introduced me to another great influence and new guy who people were just starting to talk (and argue) a great deal about—Professor Tadahiro Ohmi of Tohoku University. About this time I also started working as a mentor myself with the great folks at the University of Arizona, who had started a program to develop students actually trained in some aspect of IC manufacturing, since it was getting very hard to find people to fill vacant posts, let alone find those with experience.

I pulled up stakes again for a stint with Air Products and Chemicals to further my pursuit of closing the gap in knowledge of the relation between yields, process "chemisphere" (thanks to Dan Weber for coining that term), and feedstock quality. I was called the new Terry Francis (whom I had replaced) at Air Products, since Terry was off to Applied Materials to lead the charge in that company's new effort to reduce process contamination. I spent about four years constantly on the road with Sui-Yuan Lynn (one of the most practical PhDs I've had the pleasure to work with), a new-fangled partial-pressure quadrupole mass spectrometer, and my toothbrush as companions.

I then heard the call of a new opportunity I couldn't resist—joining a Motorola start-up in the Phoenix area that made MEMS-based accelerometers and gas, pressure, and chemical sensors. I ended up building a fab using exclusively minienvironments, an approach that was quite controversial at the time. While we started a business that continues to grow for Motorola, the team that did the original work sadly has dispersed (most have left the industry), and the fab where it all started is an empty shell waiting for office tenants.

After MEMS-1 closed down and all of its products transferred elsewhere, I made another run at building out a MOS fab for Motorola. But by the late 1990s the handwriting was on the wall and my heart just wasn't into it. As near as I could tell, except for 300-mm or specialty products, manufacturing for the most part was on its way out of the United States. I began looking for something that would crank me up like the old days of particle witch hunts, searching for the Dorian Shannon "Red X," or finding new solutions for problems.

Engineers who were cool had their own personalized tweezers, usually held onto their bunny suits with a roach clip.

An old friend (who happens to be the inventor of CVD polysilicon as it's known today) asked me if I was interested in working in a recent spin-off doing intellectual property management. To make a long story short, I'm now managing a company's IP portfolio, writing patents, and reviewing inventions from every corner of the globe.

Patents solve problems, so not a lot has changed for me, except that I write more in one month than I used to in a year, I have to wear glasses, and I continue to cram my memory banks with both arcane and new knowledge of widely various aspects of my passion—semiconductor manufacturing. It's been quite a strange journey from my early days looking for particles to my current gig eyeballing emerging technologies. **M**

MICROfactoids

- **Global semiconductor sales in 1983: $18 billion**
- **Intel sales revenues in 2002: $26.8 billion**
- **Size of killer defect/particle in advanced >1.0-µm lines in 1983: 0.5 µm (500 nm)**
- **Size of killer defect/particle in advanced 130-nm lines in 2003: 0.065 µm (65 nm)**

(sources: WSTS, IC Insights, Intel, ITRS)

Evolution, revolution, and just plain know-how

Terry Francis

Looking back 20 years at the creation of *Microcontamination* and then reviewing how it has changed into the publication that it is today is akin to cleaning out a messy closet and seeing what kind of treasures you can find. One of the first things that comes to mind is that I am sitting in an office with a 100-Gb system with three printers, digital camera, scanner, two cellphones, PDA, laptop, digital sound CV system, voice digitations system (that I am trying to figure out how to use to do the typing for me), and a spell-checker that is attempting to fix my English. This compares to my old office toolset that consisted of my handy IBM typewriter, dictionary, and what we might call one of the first office automation systems, which had about as much power as my PDA. I still can't find my desk because of all the paper, but at least my graphics have really improved.

Now besides all these new appliances and the bifocals I have to wear, I don't perceive anything differently. I do perceive that we continue to measure the reverse of our goal, which is to keep things clean. Although we still don't know how to measure clean, we do know how to measure contamination. We also know that zero is an imaginary number since, in the newer technologies, we now look at defects on an atomic layer.

When the magazine started, the microelectronics industry was just starting to focus critically on contamination, since it was affecting yields and many of the standard techniques were not delivering the goods. Prior focus had been on building the best cleanroom and controlling the environment within that

Terry Francis, formerly with Applied Materials, Air Products, and other companies, now runs his own consultancy and is an original member of *MICRO*'s editorial advisory board.

cleanroom. There was a migration afoot of those who said we needed to focus on the wafer ecosphere. The articles tended to be about the "look what I did" aspect of engineering versus the fundamental problem of what happened to the device, and how do I prevent it, control it, or make it benign.

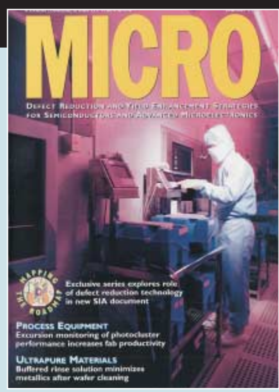
Many vendors and suppliers claimed they did not have a contamination problem with their products. But when you asked them, "How do you measure the lack of that problem?" the only reply you got was a blank stare. During one conversation I recall, it was clearly stated that there were no particle or contamination problems in the gases because no one had measured them.

The story has evolved considerably from those early days. In my case, when we started evaluating the gases, piping, and gas distribution systems employed in the semiconductor industry through the use of a laser aerosol particle counter, we saw some very interesting results. The gas suppliers have since become experts in this analysis area and have expanded their expertise to include materials selection, cleaning, and treatment technologies.

One of my primary observations about the world of contamination and defect control technology is that the individuals come from many professional backgrounds. They are chemists, physicists, engineers, biologists, and environmental scientists who all share one trait: they like to ask "why?" about almost everything. Their emotional passion needs no further explanation, while their powers of observation, analysis, and focus on "how do you measure?" border on the fanatical.

They are driven to measure in a qual-

MICROflashback...5 years



'Defects can be defined in the broadest sense as any outcome which deviates from the expected outcome. Possible defects include particles, contamination, ineffective control of physical and electrical parameters, device structure–related issues, process-to-process interactions including geometric effects, and design-process interactions. When yields are low—that is, when defect levels are high—the likelihood of adverse impacts on device quality and reliability increases. Therefore, to achieve effective manufacturing, all defect types must be minimized.'

(from "Mapping the Roadmap: New industry document explores defect reduction technology challenges," by David Jensen et al., January 1998 issue of MICRO)

itative or quantitative basis what they are observing, and then turn around and ask if what they are measuring is real. Is it an artifact of their sampling, the measurement equipment, or something else? It seems like an obvious approach to them since they are measuring contamination in the parts-per-billion to the parts-per-trillion levels. Diagnostics of contaminants and other physical defects can go from the properties of size, shape, color, and index of refraction to advanced micro-Xanes technology that requires the power of a linear accelerator to produce data. (Talk about a difficult capital expenditure to justify!) Of course, since we are dealing with some individuals who grew up in the 1960s and early 1970s, they also ask, "What does the sample taste or smell like?"

Jack Martinez de Pinillos, NIST

MICRO: How many years have you been involved with *MICRO?* Ten years?
Martinez: Working with you guys? A little more than that. One of the first technical papers I published there was probably in the early 1980s. *(It was in the April 1985 issue, to be exact.—Ed.)*
MICRO: What role do magazines such as ours play in the industry?
Martinez: Oh, an incredible role. That's one [message] that I'm trying to push a lot within NIST. The people at NIST are rewarded and encouraged to publish in academic journals and probably *Physics, Physics Review, the Journal of the American Chemical Society*. One of the problems that the people at NIST have is that most people in the industry don't normally peruse those journals unless they are looking for a specific answer. But you see them on an airplane…reading *MICRO*, you see them reading other [similar] magazines, and what we are trying to tell [NIST] is, "Look, now that you have the paper ready for *Physics Review* or whatever, let's modify it a little bit. My boss and I know most of the editors in the business. We can help you change it a little bit and publish it in this kind of magazine, which actually allows you to get to the people who work in the fabs."

MICRO has evolved a lot with the industry…and has always been there in the forefront, presenting very good technical articles that convey some highly technological things.

With the other [journals], you may be hitting the guys from the R&D group. But if you want to have a direct effect on manufacturing, you have to publish in these areas. We have actually convinced several of the lab directors at NIST to give [researchers] some kind of credit for publishing in these magazines and not just in academic journals.
MICRO: You've seen *MICRO* evolve with the industry then.
Martinez: Yes, *MICRO* has evolved a lot with the industry. I remember the days when we used to have the *Microcontamination* conferences and all that…. *MICRO* has always been there in the forefront. And I still think it is still maintaining itself in that regard, presenting…very good technical articles that convey some of these highly technological things that we are all involved with to the real people out there.
MICRO: In applied technology.
Martinez: In an applied way, yeah.
MICRO: That's the goal, anyway.
Martinez: And it's doing a fantastic job, I think.

Jack Martinez is senior scientist in the Office of Microelectronics Programs for NIST and a member of MICRO*'s editorial board. He was interviewed at a recent NIST-sponsored technical conference in Austin, TX, by* MICRO*'s senior editor, John Conroy.*

Advanced metrology may have expanded the different ways that we can analyze samples, yet it still seems to be less than what we need. Data-sampling techniques have been critical to overall metrology programs and have required advances in the device complexities that result from the successful implementation of clean technologies. Scanning probe microscopy advances have brought a new level of understanding and measurement capability to further complicate the issue.

When you evaluate the microcontamination and defect field, you find that you need a holistic approach. In order to reduce defectivity, a life-cycle analysis must be employed. Contamination begins in a generation stage that may result from some energetic reaction, either chemical, physical, plasma, electrical, or light induced. Once generated, the bad actor needs to be transported to the surface for it to be contaminated, and almost any force vector will cause it to go in that direction. Finally, it needs to deposit on the surface, and often the surface itself can be the source of the contaminant.

Interruption of this life cycle to the critical surface means a clean surface. If you can't stop this cycle, then you must move to the process of cleaning this defect. This action involves the reverse of this life cycle but for some reason, that process is more difficult. To make matters more complicated, this subsequent cleaning operation also leaves behind its own variety of contaminants that can cause additional problems.

A slightly masochistic attitude does help you in this endeavor. A change in mind-set is an effective approach, especially with the transition to quantum-level devices and atomic-layer deposition processes. Thermodynamics still apply on a macro level but probability statistics, quantum tunneling, and Poisson distributions are more likely to provide longer-term answers.

But to return to more practical matters, even with this advanced knowledge of contamination, I still have to go and do the dishes and evaluate different aspects of surface tension. M

Lawrence Larson, International Sematech

MICRO: This year is *MICRO*'s 20th anniversary. In your area of expertise, what do you foresee happening in 20 years' time?
Larson: Ah, the 20-year question. We're going to have such good fun between now and 20 years from now. Of course, I'll be retired, so who cares?
MICRO: Yeah, we are talking about 2023.
Larson: Yeah, 2023, that's a perfect time. I'll be a professor emeritus somewhere and do great. What's coming? Another really daunting idea. It's already showing up in the PIDS [process integration in device structures] area of the *ITRS*, and that's nonclassical devices. Somewhere toward the latter part of the next 20 years, [nonclassical devices] are going to become seriously real.
MICRO: Why is that?
Larson: There are a number of different ways to construct a transistor. We're doing standard planar transistors now, and . . .
MICRO: How about 3-D?
Larson: Yeah, 3-D transistors are one of them. All of these great [double-gate transistor] fin-FETS, vertical transistors, the Lucent column. That's the kind of stuff we're going to have to build 10, 15, 20 years from now in order to achieve the technical goals that are at the very end of the Roadmap.

Somewhere toward the latter part of the next 20 years nonclassical devices are going to become seriously real.

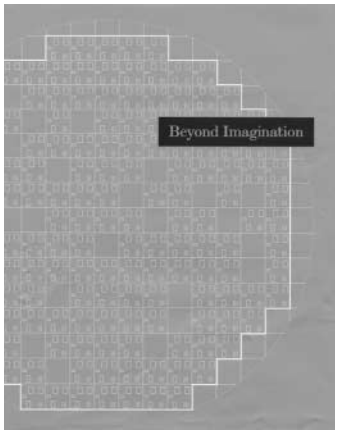
We've demonstrated stuff that's in the 5- to 10-year region with standard planar CMOS, and we're working hard on it. So that implies that yes, in 5 or 10 years we can make normal CMOS [devices], just with advanced characteristics. Well, what happens finally when those red-brick walls all line up, and we don't make whatever the critical one is? That's the next thing, these new device structures. They give you certain leverage to continue to scale what we can do.
MICRO: So these developments will still be along the lines of Moore's famous dictum?
Larson: Yeah, I would not think to predict that we're going to fall off the curve. That's a good way to be wrong. I used to do that.
MICRO: It's a good way to end the interview too.
Larson: I appreciate it. Tell me later if I've stuck my foot in it.

Lawrence Larson is associate director, front-end processes division, International Sematech. He was interviewed at the consortium by MICRO*'s senior editor, John Conroy.*

Logorama!

In recent years, *MICRO* has used logos to identify the focused series of technical articles featured in the magazine. Here are some of those iconographic emblems.

ENTER THE MICRO 20TH CONTEST AND WIN A COPY OF "BEYOND IMAGINATION"



As part of *MICRO*'s 20th anniversary celebration, we are awarding free copies of the Semiconductor Industry Association's excellent history of the semiconductor industry, *Beyond Imagination* (a $100 value), to the first 15 readers who respond correctly to the contest questions printed below. All of the answers can be found among the special 20th anniversary features in this issue. Just send an e-mail with your answers and address information to feedback@micromagazine.com. The lucky winners will be notified and sent a copy of the handsome coffee-table edition. The correct answers and winners will be posted on www.micromagazine.com at a later date.

Here are the questions:

1. What year did the magazine change its name to *MICRO*?
2. Who said, "It is not the strongest of the species to survive, nor the most intelligent, but rather the one most responsive to change"?
3. True or false: Contributing essayist Bruce Huling was working at the U.S. Forest Service when he took a job at Intel.
4. What was the name of the *Star Trek: The Next Generation* paperback inspired by the magazine?

Five Trends to Watch

IC power management

Microchips packed with more and more transistors run hotter and hotter. The number of microwatts per square centimeter of silicon will approach "the power of the sun in the next few years from an energy perspective," says Dean Freeman, a principal analyst with Gartner Dataquest. "We've got to find ways to manage that fully," emphasizes Bob Johnson, also a principal analyst with the San Jose–based market research firm. The use of strained-silicon technology is one potential solution. "They talk about the 'red-brick wall,'" Freeman notes. "This is the biggest red brick as we move forward."

Nanotechnology

Nanoscientists prefer to define their work, which takes place below the 100-nm range, "as 'building up' instead of scaling down," says Freeman. Molecular transistors and nanotubes "from a variety of different sources" are among the trends here. Freeman says nanotubes made of gallium nitride in particular have piqued his interest. "With respect to transistor density on silicon, [nanoscience] is as small as you can get. That's basically when you hit the wall on Moore's Law, looking at the number of transistors in a piece of square silicon."

Supercritical fluids

"It's very interesting to hear the hype on this," Freeman says of supercritical carbon dioxide cleaning. The nonflammable and nonpolluting CO_2 "is a wonderful material with respect to its ability to transport things in silicon, but the problem is you have to find a cosolvent that will be soluble in the liquid carbon dioxide. "Water is not soluble…so you have to, one, find something that's innocuous enough and, two, has enough power to dissolve the photoresist or residues left on the wafer and not leave any particulates." Freeman sees much potential for this trend. Supercritical fluids are used widely in purifying spices and in dry cleaning. "The question is getting it into a 'manufacturable' state in the semiconductor industry."

'Lights-out' fabs

Look-Ma-no-hands chip manufacturing will take off as 300-mm lines increase. "Finally, with 300-mm processing you are forced into fully automated wafer fabs," insists Gartner Dataquest's Johnson. The automation will encompass aspects such as scheduling, software integration, machine scheduling, maintenance management, and e-diagnostics "integrated and tied into the manufacturing execution system. You've got Applied Materials working on defect analysis and fault prediction kind of stuff. You'll see all that tied together…with no human intervention." Johnson forecasts the industry will see its first lights-out fabs in the next eight to 10 years.

Consolidations, joint ventures, consortia

As manufacturing and R&D costs soar, companies will "require creative ventures," says Johnson. Teaming up is "the only way all other than the very select few will be able to stay in the game."

Five Trends That Failed

X-ray lithography

This next-generation lithographic solution hasn't failed exactly, Bob Johnson acknowledges. It just hasn't lived up to its promise, insists the principal analyst with Gartner Dataquest of San Jose. How do you define "failure?" It's technology that was unveiled "with a lot of hoopla, but never made it," Johnson replies, "or supposedly offered long-term solutions that turned out not to be." Hailed as a "great savior" over the long term, x-ray lithography failed principally because optical lithography "just kept on going." In fact, the NGL space will likely "bifurcate," predicts Klaus Dieter-Rinnen, Gartner Dataquest's managing vice president. In other words, optical lithography will remain a trend "in the mainstream portion of manufacturing" while EUV and other initials in the NGL segment will find their niches. "Our judgment is that optical will stay with us for a very long time," Dieter-Rinnen says. In fact, optical lithography's longevity makes it a trend that bears watching, the analysts say.

Air-bearing tracks

"All marveled at wafers floating downstream, going 'bang' down the other end of the track, and settling into position," Johnson says. Unfortunately, "somebody didn't do their homework about particles and all sorts of other problems" caused by contamination.

High-pressure oxidation

In the early 1980s this oxidation technique promised to speed up the entire process, says Dean Freeman, a principal analyst with Gartner Dataquest. "Instead of 12 hours it would take 6 hours and you'd gain control over implantation and diffusion." Whoops. Instead, Freeman says, "Those suckers would implode." The technique became "a 100-torr bomb." The catastrophic effect made process engineers appreciate what they had. "They were happy to have 12 hours," Freeman laughs.

CVD aluminum

The use of CVD aluminum isn't really "one of the great failures," Freeman says. "It's something that people looked at from an R&D standpoint because of surface roughness" and other concerns. The success of PVD with tungsten and silicides left "really no compelling reason to go to CVD aluminum. Having said that, Applied Materials managed to have a great business [with the technique]. They sell a few systems to Samsung each year."

Selective tungsten

This technique was "the next Holy Grail," Freeman says. "You put tungsten right in the contact and grow it to the top of your contact. Then you'd be able to do metallization without any patterning or etch stop in between. It never got there. We spent about five years trying to make it happen." The analyst calls this stumble "probably one of the more expensive failures in the industry. I know each R&D fab had at least two to three tungsten tools because both Genus and Applied Materials thought they had it fixed."

MICRO—The Vegas Year

STAFF PHOTO

Having seen its share of bunnysuits, the *Microcontamination* crew was duly impressed in 1993 by the spangled wonder of the stage garb Elvis Presley wore for his first performance at the Las Vegas Hilton. The magazine's staff was there for the inaugural international symposium on mini-environments sponsored by IES (now IEST) during the 39th Annual Technical Meeting and Exposition. We thought the King's garment—encased in its own kind of controlled environment—suited the conference's theme quite well.

MICROflashback . . .10 years

'Vendors marketing a variety of semiconductor production tools could find their sales figures improving over the next two years as the People's Republic of China embarks on a spending spree. China is in the third year of a five-year plan during which it expects to spend $2 billion to buy a range of chip-manufacturing gear, including ion implanters, physical deposition tools, and dry etch equipment. The government's goal is to upgrade the country's microelectronics infrastructure, with the hope of breaking the submicron barrier by the year 2000.' *(from 'China opens its wallet for tools,' Industry News, January 1993 issue of* Microcontamination)