CHAPTER TWO
MEMC's Pioneering Years

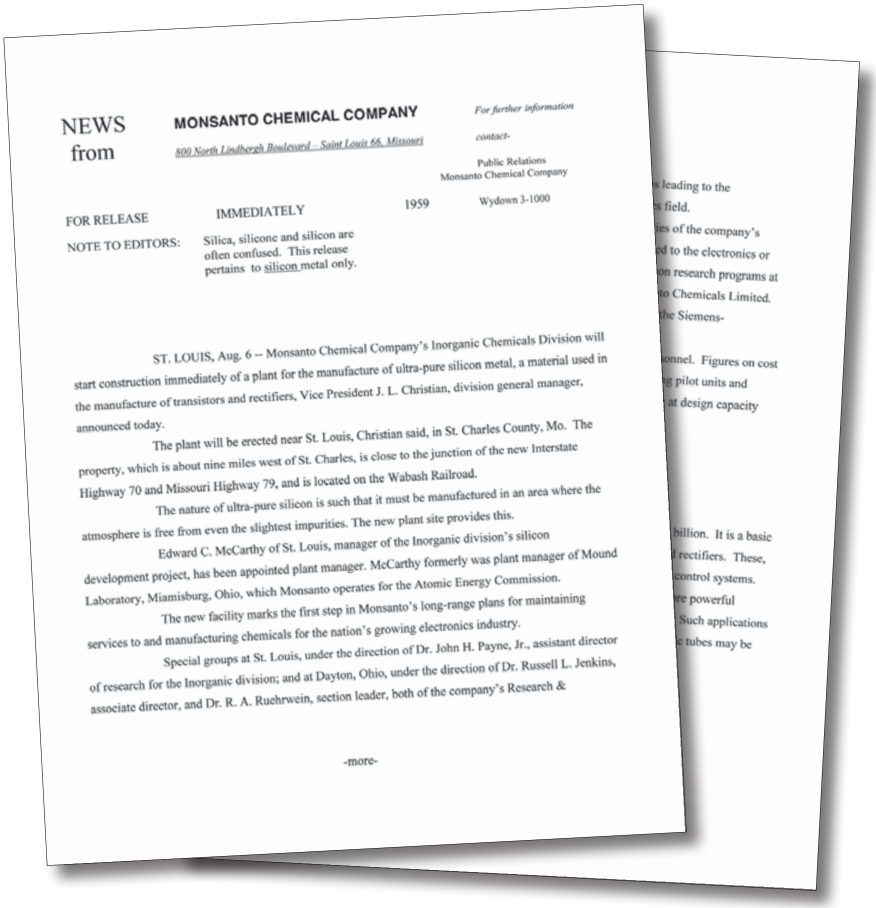
DID YOU KNOW?

The Czochralski process takes its name from Jan Czochralski, a Polish scientist who discovered this method for pulling crystal rods as early as 1916. It is said he discovered the Czochralski method in 1916 when he accidentally dipped his pen into a crucible of molten tin rather than his inkwell. He immediately pulled his pen out to discover that a thin thread of solidified metal was hanging from the nib. The nib was replaced by a capillary, and Czochralski verified that the crystallized metal was a single crystal.

ST. PETERS, MISSOURI

When Monsanto Chemical Company broke ground for the St. Peters plant in 1959, it was the newest addition to their Inorganic Chemicals Division. The plant was to manufacture "ultra-pure silicon metal, a material used in the manufacture of transistors and rectifiers," according to J. L. Christian, the division's general manager. This new venture was the culmination of several years of research conducted at Monsanto's two research labs (St. Louis and Dayton, Ohio) and represented Monsanto's first major step toward supplying products for the emerging electronics industry. St. Peters, approximately thirty miles west of St. Louis, Missouri, was a small rural village in 1959, and the clean air of the countryside was considered ideal for the extreme degree of cleanliness required for silicon wafer production.

The people who stood at the groundbreaking in St. Peters could not imagine the range and scope of the products that would one day be possible as a result of the work accomplished at this plant and at MEMC plants around the world. Few people can provide a better perspective than Stanley T. Myers, president and CEO of Semiconductor



NEWS from **MONSANTO CHEMICAL COMPANY**

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FOR RELEASE IMMEDIATELY 1959

NOTE TO EDITORS: Silica, silicone and silicon are often confused. This release pertains to silicon metal only.

ST. LOUIS, Aug. 6 -- Monsanto Chemical Company's Inorganic Chemicals Division will start construction immediately of a plant for the manufacture of ultra-pure silicon metal, a material used in the manufacture of transistors and rectifiers, Vice President J. L. Christian, division general manager, announced today.

The plant will be erected near St. Louis, Christian said, in St. Charles County, Mo. The property, which is about nine miles west of St. Charles, is close to the junction of the new Interstate Highway 70 and Missouri Highway 79, and is located on the Wabash Railroad.

The nature of ultra-pure silicon is such that it must be manufactured in an area where the atmosphere is free from even the slightest impurities. The new plant site provides this.

Edward C. McCarthy of St. Louis, manager of the Inorganic division's silicon development project, has been appointed plant manager. McCarthy formerly was plant manager of Mound Laboratory, Miamisburg, Ohio, which Monsanto operates for the Atomic Energy Commission.

The new facility marks the first step in Monsanto's long-range plans for maintaining services to and manufacturing chemicals for the nation's growing electronics industry.

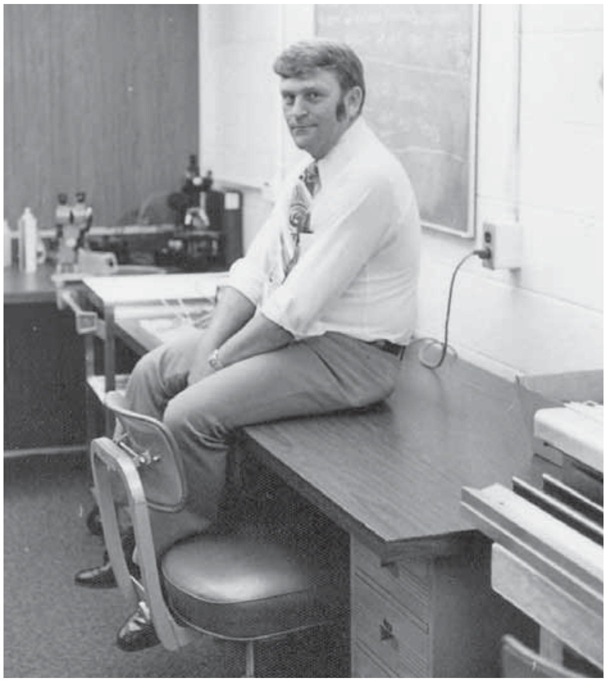
Special groups at St. Louis, under the direction of Dr. John H. Payne, Jr., assistant director of research for the Inorganic division; and at Dayton, Ohio, under the direction of Dr. Russell L. Jenkins, associate director, and Dr. R. A. Ruehrwein, section leader, both of the company's Research &

-more-

1959 press release.

Equipment and Materials International (SEMI), who worked at the St. Peters plant during its early years. In an interview he gave as part of SEMI's oral history project, Mr. Myers respectfully refers to the pioneering engineers at St. Peters as "a bunch of cowboys" and recalls that the first crystal-growing equipment was all "hand-grown," for the first ten years or so. Sounding just a little astonished at his own recollections, he said, "My first crystal-growing piece of equipment was a converted drill press, if you can imagine. The chamber was made up of a quartz inner tube, and then an outer tube was Pyrex. We circulated water between the quartz and the Pyrex to remove the heat, and the crystal was inside the quartz tube. You wouldn't do that today for anything because it would blow up on you if you got a crack in the glass. If the water hit the crystal, it wasn't a pretty picture." Luckily, he reports, though it did happen a few times, no one was injured. Compared to the extreme safety measures in place today at MEMC, it is difficult to imagine taking such risks. However, risk taking is a quality inherent in pioneers, and pioneers they were. MEMC produced its first three-quarter-inch (19mm) silicon wafer in February 1960.

Polysilicon was produced using the Siemens-Westinghouse process for which Monsanto had purchased a license. Dr. Henry W. Gutsche, who



Dr. Stanley T. Myers takes a well-deserved breather.

1959
August 6, J. L. Christian, vice president of Monsanto Chemical Company, issues a press releasing announcing construction of a new plant for the manufacture of ultra-pure silicon metal in St. Charles County, Missouri.

1961
Montecatini (Italian chemical company) undertakes the strategy to develop a pilot production of poly and single crystal at Merano. This Italian company would later become part of MEMC.

1962
Dr. Robert Walsh of MEMC pioneers the chemical mechanical polishing process.

The Czochralski (CZ) crystal-growing process is put into manufacturing at MEMC.

1965
Initially, Gordon Moore observes that transistor density is doubling every 12 months. It is later modified to 24 months. The term "Moore's law" was coined around 1970 by Caltech professor, VLSI pioneer, and entrepreneur Carver Mead.

Chemical mechanical polishing of silicon wafers is established at MEMC.

1966
Scientists at MEMC begin developing zero-dislocation crystal.

1968
The first computer with integrated circuits is manufactured.

joined the Monsanto Electronics Division in 1964, developed the process that helped make MEMC successful during his earlier years at Siemens.

FLOATING ZONE (FZ) CRYSTALS

The earliest crystals were grown using the Floating Zone (FZ) method and were used in the production of power rectifiers and transistors. Dr. Graham Fisher, current director of Intellectual Property for MEMC, described the process: "It started out with a polysilicon rod, and the process involved creating a molten zone with a moveable heater. The molten zone (floating zone or liquid zone) was thin and was held in place by surface tension. The floating zone could be moved slowly down the rod allowing single crystal silicon to grow behind it, thus converting polysilicon structure to single crystal. This could be repeated multiple times and the crystal would then be very pure, but it was very expensive to do. The crystals were quite small; the wafers were approximately half a millimeter thick, and you'd typically produce about twenty-five to thirty wafers to an inch."

By 1979, Monsanto St. Peters was supplying approximately 80 percent of the U.S. market for float-zoned silicon. The float zone process was phased out in the mid-1980s in favor of another process for producing crystal that had finally matured—the Czochralski (CZ) method.

THE CZOCHRALSKI METHOD


Early CZ crystal.

Growing crystals for wafers was job one at MEMC. However, the growing of crystals often meant more capacity, and more space was needed, so the plants would

Aerial view of St. Peters plant, 1960.

also have to grow. As early as 1962, the original plant building was expanded to provide for the Czochralski method of making single crystal rods. A Polish scientist named Jan Czochralski invented the technique in the early 1900s. Credited for discovering this method of pulling metallic monocrystals, he is still recognized as one of the founding fathers of today's semiconductor technology despite the fact that his research underwent considerable scrutiny in politically torn World War II Europe. In the late 1950s, the process was revisited as a possible method of producing silicon for transistor production and was widely adopted during the 1960s.

The Czochralski method made much larger diameter wafers possible even though it had one disadvantage. Oxygen from the crucible, in which the silicon was melted, contaminated

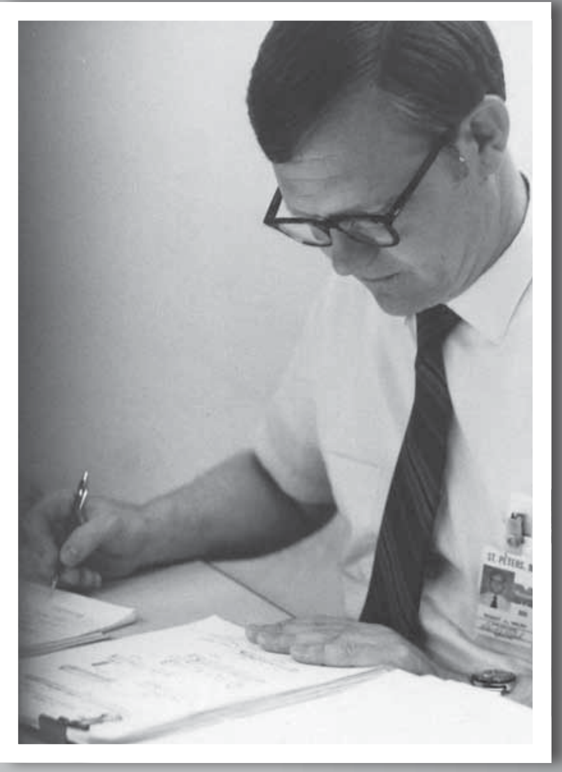
PIONEERS AND COWBOYS

When you consider how crude some of the early processes of silicon production appear compared to those of today, it's not surprising that words like "pioneer" and "cowboy" come to the minds of those who were there at the time. Some of what they experienced in those early years truly was heroic, and some of it has its comedic side. Consider, for instance, how the first wafers were shipped. While millions of dollars would eventually be spent developing packaging that kept the wafers clean and chip-free, Don Westhoff recalled that the original FZ polished wafers were shipped to a customer (probably GE) in a coin-wrapping package.

IN HIS OWN WORDS: DR. ROBERT WALSH ON CHEMICAL MECHANICAL POLISHING

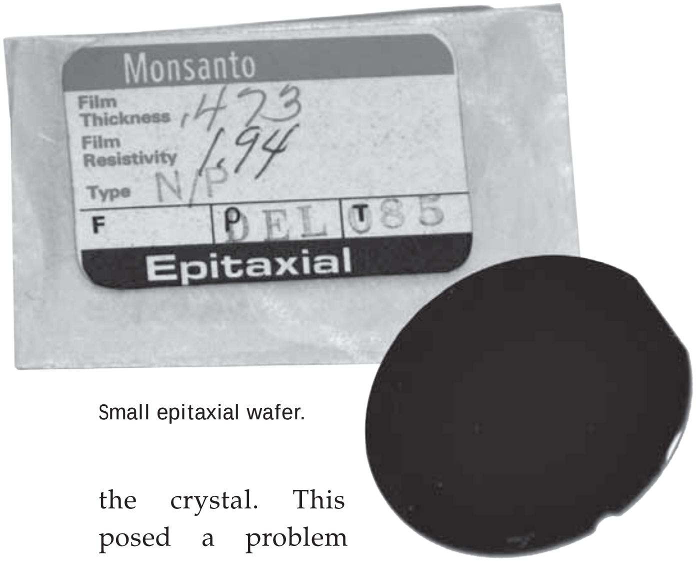
"When we started out, there was no integrated circuit industry. All the wafers that Monsanto was selling were just lapped wafers or etched wafers that went into devices—one wafer, one device. They were trying to make these multiple circuits on a wafer and the photographic process they used required very flat surfaces. You can't get that with etching alone. They needed the wafers to be nicely polished, and then epi grown on the surface. The normal polishing techniques used very fine abrasives but no matter how fine an abrasive you use, you damage the surface of the crystal. You couldn't see them in the substrate, but when they grew the layer, they'd show up. Growing an epi layer is a very serious test of how good a surface you have. We couldn't get satisfactory yields and surfaces with the old polishing method. We had to come up with something new.

"The early machines were optical polishing machines. What we found was (we were running with the finest aluminum oxide you could buy), that if you kept polishing with that same suspension of aluminum oxide, if you kept going, eventually you'd get much better surfaces on the wafers. At first we attributed it to wearing down the particle size even further until it was fine enough. Then I realized that what it *really* was, was that we were adding silicon to the polishing solution. These machines would fling the polishing solution off the edge and it would go down and be pumped back up so we were actually adding silicon to the polishing solution. So, thinking about all that, I thought, 'Monsanto makes a product that's a colloidal silicon.' So we tried it one day and it just worked like a charm. It was in water, too, but it was alkaline. We needed it to be alkaline to keep it in suspension. The minute we hit that, the epi yields went up. And as soon as we saw that all the scratches went away on the epi surface, we knew we had something. Basically, that polishing process is what made integrated circuits possible."

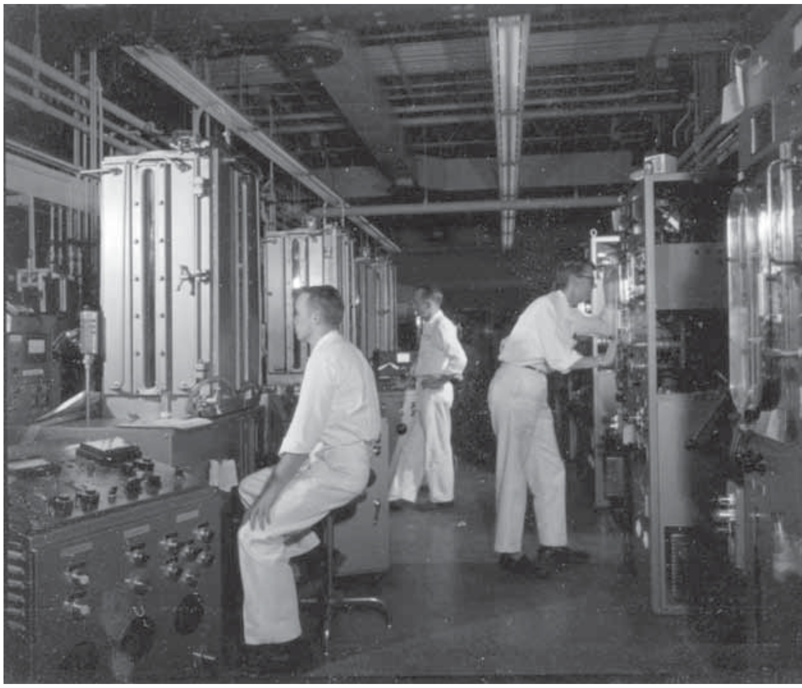


Dr. Robert Walsh developed the chemical-mechanical process for polishing wafers and received a North America SEMI Award for his work in 1986.

When asked how it felt to be such a well-known pioneer in the silicon wafer industry, Bob modestly replies, "Well, it's nice," though he received the SEMI Award of North America in 1986, an award established in 1979 "to recognize outstanding technical achievement and meritorious contribution" to the industry. He recalls those early years as "the fun years," saying, "It seemed like every day there was a new challenge to tackle."



Small epitaxial wafer.



Men operate BD-2 zone refiners, 1964.

the crystal. This posed a problem for wafers made for rectifiers. However, when the process of gettering was developed, the oxygen was used to attract impurities such as iron, copper, and nickel away from the surface of the wafer, making CZ-grown crystals preferable for semiconductors. Monsanto's work in this area in the 1980s led by Drs. Korb, Craven, and others was very significant. Later work done by Dr. Robert Falster and his team, trademarked in the mid-1990s as "Magic Denuded Zone," cemented MEMC's long history of controlling oxygen behavior in silicon.

MEMC "FIRSTS"

As MEMC marks its fiftieth year of silicon wafer production, the people of MEMC are extremely proud of the "Firsts" this company can claim. Though you will find these "Firsts" scattered throughout MEMC's history, some of the most significant discoveries are attributed to the people who pioneered silicon wafer production at St. Peters.

CHEMICAL MECHANICAL POLISHING

One of the most notable innovations during this time remains an industry standard—the process of chemical mechanical polishing developed by Dr. Robert Walsh.

Polishing, October 1970.

RECALLING DR. GUTSCHE

Dr. Robert Sandfort, who was named president and chief operating officer of MEMC Electronic Materials, Inc., in 1989, recalled a few colleagues during those pioneering years at St. Peters. "Monsanto had a first-class technical operation and was able to accommodate itself to all kinds of personalities just to get the expertise that came with it." Among those brilliant, standout personalities was a man named Dr. Henry Gutsche. Dr. Gutsche joined Siemens in 1954 as a research chemist at their laboratories in Pretzfeld, Germany. In 1956, Siemens received a patent for the work Dr. Gutsche did to produce the first semiconductor grade silicon which was 1000 ohm cm P-type uncompensated Si single crystal. In 1964, after a few years with Merck, Dr. Gutsche joined Monsanto Electronics Division in Research and Development and continued his pattern of outstanding achievements. Dr. Sandfort fondly recalled the slouch hat that Dr. Gutsche wore tilted off to one side and remembers him as being "quite a character—a very sentimental man," a trait that Dr. Sandfort attributes to the time Dr. Gutsche and his wife spent in a Nazi prison camp during World War II. In 1979, Dr. Gutsche received a SEMI award for his outstanding contributions to silicon wafer technology. Eccentric—perhaps; a brilliant pioneer—most certainly.

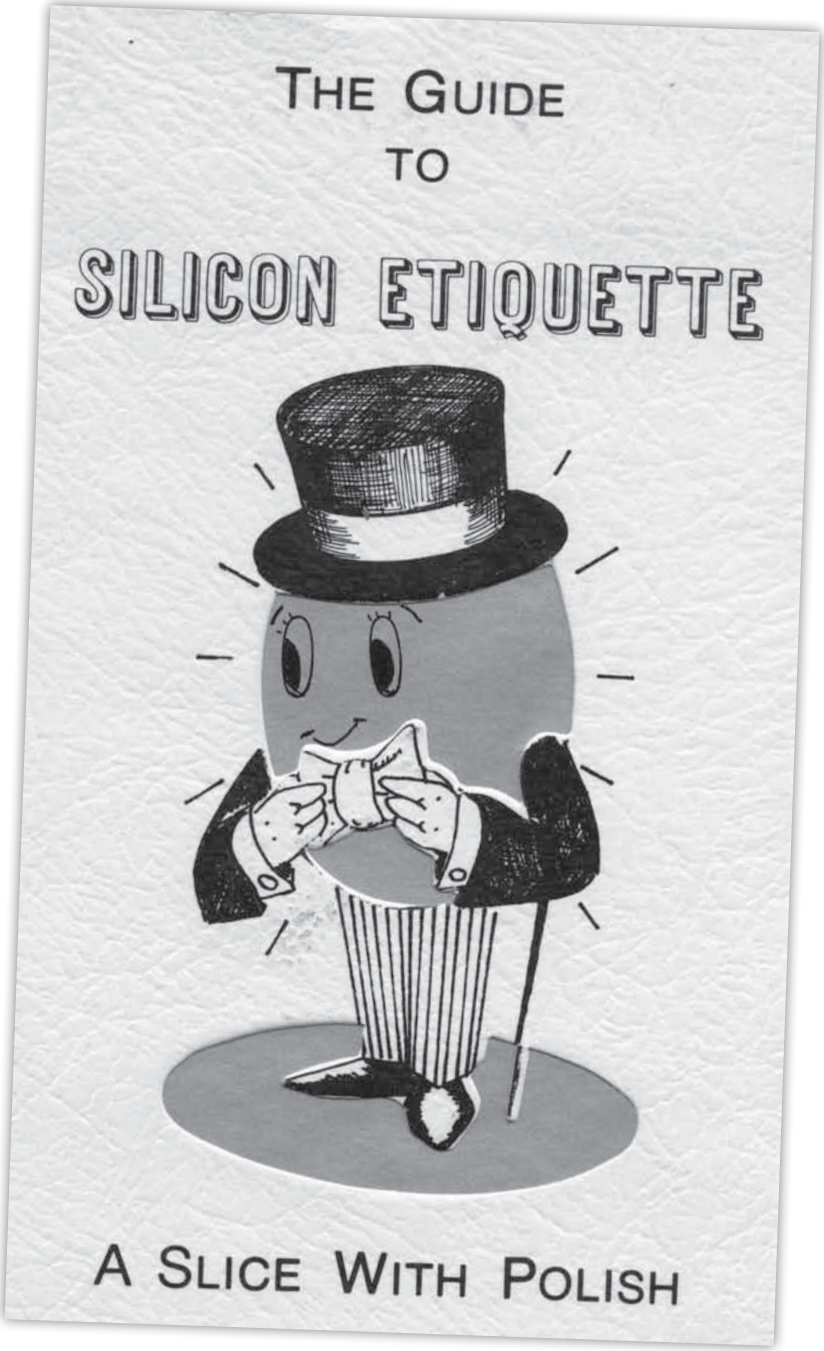
Dr. Henry Gutsche was responsible for setting up the Siemens process at St. Peters.

Up until 1965, Monsanto St. Peters produced and sold unpolished wafers for discrete devices like silicon-controlled rectifiers. With the development of integrated circuits, the device manufacturers required a more perfect wafer surface.

From 1960 to 1965, Dr. Robert Walsh worked at Monsanto's St. Louis research center developing a process to make epitaxial (epi) wafers after having spent several years in Dayton, Ohio, developing a process for single crystal gallium arsenide for III-V semiconductors. When he came to St. Peters, Dr. Walsh took on the task of devising a polishing process that would provide a more perfect wafer surface for growing epi layers.

At the time, wafers were 1" in diameter and 152 microns thick with a tolerance of 19 microns. The very fine abrasives used for polishing the wafers created scratches in the surface. Though they weren't visible in the substrate, they appeared once the epi layer was grown. The ultimate solution that Dr. Walsh devised was the chemical-mechanical method of polishing with colloidal silica in which the mechanical component was used to maintain the flatness of the wafer, and the chemical component kept the surface damage-free. The process of chemical-mechanical polishing is a key enabling factor for production of integrated circuits.

Up to this point, Dr. Walsh recalled, Monsanto hadn't shown any interest in selling polished wafers. "Everybody was trying to make perfect surfaces. When IBM got our wafers, they became very interested because they had their own internal material department and they couldn't make those perfect surfaces," he recalled. In fact, IBM managed to purchase the license for chemical-mechanical polishing, trading some patents with Monsanto as part of the deal. Within the next couple of years, sales of polished wafers greatly increased.



Silicon brochure.

EPITAXIAL LAYERS

By 1964, 1" wafers went into commercial production at St. Peters and shortly thereafter were replaced by 1.5" wafers. Then, in 1966, the first epi reactors were built and installed, giving MEMC the ability to produce a wafer with a superior surface. In epi, a thin layer of silicon is grown on top of the polished slice surface by heating it to a temperature of approximately 2000 degrees Fahrenheit (approximately 1100 Celsius) in a quartz chamber filled with hydrogen gas. Another gas containing silicon in combination with chlorine and hydrogen is introduced into the quartz chamber. The silicon layer grown in this manner is more perfect than the polished slice, having fewer defects and fewer impurities.

The ability to produce wafers with an epitaxial layer increased in significance as device manufacturers required increasingly cleaner and flatter surfaces. Dr. Graham Fisher described the development of epi as "a platform improvement" saying, "In about 1984, MEMC was the first to commercialize epitaxial layers for CMOS technology. In its

Distillation columns at the St. Peters expansion, 1970.

way, it was an enabling development to come up with that. People had been putting epitaxial layers on silicon for a while; what we did was commercialize it as a blanket layer." The epi layer and the developed MEMC methods gained industry acceptance in the early 1980s as led by Dr. Jon Rossi and his MEMC teammates.

ZERO-DISLOCATION CRYSTALS

In 1966, MEMC began developing zero-dislocation crystals when their best customer at the time, IBM, advised Dr. Horst Kramer and his team that ingots and wafers showing slip patterns would no longer be acceptable. Slip patterns are essentially stress patterns that arise during the process of cooling the crystal, and the term "dislocation" refers to atoms that are out of place in the crystal lattice. Impurities, especially metals, can collect along the structural defects, deteriorating the performance of the device.

Dr. Horst Kramer began his career in silicon crystal growth in 1959 at a company called Knapic Electro-Physics in Mountain View, California. By the mid-1960s, Dr. Kramer was given the task of eliminating slip from pulled crystals. Dr. Kramer's notes record the discovery:

The first experiments showed pretty much what we expected: an increase in pull rate resulted in a more concave interface; all other parameters remaining the same, different seed and crucible rotation combinations could change the interface from convex to concave. The next parameter was the melt level, i.e., the height of the crucible above the melt. In order to save silicon and time, I decided to skip growing the initial melt and start with only half the charge of silicon. The moment we were finished with the neck and started to increase the crystal diameter, we knew we had something special on our hands. The secondary growth lines in the taper were absolutely flat, and reflected light like a perfect mirror. The primary growth lines were strongly ridged and uniform, with no skips. In the body of the crystal, the primaries became flat, and the secondaries were visible only as shadowy lines. The bottom of the crystal, growing in the shape of an upside-down taper, also had pronounced flats, although here they occurred on the primaries. The flats sparkled like the faces of a diamond! We had just grown the first faceted silicon crystal!

Dr. Horst G. Kramer.

As Dr. Kramer noted in his report, his discovery of "Zero-Dislocation" crystal growth "made the growth of large-diameter crystals possible," saying that he did "not believe that even a 150mm diameter crystal having a low dislocation density could be grown." Further, he explained, "Dislocations are such large crystal defects that they could not be tolerated in today's [1966] device fabrication."

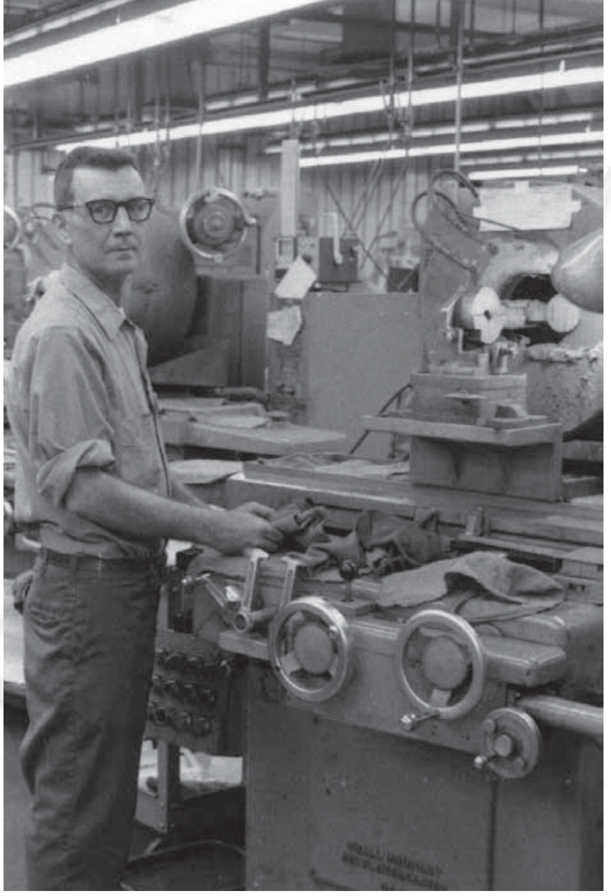
PUTTING DOWN ROOTS

Despite having garnered 80 percent of the market share by the time MEMC opened its doors,

Left is Dr. Bobby D. Stone, who invented St. Peters' zone-refining equipment, BD-1, BD-2, and BD-3.

business got off to a slow start. Nonetheless, the 1960s remained a period of steady growth for the company and laid the foundation for MEMC's future reputation as a leader in the industry. In sharp contrast to its rural setting and the cornfields that surrounded the St. Peters plant, researchers there were giving birth to a technological boom. Monsanto's roots in research and development helped create an environment that bred technological innovations, a trait that remains a hallmark of MEMC Electronic Materials, Inc., to this day.

Additional Sources:
www.semi.org
www.semi.org/en/About/Awards/index.htm
http://www.eoearth.org/article/Czochralski_Jan



Flattening and grinding wafers, 1970.

Wafer evaluation, early 1980s.

Left is Dr. Forrest "Frosty" Williams, resident expert in III-V's.

George McLeod was head of Monsanto's electronics business. In the early 1970s, he made the trail-breaking move to go offshore.

Aerial view of St. Peters plant, 1970.

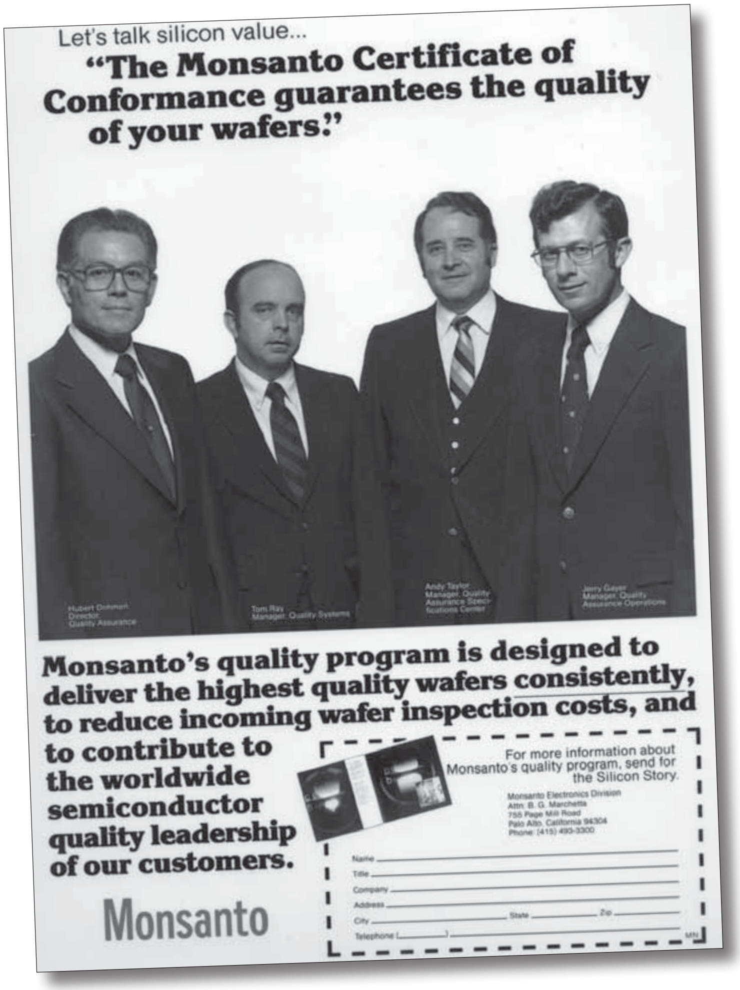
CHAPTER THREE
A Second Generation of Technology

By 1970, consumer electronics were becoming a growth industry, most visibly in entertainment-related products. The first home video games, played through television receivers, hit the market in 1972. In 1975, CB radios were all the rage along with the "Pong" home video game. The 1980s saw the first personal computers and videocassette recorders coming into the market, and by 1988, CDs were more popular than vinyl records among music enthusiasts.

The 1970s and 1980s were a time of tremendous growth in the silicon wafer industry interrupted by head-spinning highs and lows. In hindsight, the downturns that occurred in the mid-1970s and again in the mid-1980s did so for a variety of reasons. Over-production caused, in part, by optimistic chip manufacturers, competition from the emerging Japanese market, and, of course, the constant drive toward advancements in technology, all contributed to the turbulence of these two decades. Monsanto St. Peters responded to these challenges by focusing on technological excellence combined with constant quality improvement, a strategy that has brought the company to where it is today.

DID YOU KNOW?
A man named Ray Tomlinson developed the first electronic mail system in 1971. The first message of any substance was a message announcing the availability of network email and gave instructions to use the 'at' sign to separate the user's name from the host computer name.

In a study of the fifty-year history of the semiconductor silicon industry, Steven Walsh and others concluded that success in the silicon industry is determined by a company's ability to maintain the highest standards of industry-specific technological competence. He writes, "By 1980, materials companies had overtaken both captive and fabrication and assembly-based producers, and



Monsanto advertisement, featuring Hubert Dohmen, Tom Ray, Andy Taylor, and Jerry Gayer.

U.S.-based merchant chemical suppliers dominated the single crystal silicon as well as polysilicon markets. Monsanto was the leading silicon supplier in the world and dominated the worldwide single crystal silicon production with facilities in the U.S., Europe and Asia." According to Walsh, the silicon manufacturers most likely to succeed were those who excelled at both disruptive and evolutionary technology. Disruptive technologies were those innovations that remained proprietary and therefore captive for a period of time; evolutionary technologies referred to the constant incremental improvements on existing processes. Monsanto St. Peters, with its strong background in research and development, was ideally suited for both.

ICS AT THE WHEEL

By the early 1970s, integrated circuit technology was largely driving the silicon wafer business. Stanley Myers was Monsanto's Silicon Business Group director in 1972. He recalled, "In the early 1960s we knew [the development of the integrated circuit] would have a significant impact, not only on growing the crystal, but also polishing the wafer—slicing, polishing, and modifying the crystal and putting the epi layers on the wafer. All of these things became much more prominent as soon as IC

SEMI

Semiconductor Equipment and Materials Institute (SEMI) was formed in 1970 to provide visibility and support to the equipment and materials manufacturers that were the backbone of the burgeoning electronics industry. Having increased marketplace awareness through its expositions, SEMI worked to establish their standards program through which they continue to foster open markets, constructive competition, and cost containment throughout the semiconductor industry. In 1979, they established the SEMI award, given each year to individuals for outstanding technical achievements. When the industry reached global status in the mid-1980s, SEMI redefined itself to stay in step. The "I" in SEMI was changed from "Institute" to "International." SEMI offers its members technical conferences, educational events, and market data collection and analysis and advocates for the industry in public policy, environmental, health and safety issues, workforce development, and investor relations. With eleven offices in manufacturing regions around the world, SEMI serves the manufacturing supply chains for the microelectronic, display, and photovoltaic industries.

1970
The SEMI organization is founded by Bill Hugle, Fred Kulicke, and John Dannelly.

MEMC builds a plant in Kuala Lumpur, Malaysia.

1971
Electronic mail (E-mail) is invented.

The computer floppy disc is invented.

The microprocessor is invented. It is considered a computer on a chip.

1972
The word processor is invented.

1973
Three-inch wafers go into commercial production at the St. Peters plant.

1975
Four-inch wafers go into commercial production at the St. Peters plant.

MEMC opens Kuala Lumpur, Malaysia, plant.

1976
Montedison builds a second plant in Novara, Italy. This plant would later become merged with MEMC.

1979
MEMC is the first to commercially produce 125mm wafers.

MEMC is the first wafer supplier to control oxygen.

The inaugural SEMI Awards are held, with eleven individuals recognized for their achievement in advancing equipment and materials technology.

applications took hold and the market began to develop."

Industry experts agree that device manufacturers drove the change toward larger wafers, primarily as a means for cutting costs. Circuits were printed on the wafers using photolithography, and, simply put, the more devices per wafer, the lower the cost. But they also agree that the silicon wafer manufacturers, including MEMC, complied with the demands in part as a means of asserting their technological capabilities. MEMC's customers in the fast-moving electronics industry were putting more and more circuitry on smaller chip areas. To do that, they needed smaller line widths, which called for flatter, cleaner silicon wafers with improved physical and electrical characteristics.

The increased wafer diameters that resulted in lower costs for the device manufacturers came at quite a price for the silicon wafer suppliers, MEMC among them. Each increase in wafer diameter meant an outlay of capital for the equipment required to produce that larger wafer, as well as increased costs incurred to achieve the tighter specifications that were inherent in every diameter increase. As with their customers, cost cutting became a priority for the silicon wafer manufacturers.

MOVING OVERSEAS

The St. Peters plant was expanded in 1962, 1967, 1970, and again in 1974, by which time the plant had doubled from its original capacity. By the early 1970s, competition from the Japanese silicon manufacturers was getting everyone's attention. Stan Myers recalls that in the mid-1970s Japan's silicon production was "probably two generations behind the U.S.," but that "they were on a very, very rapid learning curve."

Kuala Lumpur plant in Malaysia.

MEMC's move toward international status was prompted by competition from the Japanese. The manufacturing site in Kuala Lumpur, Malaysia, built in 1970, was MEMC's first location in the Asian semiconductor market. The Kuala Lumpur site was chosen because of its proximity to the largely English-speaking population of Singapore and because Malaysia's free industrial trade zone provided attractive tax incentives for foreign investors. The most significant benefit, however, was the savings that resulted from lower costs on everything from the physical plant to supplies to labor. The St. Peters plant grew 2.25" crystals, shipped them to the Kuala Lumpur plant for slicing and polishing, and then on to customers.

III-VS

In the 1970s, the St. Peters plant started manufacturing the III-V compounds used to make light-emitting diodes, those red and green lights that first showed up in pocket calculators and digital wristwatches. This operation was eventually dismantled and sold to General Instruments in 1979.

Wafer lapping, 1975.

A CHANGING MARKET

In the April 23, 1990, issue of the *St. Louis Business Journal*, Roger McDaniel summed up the Asian influence on the silicon wafer market: "In 1980, half of the silicon sold in the world was consumed in the United States and only 25 percent was consumed in Japan. By 1985, the numbers were reversed as Japan gained dominance in the semiconductor memory market. Now the Koreans and Taiwanese are challenging the Japanese, and the United States and Europe are fighting to stay in the race."

The Milton Keynes plant in England opened operations in 1986. Etched wafers received from the United States were polished and cleaned for Monsanto's European customers, among them well-known names like Siemens, SGS, Thompson CSF, Philips, Telefunken, National Semiconductor, and Motorola. The site included a research and development center and an applications research lab.

SIZE MATTERS

MEMC's focus on providing customers with the cost-saving larger diameter wafers combined with the highest-quality features, led to their reputation as a leader in the silicon wafer industry during these turbulent years and beyond.

In 1975, Monsanto St. Peters was the first to commercially produce 4" (100mm) wafers and again the first to commercially produce 125mm wafers in 1979. The 150mm wafer was first produced in 1981, and at the time, a leading IC manufacturer projected a five-fold increase in chip yield when switching from 100mm to 150mm wafers. In addition, the flatness specification of the 150mm wafer varied less than two microns within a 20mm field of view. In 1984, MEMC partnered with IBM to produce the 200mm wafer.

EVOLVING TECHNOLOGY

In 1975, MEMC became the first wafer supplier to control oxygen in a growing crystal, a process that simply wasn't crucial in the early days. Dr. Graham Fisher explains the significance of the process: "Because the crucible is made of quartz, which is silicon dioxide, in the process of growing silicon, oxygen from the crucible can contaminate the crystal. In the early days, the level of oxygen wasn't very important. As time went on, customers started using more complex processes for making integrated circuits during which the wafer is heated and cooled multiple times. During the manufacture of integrated circuits, the successive heating and cooling causes the supersaturated oxygen atoms to precipitate in the form of small oxide clusters. The higher the oxygen concentration the higher the level of precipitation, so control of oxygen became an important development."

Ironically, solving one problem created another problem in its place because the low oxygen wafers were not as strong mechanically. Graham recalls

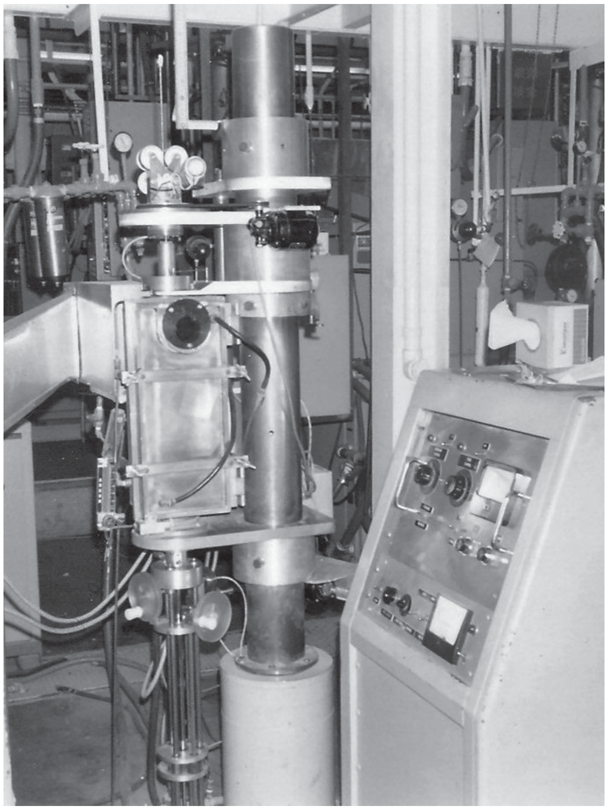
Monsanto's MEMC tradeshow booth.

the time spent in the early 1980s trying to get the right balance of oxygen and understanding how the wafer would behave in a customer's device line. "We were trying to get the oxygen at just the right level so when the customer would process the wafer on the fab line, the oxygen would start to precipitate but only to a certain degree and not near the wafer surface," he explains. "This way you maintain the mechanical strength, but the precipitates form in the bulk and not near the surface where the device is formed. An even bigger advantage of this distributed precipitation behavior is that the precipitates trap any unwanted metal impurities that might diffuse into the wafer in the bulk region away from the active device region at the surface. The technique is known as 'intrinsic gettering.'"

About the same time, MEMC added edge grinding to the basic wafer process. Starting with the 100mm wafers, MEMC began grinding the edges to a rounded profile. Before this step was added, the crisp, squared edge of the wafer was more susceptible to chipping. Ground edges meant less waste, and therefore reduced costs, for both MEMC and their customers.

100mm wafers and ingot.

Left to right: Dr. Dave Keune, Dr. Bob Craven, and Dr. Harold Korb in the Applications Research laboratory, 1975.



Zone refiner.

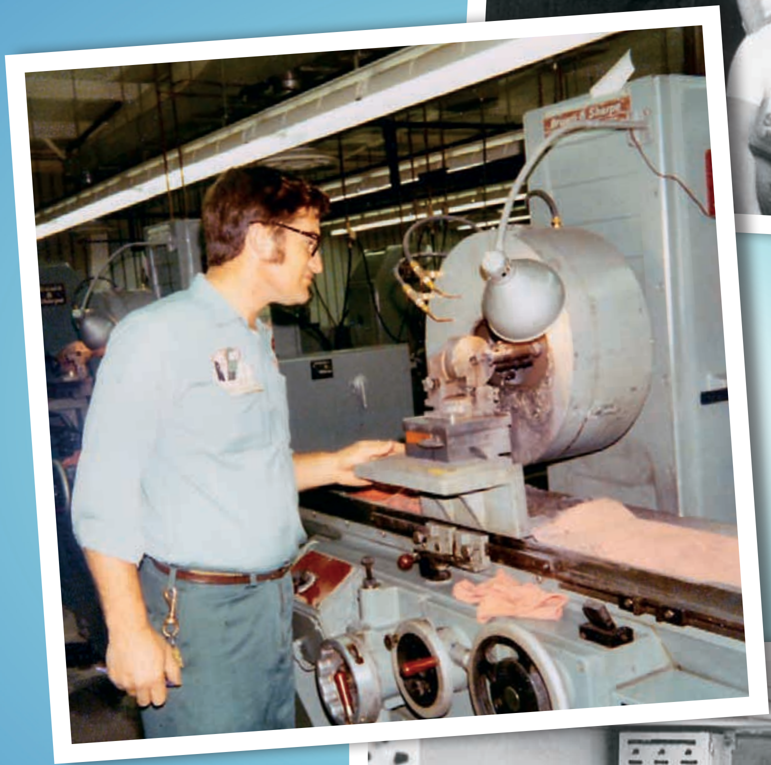
1ST

OZONATED DE-IONIZED WATER FOR WAFER CLEANING

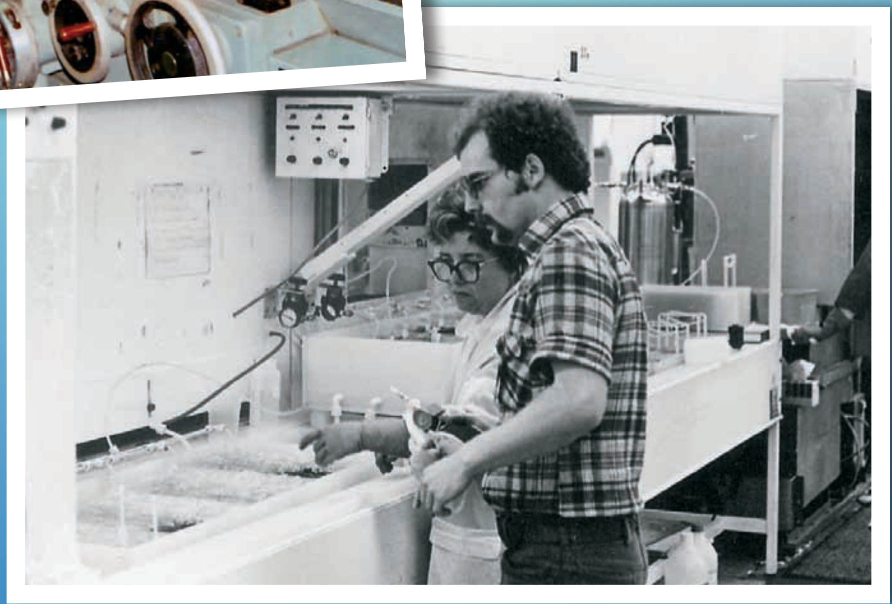
In 1983, MEMC achieved three very significant "firsts" in the area of silicon wafer cleaning with ozone. They were the first to use ozone in a silicon wafer cleaning process, first to use the combination of HF and ozone in a silicon wafer cleaning sequence, and the first to design and install cleaning equipment capable of performing an ozone cleaning process step for silicon wafers.

These innovations were driven by MEMC's recognition that the traditional cleaning chemistries, referred to as Standard Cleans 1 & 2, could not achieve the surface metals levels that were going to be required by the industry, given the purity of cleaning chemicals available. At that time, MEMC was simultaneously developing new methods for surface aluminum analysis that supported the work in cleaning. When surface metals, especially aluminum, were too high, the customer observed non-uniform oxide growth rates as a result.

Employees wear Clean Silicon Group t-shirts that were part of an advertising campaign to establish Monsanto's wafers among the cleanest on the market.



Ingot slicing.



Rack cleaner.

SPARTANBURG LEARNING DISCOVERY

In 1980, MEMC built a plant in Spartanburg, South Carolina, and began commercial production of 6″ (150mm) wafers. When production began, the plant had ten thousand square feet of space and forty-five employees. Combined with the Malaysia plant and expansions at St. Peters, Spartanburg brought MEMC's total manufacturing capacity to 330 million square inches per year, a 400 percent increase over that of 1978. John Kauffmann, currently senior vice president of Worldwide Sales, Customer Service, and Marketing, started his career with Monsanto at the Spartanburg plant and recalls that there was a worldwide learning process that took place between plants. "At our plant we made an etched wafer so it wasn't a completely finished product and we were shipping it to our plant in Japan. At that time, I was a technology leader and these wafers that we thought were really, really good opened up a learning exchange between how we did things in Spartanburg and how things were done in Japan." It was such an all-encompassing learning experience that it led to a task force, which John spearheaded, to help improve the quality of the product coming out of the United States.

Dr. Larry Shive, MEMC Senior Fellow, commented, "This work was far ahead of any previous or subsequent cleaning and was truly revolutionary." The process was developed by Wilbur Krusell and co-workers in 1982 and was first installed in St. Peters as the ozone rack cleaner in 1983. It was then copied at MEMC factories around the world. Ozone cleaning technology is now a key cleaning step in every wafer and device factory in the world, giving device manufacturers a predictable and uniform oxide growth rate.

Dr. Larry Shive.

MULTISTRATE SILICON WAFERS

A 1984 brochure entitled "Monsanto: Technology in Silicon" touts the advantages of their MultiStrate silicon wafers, a new class of multilayer products. By this time, device manufacturers were building thousands of ICs on a single chip, requiring improved circuit performance and yield. As a result, the electronic circuitry interacted more dynamically with the physical properties of the silicon. As the brochure said, "the cutting edge of semiconductor technology is now within the silicon."

MultiStrate silicon wafers were a new class of integrated silicon substrate products. The MultiStrate product line was a family of new epitaxial wafers for applications involving high-density silicon-gate CMOS and NMOS. Trademarked EpiStrate, this series of products

John Kauffmann, senior vice president of Worldwide Sales, Customer Service, and Marketing.

Inner diameter saw with back grinding capability, which reduced the amount of required lapping.

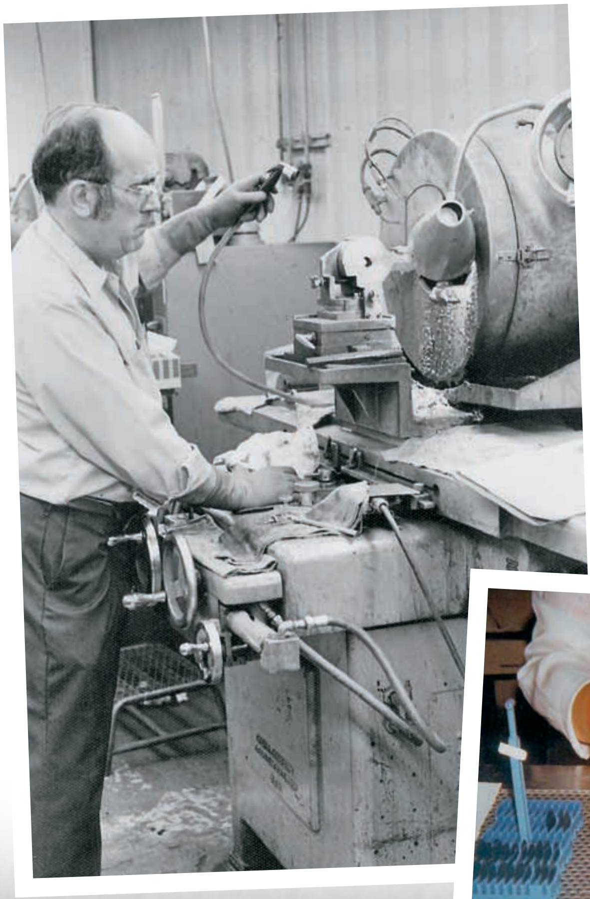
STC horizontal saw, late 1970s.

combined the superior flatness of the basic Czochralski wafer with an epitaxial layer grown on the polished surface. With the MultiStrate product line, substrate characteristics could be matched to the epitaxial process using a Monsanto proprietary technique for engineering the epitaxial/substrate interface to enhance large-scale circuit performance and yield.

Wafers are inserted into and extracted from a warming oven, slowly allowing them to heat or cool to avoid dislocations in the crystal lattice.

APPLICATION-SPECIFIC WAFERS

The introduction of the MultiStrate product line perhaps marked the beginning of the application-specific approach to increasing customer demands. In the late 1970s and early 1980s, Monsanto was instrumental in SEMI's efforts toward standardization of silicon wafer production. This was important, primarily because the more standardization Monsanto could incorporate into its manufacturing process, the easier and more cost effective it was to accommodate the customers' requests for specific features as device manufacturers required increasing customization.



Mortin Sentman slicing wafers.

Polishing two-inch wafers.

The highly competitive nature of the consumer electronics products industry created a cost consciousness that trickled down to the silicon wafer industry. The challenge for the wafer manufacturers was to accommodate the device manufacturers' demands for increased customization while simultaneously maintaining their own cost competitiveness. Perhaps the key to MEMC's survival and success was its good fortune at being birthed by a large company with the deep pockets required to stay on the cutting edge of a technology that everyone believed would someday pay off. When MEMC was featured in the September 1990 issue of the *St. Charles County Business Network*, the article read, "Since the early 1960s the giant silicon company has had to keep up with an extremely demanding and competitive market where [companies] who fail to keep up with advanced technology are out of the ballgame in short order." Nearly twenty years later, MEMC's vast technological experience and highly competitive business model has, in turn, made it extremely difficult for new competitors to enter the market.

Additional sources:
"The semiconductor silicon industry roadmap: Epochs drive by the dynamics between disruptive technologies and core competencies," Steven T. Walsh et al., Elsevier, Inc., 2003.
www.semi.org
http://openmap.bbn.com/~tomlinso/ray/firstemailframe.html

MEMC's plant in Spartanburg, South Carolina, was built in 1979–80.