4.8 OTHER EQUIPMENT

Page

4.8.1 Current Industry Characteristics

4.8 OTHER EQUIPMENT

- **This Other Equipment section includes equipment not easily classified in the previous wafer fabrication equipment sections.**
- **The four segments that make up this section are wafer manufacturing equipment, transport & transfer equipment, reprocessors & recirculators and gas scrubbers.**

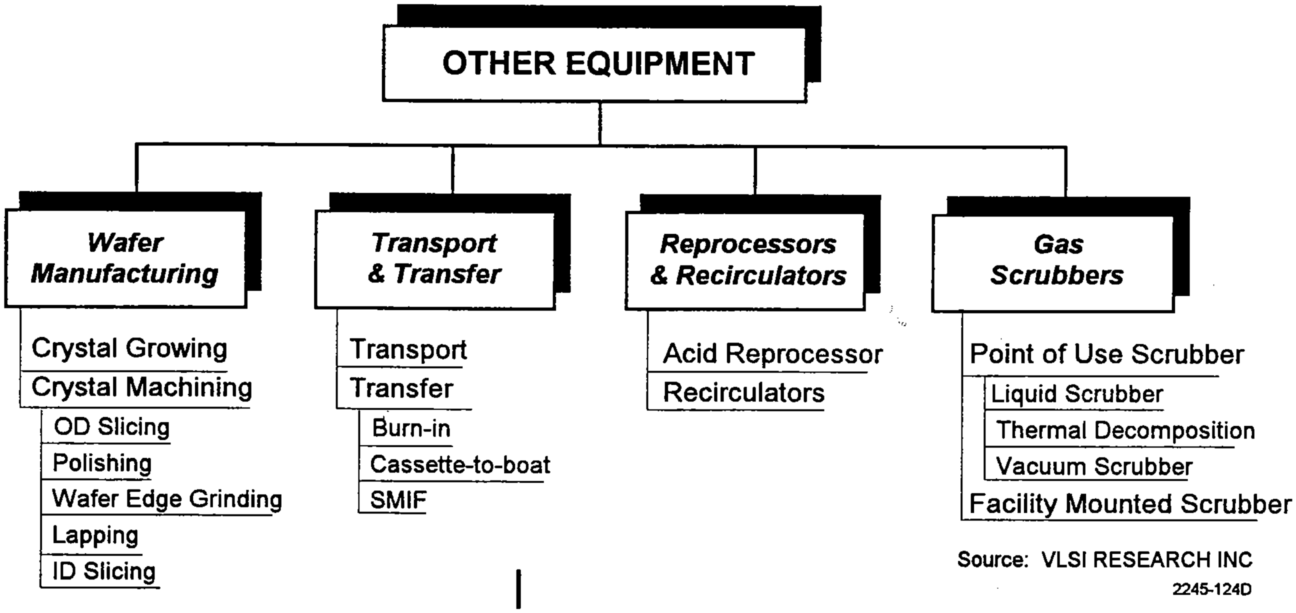
Section 4.8 covers that equipment which does not fit in the other wafer fabrication equipment categories. VLSI Research now includes two new segments under the Other Equipment classification. These segments are Reprocessors & Recirculators and Gas Scrubbers. There are now four major segments under the Other Equipment category. Besides the two listed above, the Other Equipment segment also contains Wafer Manufacturing and Transport & Transfer systems.

Wafer manufacturing equipment consists of crystal growing furnaces and crystal machining activities. These activities are outer diameter (OD) slicing, polishing, wafer edge grinding, lapping and inside diameter (ID) slicing. Transport & transfer equipment is made up of robotic equipment, burn-in transfer, cassette-to-boat transfer and SMIF equipment. Reprocessors & recirculators include acid reprocessors and chemical recirculators. Gas scrubbers consist of point-of-use scrubbers and facility mounted scrubbers. Point-of-use scrubbers include liquid scrubbers, thermal decomposition and vacuum scrubbers (see presentation 4.8.0-1).

Wafer Manufacturing

Wafer manufacturing is the starting point for wafer fabrication. It is the process which converts raw high-purity silicon into

Presentation 4.8.0-1



Source: VLSI RESEARCH INC

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thin single-crystal wafer slices. Semiconductor devices are fabricated on these wafers. Wafer manufacturing equipment consists of all equipment indigenous to the making of whole, unprocessed, wafer slices prior to 'wafer processing'.

The market is divided into two market segments, crystal growing furnaces and crystal machining equipment. Each segment has one or more subsegments as well. Crystal growing is the process of converting chunks of polycrystalline silicon into a correctly oriented large single crystal with the proper amount of dopant. Crystal machining equipment consists of equipment used to cut and process the single-crystal ingots into thin production-worthy wafers.

Transport and Transfer Equipment

Transport and transfer equipment developed as a result of automating the IC production. A transport system is any mechanism that moves grouped wafers between equipment or between areas. For example some of the transport systems include wafer cassette transporters, WIP stockers and tunnel transport systems.

Transfer equipment enables the transfer of wafers or integrated circuits (ICs) from one type of carrier to another. Transfer equipment includes burn-in transfer, cassette-to-boat transfer and SMIF equipment. Burn-in transfer systems load and unload ICs into or from burn-in boards (BIB). To load the BIB, a pick-and-place vacuum automatically inserts ICs into empty BIB sockets. For unloading the BIB, the pick-and-place vacuum automatically takes out the ICs from the BIB sockets and transfers them elsewhere. Cassette-to-boat transfer equipment transfers wafers from a cassette to a quartz boat automatically. SMIF stands for Standard Mechanical Interface. SMIF equipment consists essentially of a small, dust-proof box with a special trap door used to move a cassette of silicon wafers to and from the SMIF-pod and processing equipment.

Reprocessors and Recirculators

Reprocessors are systems that recycle and re-purify previously used chemicals. The re-purified chemicals can then be used again in the wafer fab. There are two types of reprocessors, sulfuric acid and hydrofluoric acid reprocessors. Recirculators are systems that recirculate and filter chemicals used during wet processing.

Gas Scrubbers

Gas scrubbers used by semiconductor equipment scrub gases of toxic, corrosive or inflammable gases. The function of gas scrubbers is to convert gaseous pollutants into safer, less hazardous gases, liquids, solutions or solids. There are two types of gas scrubbers: point of use (source scrubbers) and facility mounted scrubbers. Source scrubbers are located near the process tool exhaust. Source scrubbers are dedicated to one process tool. Facility mounted scrubbers are centrally located, usually on the roof of the fab. These scrubbers accommodate many process tools. Point of use scrubbers include liquid scrubbers, thermal decomposition and vacuum scrubbers. Liquid and thermal decomposition scrubbers remove reactive gases found in atmospheric pressure exhausts of gas emitting equipment. Vacuum scrubbers eliminate reactive gases in the exhausts of CVD, PECVD and etch reactors before the gases reach the vacuum pump.

4.8.1 CURRENT INDUSTRY CHARACTERISTICS

(Continues on next page)

4.8.1 CURRENT INDUSTRY CHARACTERISTICS

4.8.1 CURRENT INDUSTRY CHARACTERISTICS

- **Chemical mechanical polishing has become a critical factor as linewidths reach sub-half microns.**
- **As cleanliness of the wafer becomes more critical, SMIF boxes have become more popular.**

Chemical-mechanical polishing is a rapidly emerging industry. As integrated circuit geometries shrink and circuits become more compact, multilevel layering of metal and dielectric films becomes necessary. Unfortunately, the topography created by the first film levels often make upper film levels uneven, especially when three or more layers are applied. Current day limits of process equipment technology are taxed by multilayer metal CMOS structures. Lithography, etch and deposition fight each other as device topology variations grow. Surface planarity deteriorates rapidly once an oxide covers the first metal. Attempts to planarize oxides with an etchback have met with only limited success. A flat surface is critical for circuit performance. To compensate for this topography, chemical mechanical polishing (CMP) is used. To date, CMP is the most effective means of achieving globally uniform planar wafer surfaces for three or more film layers. CMP involves the use of mechanical pad polishing systems with a polishing slurry. Planarization of the metal and dielectric layers in these advanced devices is essential because the depth-of-field of lithographic equipment is not good enough to compensate for even small bumps, rises, or depressions on the wafer. Lithography has hard limits in its depth-of-focus. Current generation equipment can achieve submicron levels. So, surface flatness conditions are critical to achieving higher yields and device speeds. To make sufficiently fine lines, the beam needs a completely flat surface. To date, CMP is the best way to achieve flat wafers.

Another current industry characteristic is the growing acceptance of mini-environments such as SMIF systems. With cleanrooms costing over $100M, and SMIF systems averaging $55K, those companies who did not have $100M will choose to spend money on these systems. SMIF users have found that SMIF not only met the cleanliness standards of advanced cleanrooms, it also reduced costs. SMIF can convert a class 100 fab to a class sub-1 fab for the cost of a SMIF system. SMIF reduces power costs and gowning costs. Labor productivity is higher because workers need not waste time gowning and they are more comfortable. Equipment productivity is higher because there is no inter-tool contamination due to maintenance, upgrades or factory reconfiguration.

SMIF offers many other advantages. SMIF reduces daily variations in contamination and eliminates contamination spikes. This increases overall yield and week-to-week yields are more consistent. SMIF gives better control over humidity. This results in better CD control in lithography, which ultimately results in a better speed sort distribution. Some fabs have noted reduced cycle-times with SMIF. Using SMIF also decreases floorspace even though SMIF does require its own floorspace. This is because space for tables that sit next to equipment for loading and unloading cassettes in blue boxes are not needed.

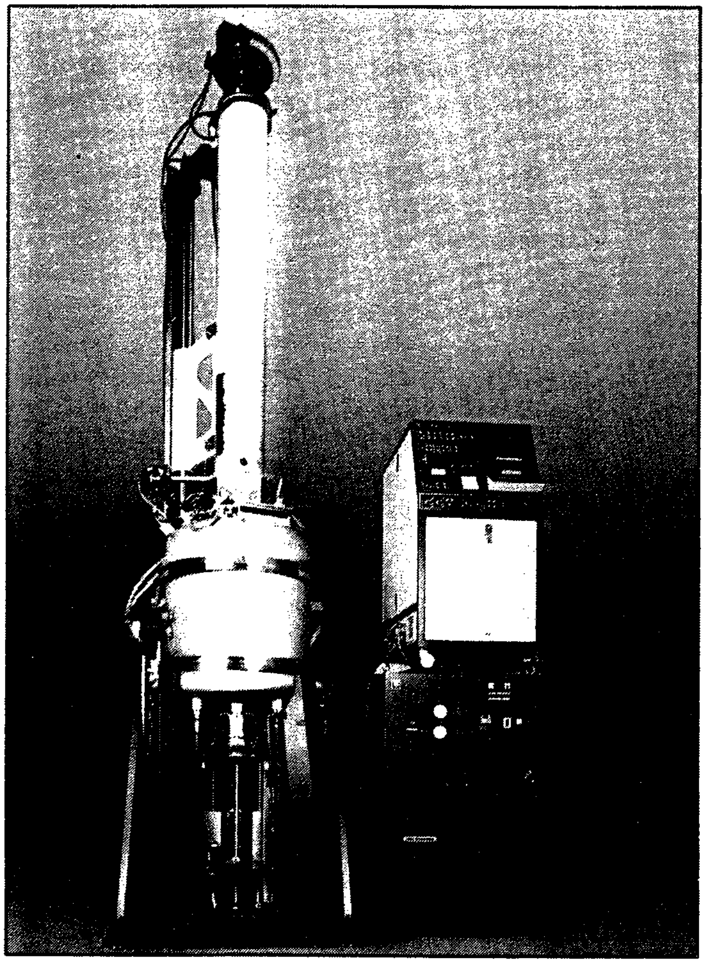
4.8.1.1 Development of the Other Equipment

This section explains the development of the wafer manufacturing, transport & transfer, reprocessors & recirculators and gas scrubbers within the semiconductor industry.

4.8.1.1.1 Development of the Wafer Manufacturing Industry

The early history for modern wafer manufacturing can be traced to 1947 when John Bardeen, Walter Brattain and William Shockley observed transistor action through point contacts applied to a single-crystal of germanium. An intense study then followed on single-crystal growth methodologies for both germanium and silicon. Silicon produced superior results over germanium and soon gained favor over germanium as the universal semiconductor material. The process for silicon production began in the early 1950's at AT&T. The actual processing techniques and equipment used today differ very little from those used 30 years ago. Subsequent advancements in the crystal growing technique for silicon resulted in equipment modifications. The Czochralski (CZ) crystal growing technique became the favored technique. This was because it can withstand thermal stress and provides an internal gettering mechanism that protects devices from potential impurities. However, when CZ crystals were marketed in the 1960s, they failed to provide sufficient performance in devices. Therefore, Siemens turned its effort to the Float Zone (FZ) method. The FZ method gained popularity in the 1960s for discrete devices. However, in the 1970s when integrated circuit (IC) development was increasing, the CZ method proved to be the less expensive of the two.

In the 1980s, two issues that determined the direction of the crystal growing furnace market was automation and increasingly larger wafer diameters. The main reason wafer manufacturers demanded automation in crystal growing furnaces had to do with repeatability. Repeatability in wafer production improves quality and consistency of the crystal. For example, automated control of the ingot diameter could reduce grinding losses. As a result, automatic features offered by some equipment companies included automatic meltdown, necking, shouldering, body growth, tail-off amd furnace shutdown. Today, crystal puller furnaces are fully automated (see presentation 4.8.1.1.1-1). Additionally, the sheer size of these ingots dictate automated equipment. As wafer sizes increased from 3" to 6" in the 1980s, an economic advantage was realized by wafer manufacturers. Since surface area increased with wafer size, fewer wafers were needed to be grown to produce the same quantity of devices. Therefore, as wafer sizes increased, fewer crystal growing furnaces were required to produce still fewer ingots. Fortunately, increases in wafer size also generates demand for newer advanced equipment. Increasing wafer diameter requires increases in crucible diameters as well as in charge sizes to accommodate the larger ingots. Moreover, quality issues such as uniformity of resistivity, oxygen and carbon throughout a single wafer becomes more important. This in turn requires more control and



Source: Ferrofluidics
2245-130

Presentation 4.8.1.1.1-1

Fully Automatic Silicon Crystal Growing System (CZ-150)

precision from equipment. In the 1990s, wafer sizes continue to increase from 6" to 12". Therefore, increasing wafer sizes is a continual factor in crystal growing furnaces.

During the eighties, the wafer manufacturing market grew from a point doubling its size annually to falling by almost half of its peak amount (see presentation 4.8.1.1.1-2). This decline was due to industry coalescence, higher processing yields, and fewer wafers being processed. However, with the rapid emergence of CMP in the nineties, by the end of the decade wafer manufacturing equipment will surpass its peak value reached in the eighties.

Chemical Mechanical Polishing

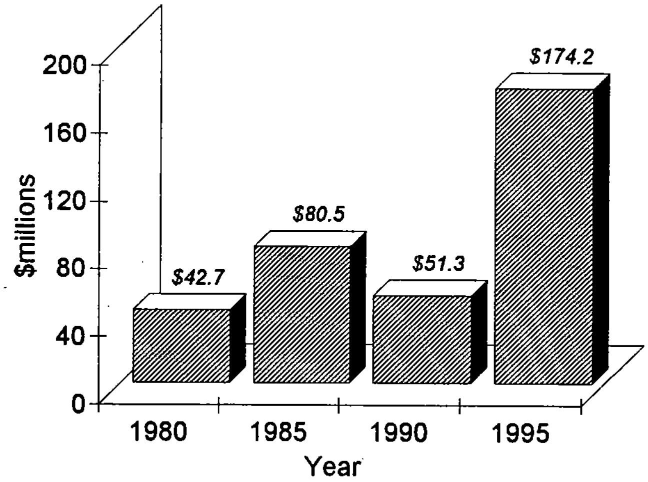
One of the hottest issues to emerge has been the development of chemical mechanical polishing (CMP). This is because chemical mechanical polishing graduated from only being used during the wafer manufacturing stage to planarizing interlevel layers. Commercial CMP systems used for inter-layer planarization were introduced in the late eighties. CMP is little more than the application of an old polishing method developed in the 1960s/1970s. Its simplicity is what is so attractive.

During the 1960s and 1970s, the development of a flat, clean and polished wafer surface was looked at closely because of the importance of these characteristics on semiconductor product performance. As a result, important changes in wafer-polishing methods occurred. One method resulted in a polished wafer surface with significantly reduced residual polishing damage. This development was called chemical-mechanical polishing process.

CMP origins date back to IBM research in the late seventies. IBM was the first company to do extensive research into the CMP process and incorporate it into the semiconductor manufacturing line. The process was developed to solve intractable etch and deposition problems with three and four level metal interconnect technology they were working on at the time. IBM found that CMP allowed the first three metals

Presentation 4.8.1.1.1-2

Wafer Manufacturing Market Between 1980 and 1995
($millions)



Source: VLSI RESEARCH INC
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levels to be fabricated at nearly the same wire pitch. IBM's chemical-mechanical polishing tool consists of a polishing pad attached to a circular polishing table, and a carrier to hold the wafer against the pad. Both the table and carrier rotate in the same direction as the wafer is pressed down against the pad and a polishing slurry flows onto the pad. IBM had to modify the current polishing equipment to accommodate planarizing interlevel layers.

In conventional polishing equipment, wafers are attached to the carrier with wax. The wafer back is bonded to the carrier with a thin layer of hot wax strong enough to resist force during polishing. Cleanliness and care were needed to assure good polishing results because contamination between the wafer back and the wax can show through as nonuniform polishing. However this method was undesirable for device planarization since the wafer is not globally flat because of film stress.

Effective planarization requires that the polishing follows the front rather than the back contour of the wafer. IBM achieved this by mounting an insert pad on the carrier face through a microscopic open pore structure in the surface layer. When the wafer's back is pressed against the wetted film, the wafer is held by surface tension and the resilience of the cushioning film allows the wafer front to follow the polishing pad. The force between the film and wafer is too weak to resist shear forces during polishing and the wafer edge must be caged by a retaining ring. The wafer is advantageously allowed to slip and rotate within the cage to average the high and low spots of the insert pad, which cannot be made sufficiently flat.

IBM found that non-uniformity, rounding, dishing and erosion were all problems that had to be solved. Non-uniformity refers to polish-rate variation, which can occur across a wafer, a lot, or lot to lot. Rounding is the ineffective planarization of wide features and is most often seen in oxide polishing. Dishing denotes the thinning of the fill material in the center of a wide inlaid trench. Erosion occurs when the polishing process can not be completely stopped. The choice of a polish pad has the most influence on rounding and dishing. Hard, incompressible pads are the most effective. Erosion can best be controlled by the materials set and the slurry chemistry.

The secret to IBM's success with CMP was in the slurry, which continues to be a closely guarded secret to this day. The slurry is a mixture of polishing particles and liquids that make-up what is essentially a liquified polishing compound. The idea for CMP had actually been kicked around by several companies as early as 1984, but it was always dismissed for fear of contamination. This is because polishing uses particles to grind away at the surface of the wafer. This is both dirty and stressful to the wafer.

By 1988, CMP was being researched independently by NEC and IBM. They used it to solve yield problems encountered with trench capacitors and trench isolation. Both companies were up against insurmountable problems with trenches and tried CMP for lack of any other alternative. What they found was that it is the best way to get wafers flat. By that time both NEC and IBM were also working on CMP for global planarization. They viewed it as the best potential enabler for multi-level metals. Polishing's success with trench capacitors led to further experimentation as an oxide planarization solution for multilayer metal structures. Mitsubishi/Cybeq was the only company marketing modified polishers designed for global planarization at the time. Because of the Japanese lead in equipment, and the lack of any American supplier, SEMATECH saw CMP as a critical issue and launched a program with Westech. Meanwhile, the Japanese lost interest. Trenching was replaced with stacked capacitators and recessed LOCOS. Early efforts to use CMP to planarize blanket tungsten were largely unsuccessful due to cost and yield problems. Eventually the yield problems were mastered. Moreover, it was not really needed for multi-level metallization yet. It becomes essential once four levels of metals are reached, but at the time most of the world was still using two level metal. Consequently, the market for CMP equipment slowed to a crawl. Therefore, Mitsubishi/Cybeq de-emphasized it.

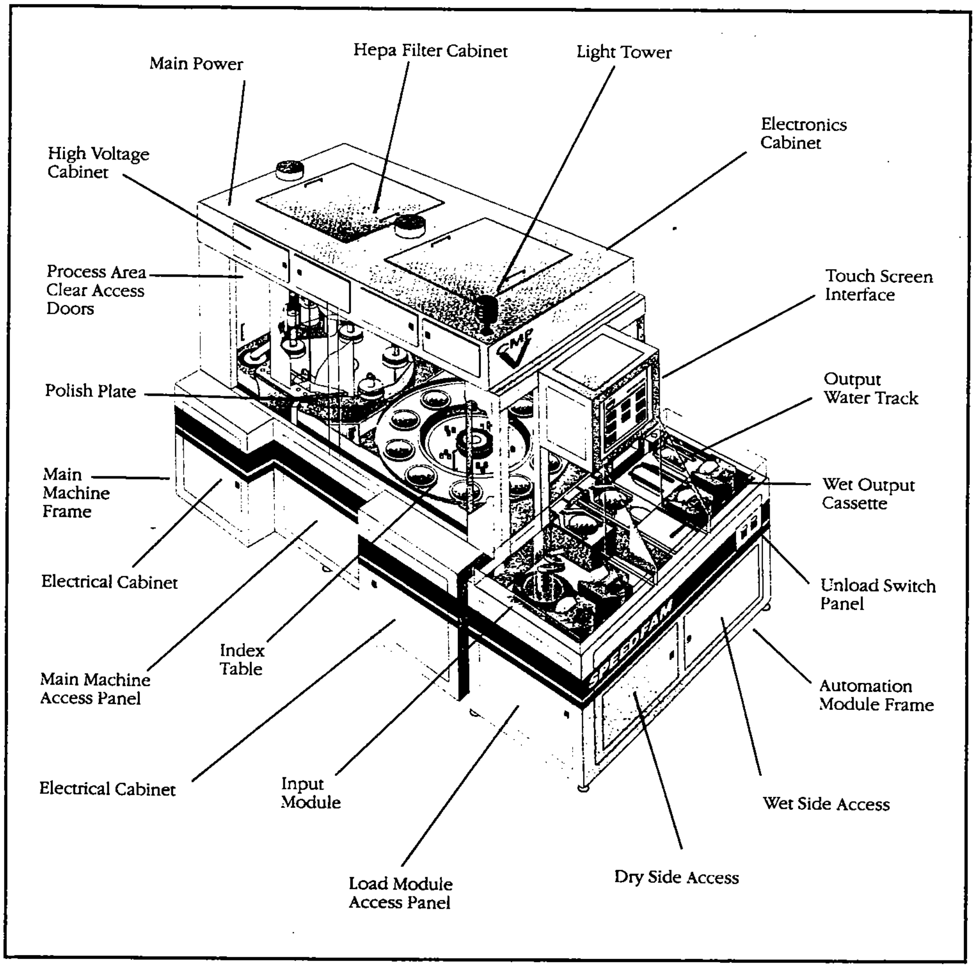
However, some of the other polishing equipment vendors considered CMP to be a lucrative market. Since a CMP tool is basically a modified version of a polishing tool, it was easy for these vendor to enter the market with a CMP system. They were Westech, Speedfam, Fujikoshi, Strausbaugh and Pressi. In 1990/91, with help from Sematech and AT&T, Westech was able to successfully make a tool with the ability to measure the thickness of the layer that is being planarized (end-point detection). With this feature, Westech soon gained the majority of the market share. However, due to capital and other problems, Westech was bought by IPEC in 1993. CMP re-emerged in 1993, first as a hot issue when Westech was put up for sale and then when Intel presented SEM's of its new Pentium processor showing heavy use of CMP. (see presentation 4.8.1.1.1-3).

CMP has several distinct advantages. It eases step coverage problems, resulting in higher sputtering yields. D.O.F. limits can be narrowed, resulting in tighter CD's. Resist uniformity is better, resulting in better CD control. It eliminates the additive effect of topography variation as layers are stacked. This results in higher yields. It can be used for both metals and dielectrics and it is simple and reliable. It does not require any vacuum pumps, gas panels, scrubbers or RF generators. Polishing compounds are water soluble and can be easily cleaned. Finally, it is the best way to get wafers flat.

Disadvantages that CMP poses involves contamination from particulates generated from the polishing pads and slurries used in the process. Wafer breakage is another issue. One pass through a polishing machine places the wafer at some risk, and CMP often means multiple polishing runs. For some users, the disadvantage of CMP planarization is limited productivity. Some polishers accept only one or two wafers, so throughput is low and cost per wafer high, particularly for processes that require polishing times of up to one hour.

4.8.1.1.2 Development of the Transport & Transfer Equipment Industry

Transport and transfer equipment used in the manufacture of semiconductors is a relatively small market. It first appeared in the early eighties as a result of the trend to



Source: SpeedFam
2245-132

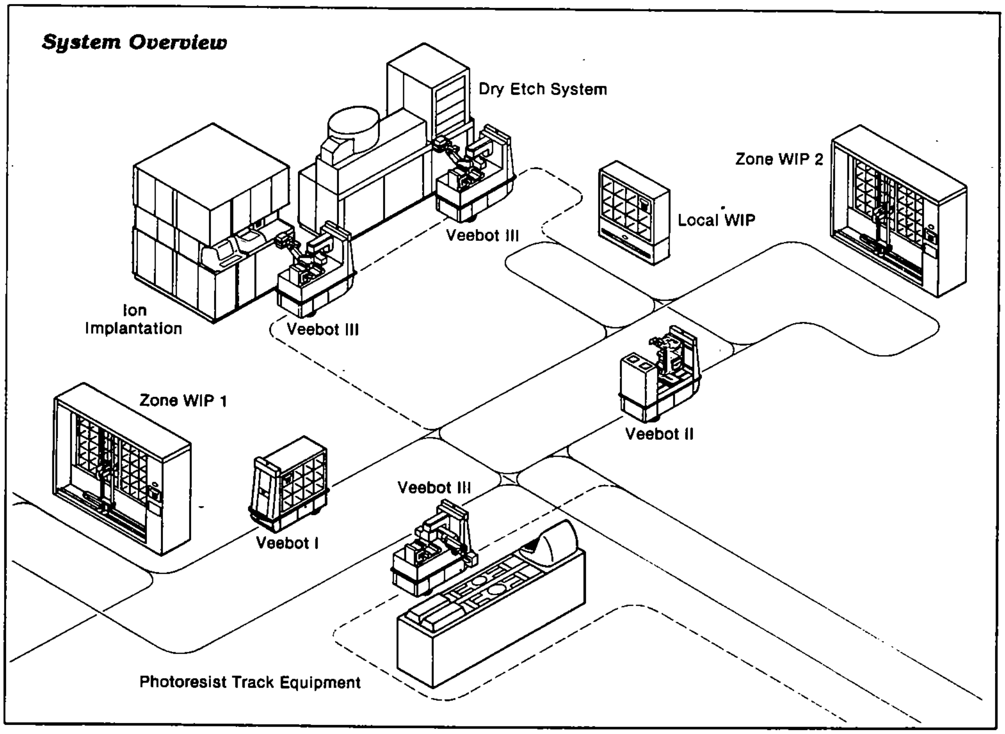
Presentation 4.8.1.1.1-3

Detail View of a SpeedFam CMP-V Planarization System

automate IC production. By the mid-eighties, the market had amounted to just over $12M. By the early nineties, it had grown to over $50M, still small but beginning to become substantial.

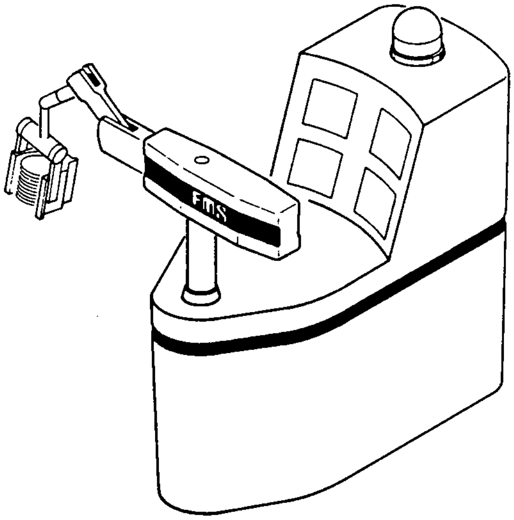
Transport Equipment

The transport system industry, as originally defined, has all but died out. It was originally defined to be any type of mechanism that moves grouped wafers between equipment or between areas. As cluster controllers developed, they too were included in this section. As originally defined and then later modified, the segment included wafer cassette transporters, WIP stockers, automatically guided vehicles, tunnel transport systems and the like. Two concepts from the late eighties are shown in presentation 4.8.1.1.2-1. It was subsequently found that robotic-like transporters such as these were too slow when movement was scaled down to prevent particulate throw off. So the approach was all but abandoned. Today, a few overhead racks exist but these are dominantly custom-built affairs. Meanwhile,



Source: Veeco

Veeco's Flexible Automation System



Source: Flexible Manufacturing Systems
2245-133P

Flexible Manufacturing Systems' AGV

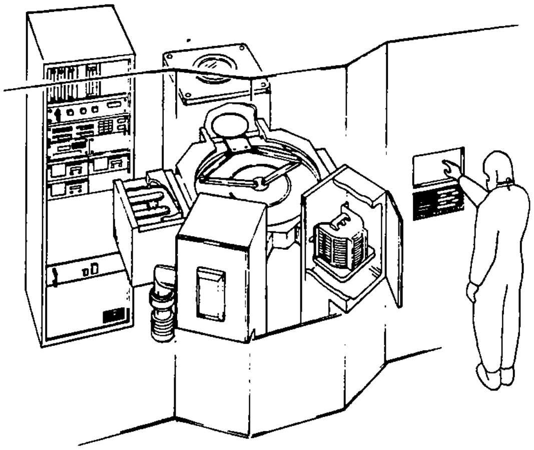
Presentation 4.8.1.1.2-1

Early Experiments with Automatic Guided Vehicles

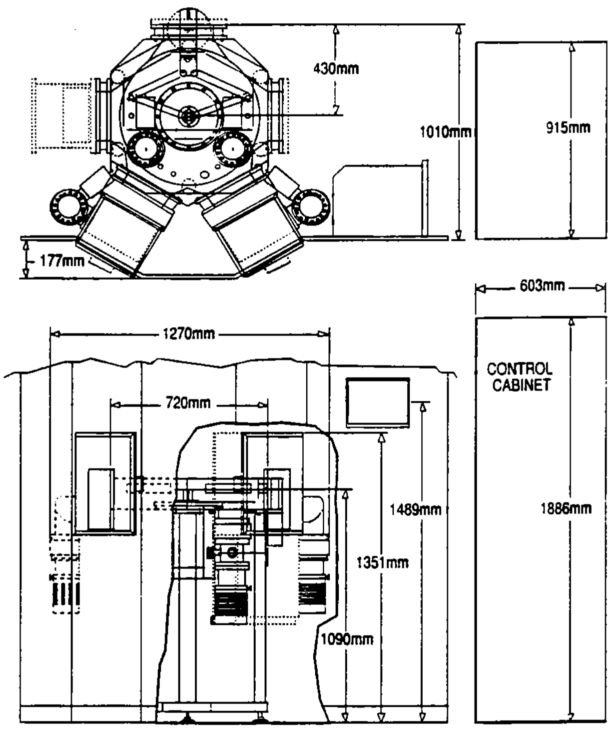
robotic arms became incorporated into conventional equipment and the remaining companies OEM'd these to other full-system suppliers. Brooks Automation is the only surviving company. It has a cluster-vacuum controller which acts as a server to other equipment. An example of Brooks Automation's approach is shown in presentation 4.8.1.1.2-2.

The history of automation is important since it helps define how equipment evolved. In the mid-seventies, automation was driven primarily by in-house efforts at the major American semiconductor companies. IBM, National Semiconductor, Motorola and Texas Instruments had all built partially mechanized fabs. But, these fabs were only mechanized, not automated. They lacked adequate software control. Moreover, equipment was bolted together which forced fabs to be very inflexible. By the end of the seventies, most of these fabs had been dismantled. The driving force then shifted to equipment manufacturers.

By 1980, the focus upon automation in the United States had shifted from mechanization of the line to automation of the equipment, the degree of interface to other equipment, and the degree of equipment 'smartness'. Equipment manufacturers began to offer equipment which is computer controlled and which can automatically load and process wafers from cassettes. One benefit of a fully automated fab is quick turnaround. At one time it was not uncommon to require 16 to 20 weeks to get a product through the plant. By 1985, 3 to 6 weeks was more common. With full automation, only a few days is expected. Relief from trained labor shortages is another benefit. As machines become more automated, and more reliable, fewer trained people would be needed and day shortages would subside. However, one constantly voiced fear of semiconductor manufacturers is that they will replace low cost labor with highly trained, high cost maintenance technicians. While fewer workers are needed in fully automated fabs, they must be more highly qualified than ever before.



Source: Brooks Automation



Source: Brooks Automation
2245-134

Presentation 4.8.1.1.2-2

Brooks Automation's Model CWH-500 Isolation Transport Module

In Japan, automation trends started in the late-seventies. The first mechanization there came in the early eighties - about five years behind the United States. NEC and Hitachi were the first Japanese companies to mechanize fabs. Virtually every major Japanese company soon followed.

As automation matured in Japan, a shift from bolted-down in-line systems to robotics was made. This began to occur around 1982. At least three generations of robots were made. The first generation was fully automatic guided vehicles (AGV's) with robotic arms to load cassettes. However, the software to flexibly run them was lacking. Equipment interfaces were not available. In addition, the AGV's contaminated the fabs. The second generation robots were material-movement carts. They simply moved cassettes from station to station where workers picked up the cassettes for processing. However, these robots also contaminated the fabs, throwing off more particles than did humans. The reason that the first two generations of robots had a substantial contamination problem is because they were initially designed for industrial manufacturing. Finally, a third generation of material movement carts which were particulate free appeared in early 1984.

All of the activity in Japan began to spur a rebirth of automation efforts among American semiconductor companies by 1983. This was evidenced by VLSI Research's first automation conference in early 1984. The general consensus was that the United States had fallen behind Japan in automation and that something had to be done.

The first visible products of a rebirth of automation in the United States were the introduction of carrier transfer systems and tunnel type transport systems. However, most of the effort went into software development. The importance of this software was that it provided part of the infrastructure for robotic AGV transport. Development outside of the semiconductor industry provided much of the rest–i.e. sonar object detection & docking, infrared communication, robotic arms, etc. By 1984, the first commercial AGV's were being offered by Veeco. FMS soon followed. These automated guided vehicles had several advantages. These were reduction in particulates generated as compared to previous generations of AGV's, reduction of costly WIP, improvement in yields through consistent processing as well as flexibility to process or equipment changes.

These early efforts uncovered several fatal fallacies with automation. T.J. Rogers at Cypress Semiconductor first revealed part of the difficulty in a prepared speech for a SEMI dinner audience. He pointed out that '...an AGV takes in one dollar but only gives back fifty cents...' Soon, another issue began to show up everywhere–the AGV's simply splayed out too many particulates unless they moved very, very slowly. IBM threw in the towel in the late eighties and in a well-publicized statement, repeated that point and then made another. The statement first pointed out that AGV's spent 85% to 90% of their time moving from one point to another, and only 10% to 15% doing useful work. It then went on to state that henceforth IBM would concentrate upon under-the-hood automation. This meant smarter equipment that concentrated upon process improvements, not necessarily more automated equipment.

In addition to automating the fab, contamination problems involving people were dealt with. In the late eighties, people accounted for 34% of the defects on a VLSI process line (see presentation 4.8.1.1.2-3). They were the leading source of defects. By eliminating defects due to people contamination, direct yield improvement soared upwards. Moreover, some indirect improvements showed up with automated transport. One of the main benefits of transport

Presentation 4.8.1.1.2-3

Killer Defect Sources
(for a six inch wafer, circa 1988)

Rank	Source	Defect Count	Defect Density (D/Sq.in.)	Distribution
1	People	15.2	0.54	34%
2	Equipment	12.1	0.43	27%
3	Process	8.0	0.28	18%
4	Liquids	4.9	0.17	11%
5	Air	2.7	0.10	6%
6	Gases	1.8	0.06	4%
TOTAL		44.7	1.58	100%

Source: VLSI RESEARCH INC
2245-135P

equipment was the improvement of processing yield by getting people away from the wafers.

However, after this was accomplished, equipment was then found to be the second largest source of killer defects. Equipment creates almost thirty percent of total contamination. Anything that rubs, waves or flaps gives off metal flakes, and if it is bumping wafers, it is creating silicon dust as well. These are significant threats and fears to the customers. Replacing dirty people with dirty equipment is very costly. Simple mechanization was not the answer. Several factories had been automated in Japan with industrial robots only to find that the robots were worse contaminators than people. Equipment had to be designed for cleanliness.

The benefits of solving both sources of defects were tremendous. Equipment and people account for 61% of all killer defects. When both sources of defects are eliminated, yields surpass 80%. Herein lies the dilemma of enclosed track versus AGV's versus SMIF. Does one seal off the clean room and only allow robots near wafers? Or, does one shrink the clean room down to a sealed track or a SMIF system? There is simply no clear answer to either question. Presentation 4.8.1.1.2-4 sheds some light on this by listing the various issues as they affect equipment types.

Manual material transport clearly has the most disadvantages. It requires a large inventory in-process since wait times between processing steps are excessively long. This causes inventory costs to be higher as well as yield to be lower. AMD claimed that there is a direct correlation between yield and the total time that a wafer was in the process line.

Wait time is aggravated in a manual line by non-constant operation of equipment. Operators are at another machine or they're off on breaks and out to lunch. This causes poor equipment utilization. Manual handling also suffers from an inability to easily move large wafers of platters. The cassettes weigh too much and larger wafers break when handled with tweezers.

Automation is enticing. Virtually, every generation of manufacturing engineers seems to find a compelling urge to make it work. The current generation of manufac-

Presentation 4.8.1.1.2-4

Transport Equipment Attributes

Type of Limitation	Specific Attributes	Effect	Transport Method Affected			
			Manual	Robots	SMIF	Track
Production Scale Limitations	Flexibility	Product types offered				●
	Inventory in-process	Costs, yields	●		●	
	Production changeovers	Hardware/software changes		?		●
Handling Induced Limitations	Human handling	Yield, Cost, Labor Issues	●	?	●	
	Room contamination	Yield	●	●		
	Close proximity to air flow	Yield				●
Operational Limitations	Clean room needed	Cost	●	●		
	Large wafer sizes	Processing yield loss	●		●	
	Wait time	Inventory costs, yield	●		●	
	Non-constant operation	Equipment utilization	●		●	
	Closed loop processing	Yield	●	?	●	?
Equipment Limitations	Complex mechanical systems	Adds to maintenance cost		●		●
	Large inventories of wafers locked away in clean tunnels	Production shut-down		?		●
	Extensive computer control	Dependency on host control		●	?	●

Source: VLSI RESEARCH INC
2245-136P

turing engineers have re-embodied the concept of automation into the cluster tool approach. Cluster tools offer at least one new twist in processing improvements that the older forms of automation missed. The cluster tool keeps the wafer in a clean, vacuum environment. This helps substantially, particularly in keeping water vapor from the surface of the wafer during interim steps.

SMIF Systems

The issue concerning automated wafer movement is really two-fold. The first merely deals with the act of transporting the wafer, which is more aptly termed mechanization. The second has to do with contamination free transportation. The SMIF approach addresses both of these issues. Currently, Asyst is the only major manufacturer of SMIF systems.

SMIF stands for standard mechanical interface. It was conceived at IBM on their now-defunct QTAT line, but perfected by Hewlett-Packard (HP). HP has subsequently encouraged its use as a SEMI standard. Asyst was the first company to license the technology from HP by offering a full line of loading mechanisms to equipment vendors, and SMIF systems to semiconductor manufacturers.

Without some form of enclosed or automated transport system, workers must carry the wafers to differing fab areas. Moreover, when movement is not automatic, production control and communication becomes a problem without tight logistics control. Wafers must wait for long periods of time between processing steps. Consequently, manual transportation causes the wafers to be exposed to many sources of contamination. This additional particulate contamination occurs from people carrying wafers, as well as from dust and dirt particles in the air. Therefore, one of the main reasons for the development of an automatic transport system was that it offered a reduction in the amount of contamination, while simultaneously controlling the location of the wafer.

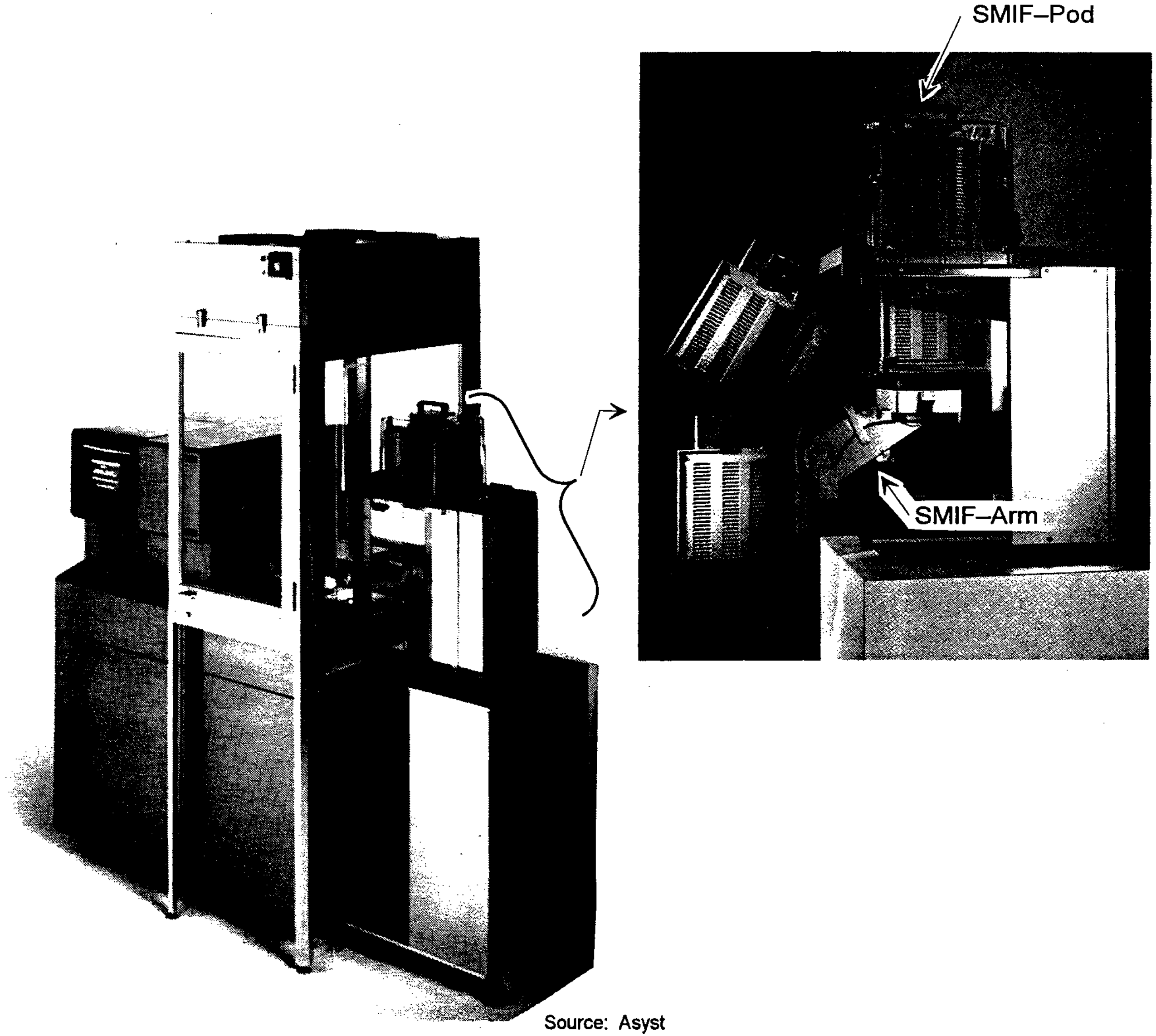
A SMIF system is essentially a small, dust-proof box with a special trap door used to move a cassette of silicon wafers to and from the box and the processing equipment (see presentation 4.8.1.1.2-5). Dust levels in SMIF boxes are about 100 times lower than in the air in a typical clean room. In addition, SMIF allows less stringent clean-room levels in the area technicians work.

Both HP and Asyst have published contamination measurements with and without SMIF. Typical results from HP are:

A Clean Room without SMIF: 74 PWP
A Clean Room with SMIF: 7 PWP
SMIF in an office area: 10 PWP
PWP: Particles per wafer pass.

In the simple loading and unloading of cassettes into equipment, there are 0.8 PWP without SMIF, but only about 0.2 PWP with it. In particles accumulated per wafer per day (PAWD) a wafer in a clean room without SMIF gathers about 0.85 PAWD, while with it, only about 0.1 PAWD is measured. SMIF is competitive with tracks and robots for reducing defects. The issue of how best to eliminate contamination is an important one since it is intimately tied to the automation efforts of the industry.

Despite the apparent benefits of SMIF boxes, they only began to find significant use in the early nineties. In the eighties, both manufacturers and vendors took a wait-and-see attitude. Without manufacturers pressures, vendors did not plan to supply equipment compatible with SMIF systems. Without such complimentary equipment, manufacturers were reluctant to commit to SMIF. Consequently, semiconductor manufacturers showed little inclina-



Source: Asyst
2245-137

SMIF System

Presentation 4.8.1.1.2-5

tion to adopt SMIF. A 1987 survey by VLSI Research indicated that those who were not using SMIF felt that there was no ready base of designs to modify existing equipment to be made SMIF compatible. Funding was another roadblock during the 1986 semiconductor downturn. However, these attitudes changed in the nineties. SMIF sales have grown exponentially. Now most manufacturers say that SMIF is the way to go.

Transfer Equipment

Transfer equipment enables the transfer of wafers from one type of carrier to another. For example, in the transferring of wafers from a cassette to a boat. Equipment in this category does not included mechanisms which are integrated into a system to load or unload carriers. For example, cassette elevators, furnace loaders and general purpose robotics are not included.

Burn-in was the first area in which transfer equipment was used. It greatly reduced the time needed to load and unload each socket on a board. Since the actual burn-in process can take anywhere from 8 to 48 hours, one transfer system can serve many burn-in ovens. Therefore, the transfer system has a fast payback period. However, the market has remained small as a result.

Cassette-to-boat wafer transfer equipment was the second type of transfer equipment to be introduced. Such a system transfers all of the wafers from carrier-to-quartz boat automatically. It was developed in order to reduce breakage of wafers due to human error. Transfer time was also reduce.

In 1974, Robert Butler at Micro Glass Inc. (MGI) was the first to produce an automatic cassette-to-boat transfer model. This first system used a windmill-type motor. In 1982, Butler came out with a more efficient model that used a pneumatic motor. This model was subsequently duplicated by Mactronix in 1983, except that Mactronix's pneumatic model was smaller and cost less. With these features, Mactronix quickly gained the majority of the wafer transfer market, which it still maintains today.

Consequently, semiconductor manufacturers were finding minor contamination problems as a result of using pneumatic motor driven transfer equipment. The pneumatic motors tended to generate particles which got onto the wafer. Therefore, in mid-1983, another company appeared on the scene with a transfer system which used an electric motor. This company was Faith Enterprise. Electric motors did not generate contaminates. Therefore, in 1986, MGI Systems came out with an electric motor transfer system. By 1993, MGI Systems abandoned the pneumatic motor altogether. However, Mactronix has remained steadfast with their pneumatic motor transfer equipment.

Cassette-to-susceptor transfer systems were the third type of transfer equipment introduced. These systems were used to load and unload hex etchers. Plasma-Therm was the only manufacturer of such a system. They began selling this system in 1982. At that time, they were delivering most of their hex etchers with this option attached. However, in 1985, they discontinued the hex etcher. They subsequently discontinued their cassette-to-susceptor transfer systems, as well.

4.8.1.1.3 Development of the Reprocessors & Recirculators Industry

The driving force for the development of acid reprocessors was to reduce the escalating cost of chemicals. To do this, manufacturers had to reduce chemical consumption. The only way this could be accomplished was to repurify and reuse the chemicals. It is less expensive to repurify and reuse chemicals than to buy fresh chemicals. Therefore, semiconductor manufacturers wanted a system that could reprocess and repurify chemicals. Reprocessors recycle and repurify previously used liquid acids. In 1987 Athens introduced the first acid reprocessor destined to be used in a semiconductor fab. It was used for reprocessing sulfuric acid. Shortly thereafter Athens introduced hydrofluoric acid (HF) reprocessors. Athens developed these two reprocessors because sulfuric acid and HF are the two highest volume liquid chemicals used in the fabrication of semiconductor devices. More sulfuric acid is consumed than is hydrofluoric acid. However, about 72% of all hazardous waste generated by U.S semiconductor manufacturers are HF solutions. Sulfuric acid is commonly used in wafer cleaning and photoresist stripping operations. HF is commonly used in cleaning. In addition to producing remarkably pure chemicals another benefit semiconductor manufacturers found was that by using reprocessors defect densities are lowered, yields improved and costs were reduced further.

4.8.1.1.4 Development of the Gas Scrubber Industry

Concern for the environment has focused considerable attention on the total amount of hazardous material being handled and disposed of by semiconductor manufacturing. As the volume of devices increases each year, the semiconductor industry will be forced to be more efficient in terms of chips produced per unit volume of hazardous waste.

The issue surrounding safety in a semiconductor fab also turned attention to dangerous gases. Silane, a commonly used reactant, is pyrophoric in contact with air and has been the cause of several fires in semiconductor factories. Other semiconductor manufacturing by-products are dopant hydrides, which are poisonous at levels of only a few parts per million. Upon exposure to water vapor in the air, these hydrides can explode into the atmosphere. Scrubbing noxious, poisonous, corrosive, or pyrophoric gases before they enter the atmosphere is both prudent and generally required by law. The function of gas scrubbers are to convert gaseous pollutants into safer, less hazardous gases, liquids, solutions or solids.

Prior to 1975, gas scrubbing was usually implemented by means of water sprays or burn boxes. Most gases were disposed of by scrubbing or direct discharge into the atmosphere. In addition, chloroflurohydrocarbons (CFCs) was used extensively as a cleaning agent. Semiconductor manufacturers thought that CFCs were harmless to the environment because they are not flammable or photo reactive. However, in the eighties scientists determined that CFCs were harmful to the ozone layer. Therefore, in 1989, the Montreal Protocol was signed by thirty nations committing governments to enacting regulations to reduce CFC use significantly.

Because of the high level of interest in toxic substances since the early eighties, industry had to prepare for new regulatory controls and other safety issues for gaseous effluents. Growing concerns about toxic gas effluents in California led to the passage of Assembly Bill 1807 in September 1983. This bill requires the Air Resources Board to determine the extent of public exposure to toxic substances and describe the nature and magnitude of human risk caused by exposure to these substances. In addition it requires an appropriate regulation for each toxic substance.

The number one environmental concern in North America is air quality. The 1990 amendment to the U.S. Clean Air Act, the Montreal Protocol, and legislation in Canada and Mexico all affects emissions of pollutants which in turn drives an increase demand for air pollution control equipment. Through the Clean Air act, the U.S. Environmental Protection Agency sets air quality guidelines for various pollutants. To comply with the Clean Air Act, companies have to implement gas scrubbers.

Gas scrubbers scrub gases of toxic, corrosive or inflammable gases. The function of gas scrubbers are to convert gaseous pollutants into safer, less hazardous gases, liquids, solutions or solids. Gas scrubbers are divided into two categories, point-of-use and facility mounted systems. Point-of-use scrubbers are located near the process tool exhaust and are dedicated to that particular tool. Facility mounted scrubbers are centrally located, usually on the roof of the fab. These scrubbers accommodate many process tools.

Since semiconductor manufacturers have incorporated gas scrubbers as required by law, they are finding that scrubbers, point-of-use in particular, offer many advantages. These advantages include increased process tool uptime, productivity and profitability.

Other positive attributes are that deposition and etch systems performances improve, maintenance on these systems lessens, personnel exposure to hazardous materials decreases, and destructive duct blockages, corrosion and fires are prevented.

4.8.1.2 Technology of Other Equipment

This section contains descriptions of the applications and the technologies used by wafer manufacturing equipment, transport & transfer equipment, reprocessors & recirculators, and gas scrubbers.

4.8.1.2.1 Wafer Manufacturing Technologies

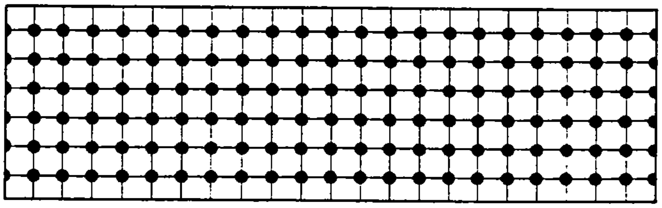
Crystal Growing

Silicon is most commonly found in nature as an oxide or silicate. It is readily available being second only to oxygen in natural abundance. The silicon manufacturing process begins with the purification of raw sand, and the conversion of the silicon extract into pure polycrystalline silicon. Silicon can exist in amorphous, polycrystalline or mono-crystalline form (see presentation 4.8.1.2.1-1). In amorphous silicon, atoms are randomly arranged. In polycrystalline silicon, many small single crystals exist, but they are randomly oriented with respect to each other. These must be converted into a single crystal throughout the entire ingot. To do this, the purified polycrystalline silicon is first crushed and then loaded into a high-temperature crucible in a crystal growing furnace where it is melted. A dopant is added to determine the type of material. Typically, phosphorous or antimony dopant is added for N-Type wafers, while boron or arsenic dopant is added for P-Type. The quantity of dopant which is to be added to the melt also determines the resistivity of the ingot.

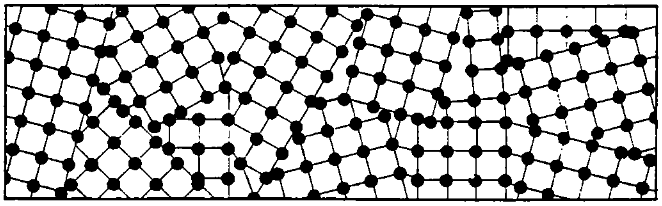
Crystal growing furnaces uses three different methods to grow an ingot of single-crystal material. These are Czochralski, Float Zone and Bridgman techniques. Each

Presentation 4.8.1.2.1-1

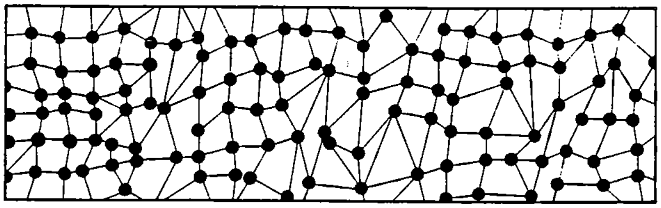
Crystalline Lattice Structures



Lattice Structure of a Monocrystal



Polycrystalline Lattice Structure



Structure of an Amorphous Soild-State Body

Source: Leybold-Heraeus

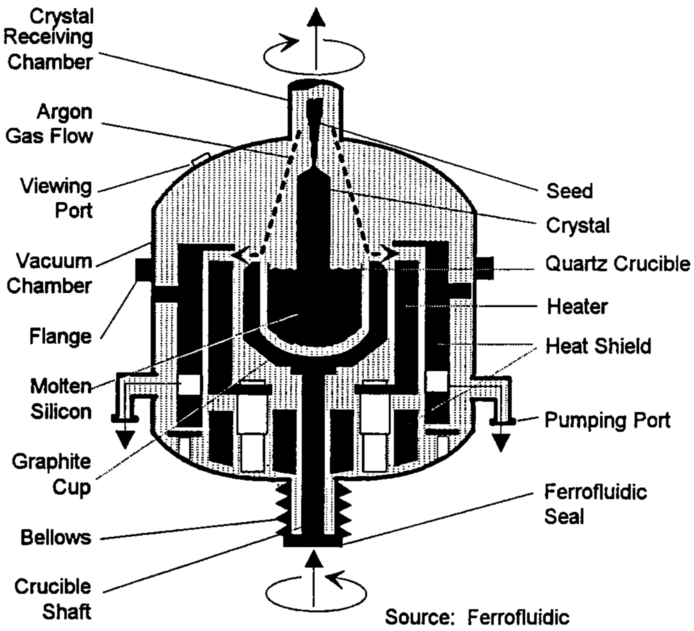
2245-125D

uses a slightly different method. In the Czochralski (CZ) method, the crystal is grown as it is pulled from a crucible of molten silicon. After the melt has reached the appropriate temperature, a seed crystal is lowered from above. The seed crystal will determine the directions of crystal growth. To accomplish this, the seed crystal is first dipped into the melt and then slowly pulled from the melt, just as in the making of dipped wax candles. Molten silicon hardens along the outside surface as a single crystal with the same orientation as the seed. The seed is rotated as it is pulled. Pull rates and rotation rates are critical parameters in the process, so they are carefully controlled. The mold and the crystal rotate in opposite directions. The rotation and pull rate control the grown diameter of the ingot. As the ingot is pulled, the dopant distributes unevenly, being lighter at the top of the ingot. Hence, resistivity is higher there. The converse is true near the bottom. However, within some given span, the entire ingot will contain an acceptable amount of dopant and resistivity. Once the crystal has been pulled, the seed and tail of the ingot are removed, thus completing the crystal growing step (see presentation 4.8.1.2.1-2).

The Float Zone (FZ) method begins with a polysilicon ingot being placed in a horizontal furnace. An RF coil surrounds the ingot. As the RF coil begins to heat and create a melt zone on the ingot, a seed is placed in contact with the ingot. The ingot is slowly moved in a continuous motion while the RF coils remaining stationary. This allows the previous melt zone to solidify along the same orientation as the seed. As the ingot solidifies after being heated it continues to take on the orientation of the seed (see presentation 4.8.1.2.1-3).

The Bridgman method uses a vertical crucible design with a conical bottom. First, the polycrystalline silicon is melted in the crucible. To achieve a definite orientation, a seed crystal is used. The seed is placed at the lowest point in the crucible. Upon achieving the proper molten temperature, the crucible is lowered into the cooling zone (see presentation 4.8.1.2.1-4). The crystal then solidifies in the crucible. This method is typically used for GaAs and Ge. It is rarely used for silicon since the crucible wall causes lattice damage during solidification.

Of the three crystal growing techniques discussed, the CZ process is the most commonly used. FZ is the second most commonly used technique. CZ is preferred for its simplicity and low cost. Moreover, it is appropriate for making many device types. But, CZ grown silicon contains excess oxygen dissolved from the quartz crucible. This may cause problems in manufacturing some types of devices; in particular, those devices which operate at high voltages. Also, the dopant is not homogeneous throughout the crystal. In contrast, crystals grown using the float zone method do not contain oxygen and tend to be more evenly doped. This is because the molt never touches the walls of the crucible. However, this method is not



Source: Ferrofluidic
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Presentation 4.8.1.2.1-2

Czochralski Crystal Growing System

commonly used due to its higher degree of difficulty in implementation, resulting in higher costs.

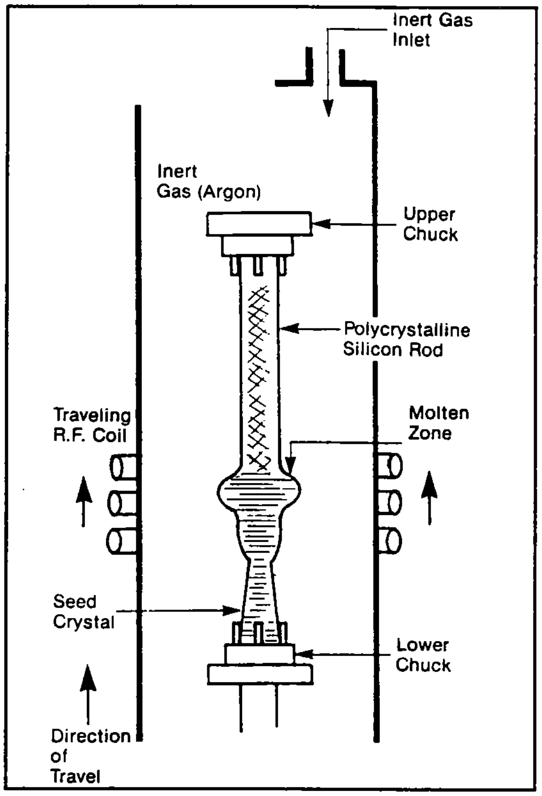
The presence of oxygen has both positive and negative aspects. The beneficial aspects include gettering and slip retardation. Harmful effects are the formation of additional oxygen donors, nucleation of oxygen induced stacking faults, bulk stacking fault generation and induced wafer warpage. But through the selective heat treatment of silicon, oxygen levels can be controlled.

Crystal Machining

After removal from the crystal grower, the crystal goes through a series of steps that result in transforming the ingot (silicon, GaAs, etc.) into production viable wafers. Crystal machining equipment is used to accomplish a finished wafer.

First, the crystal ingots are ground to the desired outside diameter using cylindrical

Float-Zone Crystal Growing System



Source: Microchip Fabrication, 2nd edition
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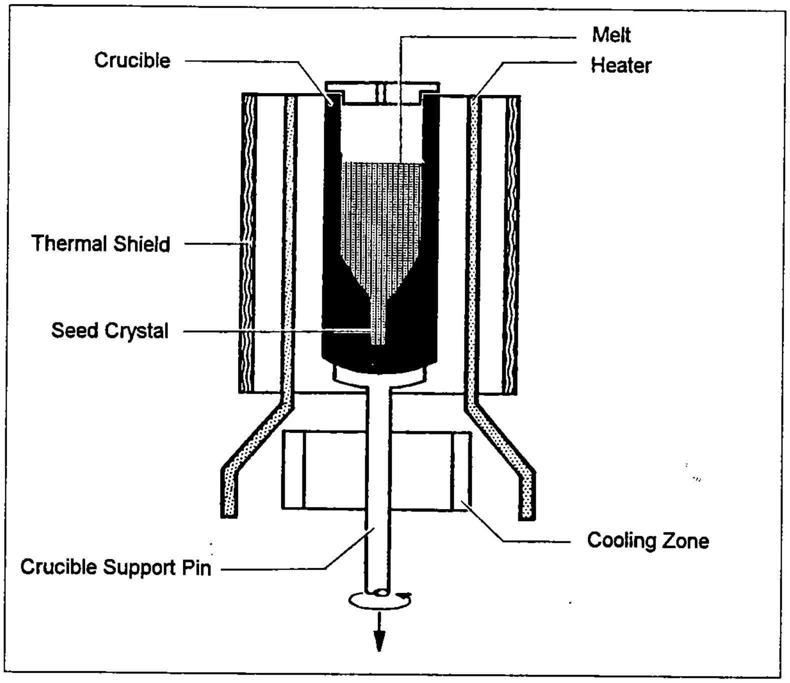
Presentation 4.8.1.2.1-4

Schematic of the Bridgman Process



Source: Leybold-Heraeus
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grinders. These grinders are used to smooth and round the ingot surface to the required diameter. Following this, the atomic structure is analyzed to determine the growth axis or the crystal plane. The ingot is x-rayed in order to locate the exact crystal plane along which it will be cut. Wafers can be cut from the crystal at several different angles. Each angle represents a different plane which result in different chemical, electrical and physical properties. A specific crystal plane must be specified for the wafers. Orientation is usually along the <100> or the <111> crystal planes. The <100> plane has a square shape, and the <111> plane has a triangular shape. MOS and GaAs devices are fabricated from <100> oriented wafers. Bipolar devices are fabricated from the <111> oriented wafers.

Once the crystal is oriented, a flat is cut with OD slicers along one side of the ingot to identify the crystallographic orientation. The position of the flat is along one of the major crystal planes, therefore it is called the major flat. The major flat is both a location and an alignment device. The major flat is aligned parallel to the growth axis. Depending on the dopant, there may also be a minor flat. The position of the minor flat is determined by the location of the major flat, and according to SEMI standards. For example, for P or N type material along different planes the flats are:

P111 - no minor flat
P100 - 90 degrees clockwise from the major flat
N111 - 45 degrees clockwise from the major flat
N100 - 180 degrees from the major flat

There is a trend towards laser marking and notching wafers to replace the minor flats. This is because of the difficulty in performing automatic alignment on wafers with two flats.

Ingot slicing occurs after the flats are cut. Inside diameter (ID) slicing equipment is used to slice the ingot into wafers. The optimum ID saw is one that slices a wafer with maximum flatness and minimum kerf loss. Ingots are sliced into thin wafers to a nominal thickness with ID slicers that look much like delicatessen slicers. The slicing phase leaves wafer edges square and somewhat ragged. This can lead to future fractures, breaks, chipping and loading difficulties. Therefore, in the next step, wafer edges are ground until round. Edge grinding equipment is used to round off the wafer edges. This process helps to reduce chipping in subsequent wafer processing. Grinding wafer edges reduces the possibility of potential defects. During subsequent steps, the excess thickness will be removed. After slicing and edge grinding, wafers move on to lapping.

Lapping equipment is used to remove rough material from each side of the recently sliced wafer. It uses an abrasive technique to remove the rough surface from the wafer. Lapping is a mechanical smoothing process, as well as a chemical process. It is used to remove excess material from wafers and to smooth their surface.

Lastly, wafers are polished. Polishing equipment is used in two phases, primary or rough polishing and final or chemical-mechanical polishing. The preliminary stage is stock removal. The rough polish station rapidly removes material to the desired flatness with minimal surface damage. The polisher removes approximately one millimeter from one side of the wafer surface. Rough polishing is a conventional, abrasive, slurry lapping process fine-tuned to semiconductor requirements. Rough polishing removes surface damage leftover from the wafer-slicing process.

The final polish is a more refined process to eliminate all of the minute flaws on the wafer surface. Chemical-mechanical polishing (CMP) is a combination of chemical etching and mechanical buffing. The wafers are mounted on rotating holders and lowered onto a rotating surface that is flooded with a mild etchant solution. The etchant grows a thin layer on the wafer that is almost simultaneously removed by the buffing action. Surface etching is performed to smooth the wafer surface still further until it reaches a mirror finish. CMP is a very controlled polishing process accomplishing an extraordinarily flat surface. Each lapping and polishing step improves wafer finish and quality while reducing damage.

Wafers are inspected before packaging. SEMI has established standards for evaluating wafers. These include guidelines for acceptable wafer diameter thickness, bow and thickness variation. Wafers are further inspected for flatness, warpage and taper. Suppliers and users determine acceptable parameters for these characteristics. Similarly, wafers are inspected and graded as to resistivity gradient, oxygen content and carbon content. They are also examined for physical defects such as streaks, finger prints, dimples, etc. Generally, twenty-five wafers are packaged per cassette. The finished wafers are now ready for wafer fabrication, their final destination. A process flow for wafer manufacturing is shown in presentation 4.8.1.2.1-5.

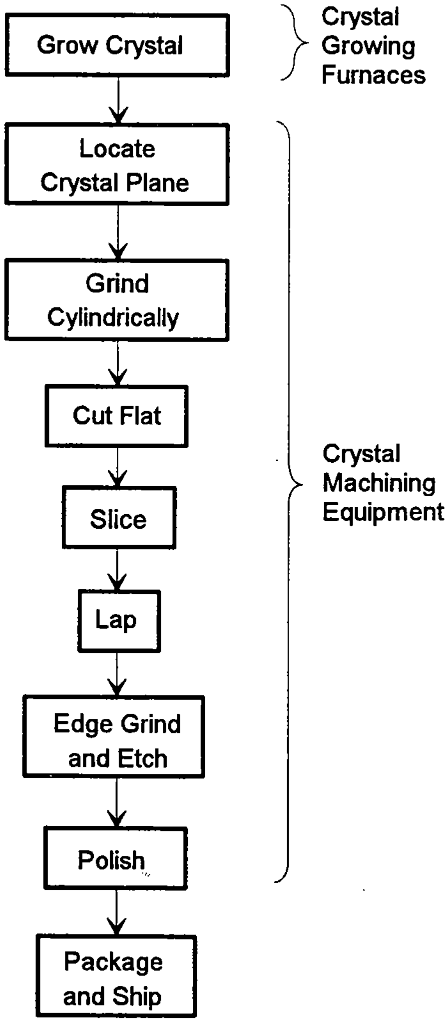
Chemical-mechanical Polishing for Interlevel Layering

CMP is a very controlled polishing process accomplishing extraordinarily flat surfaces. Since CMP can accomplish incredible flatness, it also has applications in interlevel planarization of advanced devices. CMP is becoming prevalent for the use of planarizing interlevel dielectrics and selective removal of the aluminum or tungsten overburden following metal fillings of studs and interconnects. The CMP planarization process produces a smooth, damage-free surface for subsequent device processing.

CMP machines use orbital, circular lapping motions. At the beginning of the CMP process, wafers are transferred from the cassette to a carrier. The wafer is held on a rotating carrier while the face being polished is pressed against a flexible polishing

Presentation 4.8.1.2.1-5

Typical Process Flow of a Wafer Manufacturing Line



Source: VLSI RESEARCH INC
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pad attached to a rotating platen disk or polish spindle. The polishing pad is prewetted with slurry and/or D.I. water. The polishing pad is an essential part of the CMP process. It is usually polyurethane or a polyester felt impregnated with polyurethane, a pad type intended for glass polishing. The spindles lower to the polishing surface, and the carrier and spindles accelerate to their programmed RPM. Polishing speed depends on pattern density, local geometry and point-to-point temperature and pressure variations. Polishing slurry is fed to the carrier during polishing. For oxide or silicon polishing, an alkaline slurry of colloidal silica is used as the chemical-mechanical abrasive. This slurry chemically attacks the wafer surface, converting the Si top layer to a hydroxylated form that is more easily removed by the mechanical abrasive action. At the end of the polishing time, slurry flow is stopped and D.I. rinse water is introduced and continued until the wafer carriers are raised from the table and transported back to their stages, where a de-ionized water spray is directed onto the wafers and continues to wet the wafers until the polishing head clears the loader area.

4.8.1.2.2 Transport & Transfer Equipment Technologies

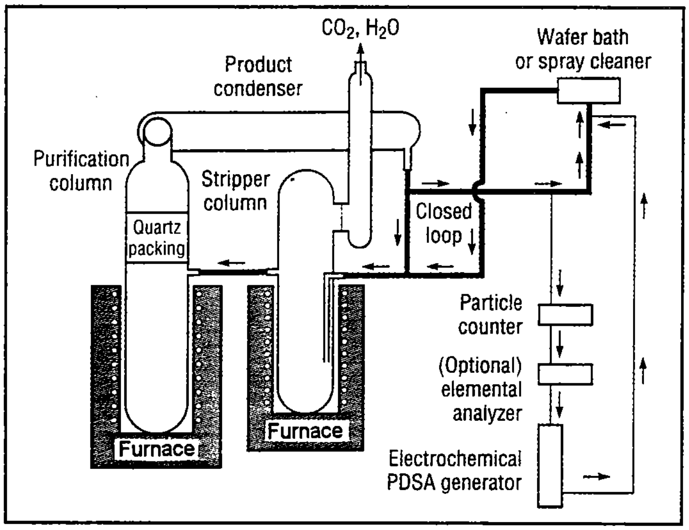
Transfer equipment enables the transfer of wafers or integrated circuits (ICs) from one type of carrier to another. Transfer equipment includes burn-in transfer, cassette-to-boat transfer and SMIF equipment. Burn-in transfer systems load and unload ICs into or from burn-in boards (BIB). To load the BIB, a pick-and-place vacuum automatically inserts ICs into empty BIB sockets. For unloading the BIB, the pick-and-place vacuum automatically takes out the ICs from the BIB sockets and transfers them elsewhere. Cassette-to-boat transfer equipment transfers wafers from a cassette to a quartz boat automatically.

SMIF Systems

The standard mechanical interface (SMIF) concept involves the use of small, sealed containers for storing and transporting wafer cassettes. These containers transfer cassettes through a port door to process or test equipment. The equipment is contained in an enclosure which provides a small ultraclean environment. A typical SMIF system has three components. The first component is a SMIF-pod. This is a sealed wafer carrier that completely isolates wafer cassettes from the environment. The second component is a SMIF-arm. This is an automatic transfer mechanism that removes cassettes from the pods and place them on the process equipment. The third component is a SMIF-enclosure. This is a mini-environment that surrounds the process and test equipment. The SMIF-enclosure allows the wafers and equipment to be completely isolated from personnel and the cleanroom environment during the entire production cycle. An alternative component is a SMIF-loader. A SMIF-loader removes wafer cassettes from a SMIF-pod via an elevator. An operator than manually transfers the SMIF-pod to the equipment. The sole purpose of SMIF systems is contamination control. By keeping wafers in SMIF-enclosures, equipment generated particles cannot accumulate on the wafer. Thus wafer cleanliness improves and wafer defect density declines.

4.8.1.2.3 Reprocessors & Recirculators Technologies

There are two types of reprocessors, sulfuric acid and hydrofluoric acid reprocessors. Sulfuric acid or piranha reprocessors are the first and most common chemical reprocessors in the semiconductor industry. Sulfuric acid is often used to strip photoresist or clean organic impurities from silicon wafers. Piranha is a mixture of sulfuric acid and oxidants. Piranha got its name because it aggressively strips a wafer surface free of organic material.



Source: Athens Corp.
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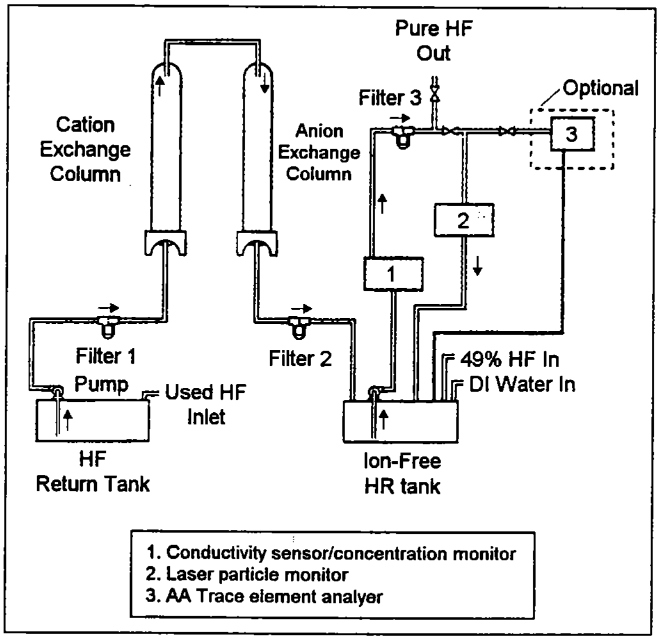
Presentation 4.8.1.2.3-1

Sulfuric Acid Reprocessor

Sulfuric acid reprocessors recycle and repurify through four operations. These operations are concentration, purification, quality control and oxidant generation. First, used sulfuric acid is concentrated from 92 wt% to 94-96 wt% in a stripper column. Concentration is accomplished by bubbling nitrogen gas through the hot acid (285 C). Next, the hot acid passes through a transfer leg to the purification column. Here, ionic and particulate impurities are removed. The reprocessed acid then is checked for impurities that remain. A particle counter and external sodium ion monitor scrutinize the solution for impurities. This way quality control is maintained. In the final stage, the peroxydisulfuric acid (PDSA) oxidant is generated by electrosynthesis. After the quality control stage, the concentrated acid goes through a water-cooled, quartz mixer. Here, the acid is diluted with deionized water. The diluted acid then enters the electrochemical system, where PDSA oxidant is formed. The oxidant is now repurified and ready to be reused (see presentation 4.8.1.2.3-1).

Hydrofluoric acid reprocessors use ion exchange and filtration to remove soluble and insoluble impurities from dilute HF solutions. Used HF fills the HF return tank. The HF is pumped through the purification train and through a filter. The filter prevents particles in the used HF from entering the ion exchange system. The HF next flows through a cation column and then through an anion exchange column where ionic impurities are removed. The HF now passes through another filter which removes any particles that might have originated in the ion exchanger. Finally, the purified HF enters the product tank. A quality control check is then performed. A second pump recirculates the purified HF through a third filter, then through a particle monitor, and back to the product tank (see presentation 4.8.1.2.3-2).



Source: Athens Corp.
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Presentation 4.8.1.2.3-2

HF Reprocessor

4.8.1.2.4 Gas Scrubbers Technologies

As environmental ordinances to control the dumping of catastrophic chemicals expand globally, semiconductor manufacturers are implementing facility mounted and point-of-use scrubbers in their fabs. Since many semiconductor equipment use various hazardous gases, these scrubbers are critical (see presentation 4.8.1.2.4-1). In addition, point-of-use scrubbers' usage is increasing because some semiconductor manufacturing processes actually need scrubbers. For example, consider a CVD system that uses silane during processing and then uses a fluorine to clean the chamber. If the cleaning gas NF3 mixes with silane in the exhaust, an explosion will take place. Therefore, an exhaust treatment to remove both gases after they are used in this system is essential. Another process that is demanding point-of-use scrubbers are etch systems

Presentation 4.8.1.2.4-1

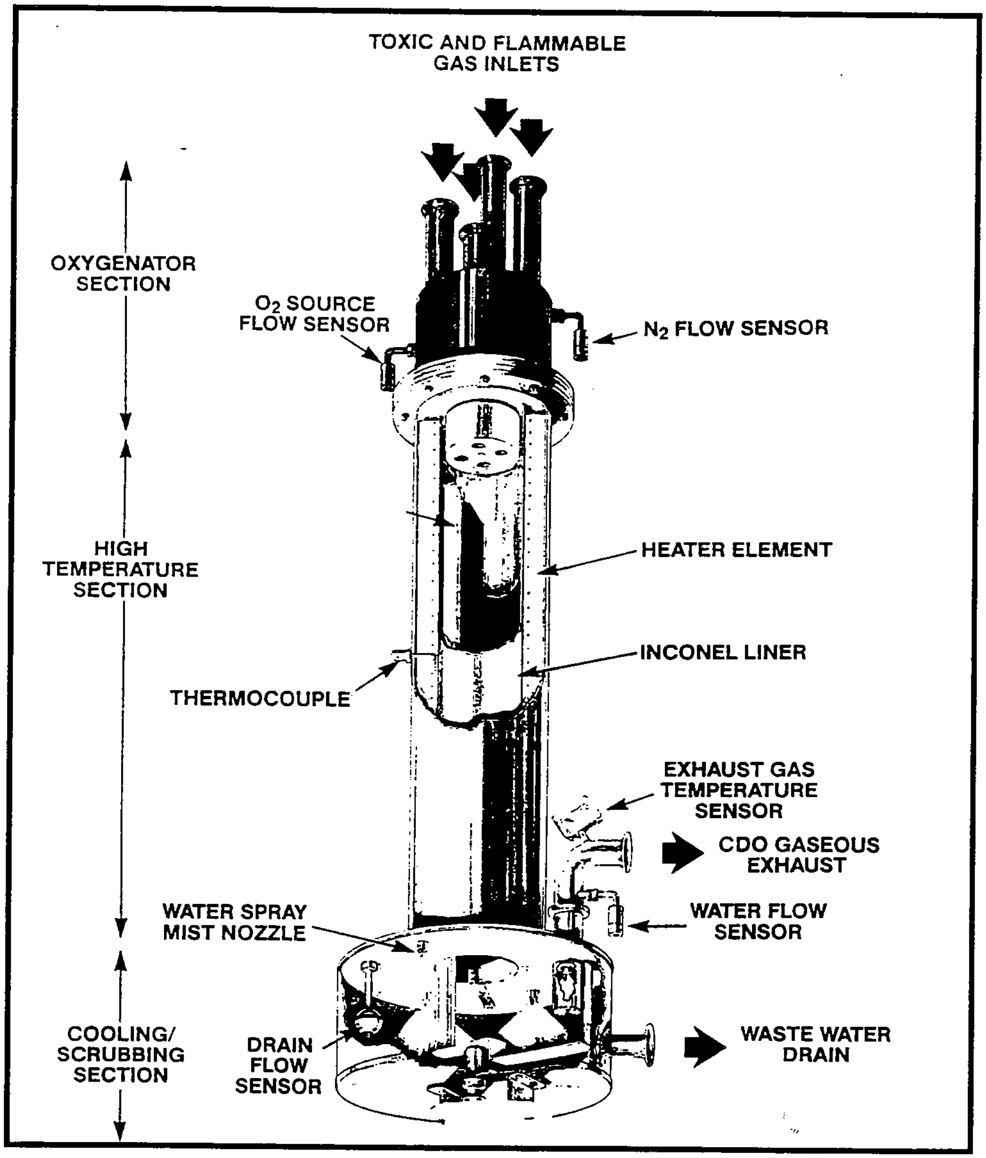
Typical Semiconductor Processes that Require Gas Scrubbers

Process	*Gas Emissions*	*Symbol*	*Point of Use*	*Central System*
Depostion:	Ammonia	NH_3	X	
CVD	Arsine	AsH_3	X	
PVD	Diborane	B_2H_6	X	
Epitaxial	Dichlorosilane	SiH_2Cl_2	X	
	Phosphine	PH_3	X	
	Silane	SiH_4	X	
Plasma Etching	Boron Trichloride	BCl3	X	
	Carbon Tetrachloride	CCl_4	X	
	Carbon Tetrafluoride	CF_4	X	
	Chlorine	Cl_2	X	
	Chlorine Based Compounds	CCl_2F_2	X	
	Fluorine Based Compounds	C_2F_6, C_3F_8	X	
	Hydrogen Chloride	HCl	X	
	Trifluoromethane	CHF_3	X	
	Tungsten Hexafloride	WF_6	X	
Ion Implanter	Arsine	AsH_3	X	
	Diborane	B_2H_6	X	
	Phosphine	PH_3	X	
	Silane	SiH_4	X	
		BF_3	X	
Wet Process	Acidic Aerosols			X
	Alkaline Aerosols			X
	Hydrogen Chloride	HCl		X
	Hydrogen Fluoride	HF		X
		NH_3		X
		NOx		X
Microlithography	Waste Air Containing Solvents			Central adsorber with nitrogen purge

Source: VLSI RESEARCH INC
2245-139P

that use HBr, a gas that replaced Freon. HBr produces extremely corrosive byproducts that corrode stainless steel and plastic ducting. Implementing a gas scrubber may be cheaper than continually replacing stainless steel and plastic parts.

Point-of-use scrubbers include liquid scrubbers, thermal decomposition and vacuum scrubbers. Liquid and thermal decomposition scrubbers remove reactive gases in atmospheric pressure exhausts of gas emitting process tools. With thermal decomposition, exhaust gases mix with oxygen and pass through a flame or ignitor where remaining process gases and byproducts burn or crack (see presentation 4.8.1.2.4-2).



Source: Delatech
2245-140

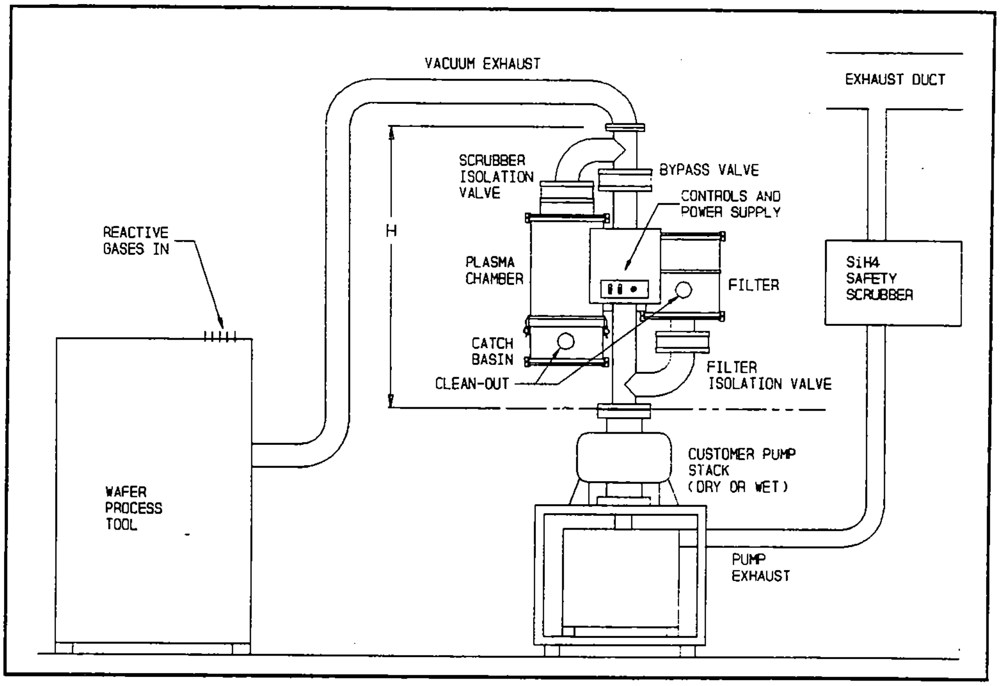
Presentation 4.8.1.2.4-2

Cut-Away View of a Thermal Decomposition Scrubber

In liquid scrubbers, exhaust gases pass through absorbing sprays of water or chemical solutions. The scrubbing liquid in liquid scrubbers is typically water. However, for gases that are water insoluble, the liquid is a mixture of water and an oxidizer, for eg. potassium permanganate. The scrubbing liquids neutralizes the gases. Gaseous substances are absorbed by a liquid in one of two ways–physical or chemical absorption. In the first case, the gas is dissolved in a scrubbing liquid. In the second case a chemical reaction takes place. Nevertheless, the possible regeneration of the scrubbing liquid must be taken into consideration. Therefore a system for the treatment of the scrubbing liquid is installed along with a liquid gas scrubber. Usually the scrubbing liquid is recirculated.

Vacuum scrubbers eliminate reactive gases in the exhaust of CVD, PECVD and etch reactors before the gases reach the vacuum pump. In 1991, PlasmaChem introduced the first and to date the only vacuum scrubber. These vacuum scrubbers operate in the vacuum exhaust lines of CVD, PECVD and plasma etchers. They are designed to remove about 90% of the hazardous, reactive gases in the vacuum exhaust line before the gases reach the vacuum pump. The intention is to extend the operating life of the vacuum pump. PlasmaChem's vacuum gas scrubbers operate by eliminating hazardous gases in a plasma scrubber chamber and filtering out the solid particulate so that the vacuum pump, the pump exhaust plumbing and the exhaust ducting are not contaminated with particles or reactive gases. Vacuum gas scrubbers use high intensity plasma energy to complete the reactions already started in the process chamber. Such vacuum gas scrubbers are able to operate within the vacuum because pressures are within the range of easy plasma generation. Vacuum gas scrubbing reduces the total amount of toxic gas in the exhaust stream, prevents build-up of solid waste in the vacuum pump and in the downstream exhaust lines and reduces the total amount of waste material to be handled (see presentation 4.8.1.2.4-3).

Presentation 4.8.1.2.4-4 portrays which point-of-use scrubbers are more effective on particular effluent gases.



Presentation 4.8.1.2.4-3

Source: PlasmaChem
2245-141

Vacuum Scrubber

Presentation 4.8.1.2.4-4

Point-of-Use Scrubber Recommendations on Effluent Gases

Effluent Gases	***Chemical Element Symbol***	***Liquid Scrubber***	***Thermal Decomposition***	***Vacuum Scrubbers***
Ammonia	NH_3	Yes		Yes
Arsine	AsH_3	Water + Oxidizer	Yes	No
Chlorine	Cl_2		Yes	
Chloro-Silane	$SiCl_4$	Yes		
Dibocane	B_2H_6	Yes		Yes
Dichlorosilane	SiH_2CL_2			Yes
Flourine	F_2	Yes		
Hydrogen	H_2	No	Yes	No
Hydrogen Chloride	HCl	Yes		
Hydrogen Fluoride	HF	Yes		
Phosphine	PH_3	Water + Oxidizer	Yes	Yes
Silane	SiH_4	No	Yes	Yes
Tungsten Hexafloride	WF_6	Yes		
Vacuum Pump Fluid Vapors		No	Yes	

Source: VLSI RESEARCH INC
2245-138P