5 ASSEMBLY EQUIPMENT

5.0.0 ASSEMBLY EQUIPMENT

Assembly equipment consists of those types of equipment used to separate the completed wafer into its individual dice and to assemble each die into its own package.

The assembly equipment market comprises roughly 11% of the total equipment market for all semiconductor manufacturing. Exact percentages of the total segment and its subsegments will be found in the database sections of each of the following chapters.

Historical sales and bookings for the total assembly equipment industry are shown in Figure 5.0.0-1. The assembly equipment market is seen to have reached an all-time peak in sales during 1984. Annual sales in 1984 were $800M. In 1985, the assembly equipment market began experiencing the effects of the recession already deeply felt with wafer fab equipment, and orders began falling off. In 1986, this market dropped approximately 40% from its previous high of 1984.

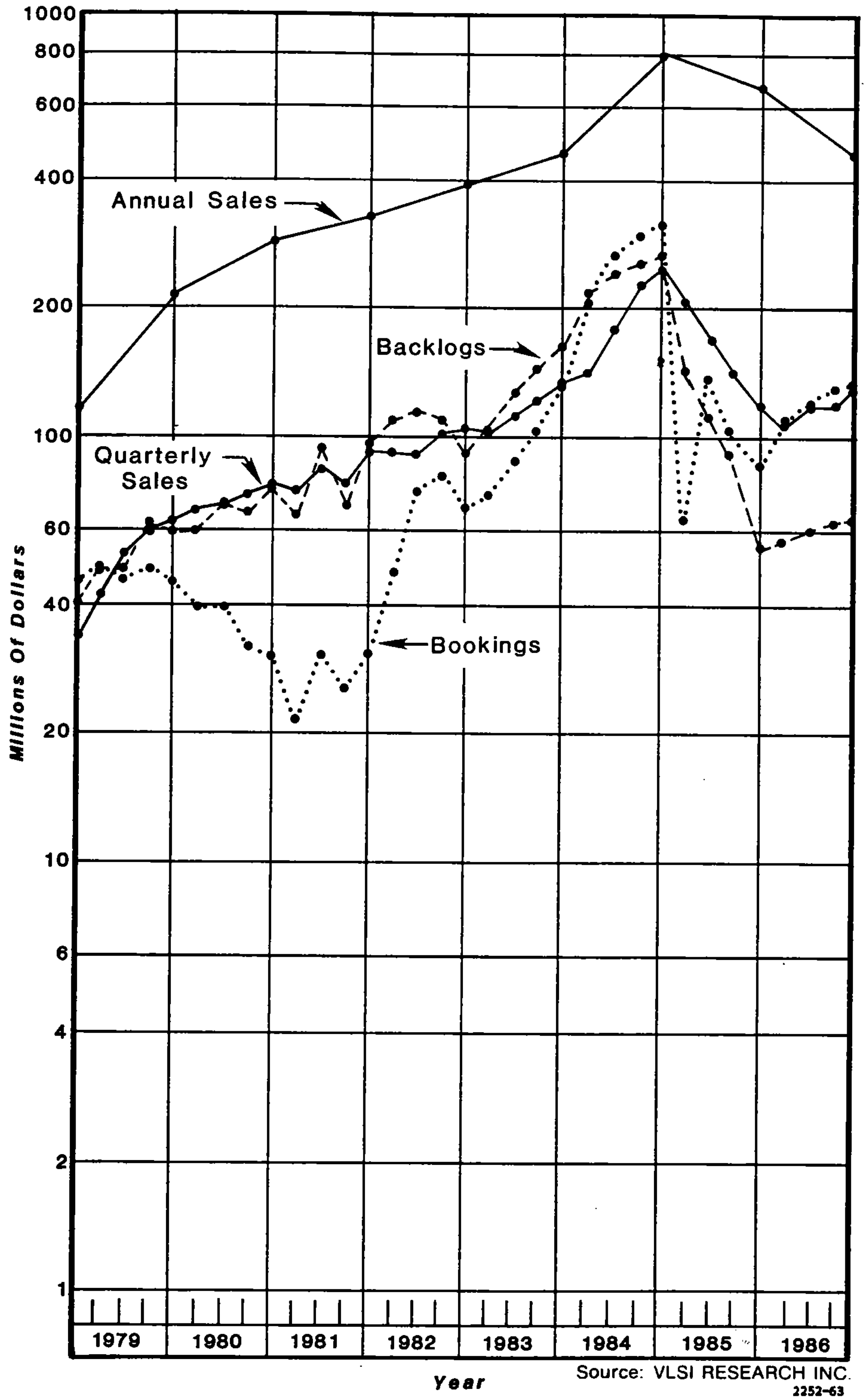

Figure 5.0.0-1

Worldwide Assembly Equipment Sales And Booking 1979-86

TABLE 5.0.0-2

ASSEMBLY EQUIPMENT VIC CODES

VLSI Research uses a standard industry code that is self-consistent throughout all VLSI Research databases—both those provided in printed media and those on magnetic media. The code is called the VIC code for 'VLSI Research Industry Code'. A complete code listing can be obtained by ordering the document entitled 'Master Source Codes in use at VLSI Research'. Abbreviated copies are found throughout this document. The VIC code numbering system follows the section-by-section outline of 'The VLSI Manufacturing Outlook'. For assembly equipment it is as follows:

```
500.00  ASSEMBLY EQUIPMENT
        530.00  Dicing Equipment
                533.00  Sawing Equipment
                534.00  Scribing Equipment
                535.00  Dicing Accessories
                        535.30  Breaking Equipment
                        535.40  Mounting Equipment
                        535.50  Surface Grinding Equipment
        540.00  Bonding & Inspection Eqpt
                543.00  Die Bonding Eqpt
                544.00  Wire Bonding Eqpt
                        544.30  Manual Wire Bonders
                        544.40  Automatic Wire Bonders
                        544.50  Gang Bonders
                545.00  Assembly Inspection Equipment
                        545.30  Die Counting Systems
                        545.40  Second Op Stations
                        545.50  Third Op Stations
        550.00  Packaging Equipment
                553.00  Molding & Sealing Equipment
                        553.30  Belt Furnaces
                        553.40  Welders
                        553.50  Presses
                        553.60  Die & Die Molds
                        553.70  Heaters and Ovens
                554.00  Finishing & Marking Eqpt
                        554.30  Lead Trimmers and Benders
                        554.40  Deflashers
                        554.50  Solder Dip and Tin Plate
                        554.60  Ink Markers
                        554.70  Laser Markers
                555.00  Lead Scanning Equipment
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Source: VLSI RESEARCH INC.
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5.1 SEMICONDUCTOR ASSEMBLY MANUFACTURING CHARACTERISTICS

5.1.0 CURRENT SEMICONDUCTOR ASSEMBLY MANUFACTURING CHARACTERISTICS

In the 1980's, assembly equipment suppliers have been under exceptional pressure by semiconductor manufacturers to increase throughput, to automate and to increase the flexibility of each system. This pressure comes about because assembly equipment is critical in the economics of the factory. By the time a wafer arrives at assembly, some 80-90% of its value has already been invested. To lose a large number of wafers or dice at this point would be very costly. Fortunately, the yield in assembly has been about 92% in the past. But with the advent of automation new issues arose. User's in this timeframe often speak of a 'lights-out factory' or of a 'peopleless assembly'. The spiralling costs of assembly as well as unrest in third world nations such as the Phillipines where much of the world's assembly is done, had manufacturers looking for more economical approaches to assembly. There was even talk of bringing assembly back 'onshore'. The pressure to return assembly onshore is also a function of the increase in ASICS. Because ASICS are low volume devices, they require fast turnaround. ASICS also place a premium on demand for new types of packaging equipment as the number of device types increase.

5.1.1 Overall Development Of The Industry

The assembly equipment industry grew out of the transistor packaging methods of the 1950's. As early as 1952, transistors were being made in standardized packages. At that time, systems began to be developed that were intended for commercial applications.

Today, the assembly equipment market can be categorized by three major segments, along with some eight or more subsegments (see Table 5.1.1-1). Assembly is the final process in semiconductor manufacturing. VLSI Research classifies it as being that manufacturing activity which begins with a finished wafer and ends with a labeled package. A flow chart of a typical assembly line is shown in Figure 5.1.1-2. This is the so-called back-end of the semiconductor manufacturing process.

After wafers have been probed and inked, they are delivered to a dicing station. At the dicing station, each wafer is first attached to a carrier of mylar tape for holding the dice in place once they have been separated. This allows easy transfer to die attach, where dice are attached to a lead frame. Holding each die in place also speeds up pattern recognition during the die attach step. This carrier, along with the wafer, is then placed in a dicing saw which saws the wafer, but not the tape, and separates the dice, while maintaining them in place.

TABLE 5.1.1-1

OVERALL ASSEMBLY EQUIPMENT SEGMENTS

■ DICING ■

- Sawing
- Scribing
- Dicing Accessories

■ BONDING AND INSPECTION ■

- Die Bonding
- Wire Bonding
- Assembly Inspection

■ PACKAGING ■

- Mold and Seal
- Finish and Mark

Source: VLSI RESEARCH INC.
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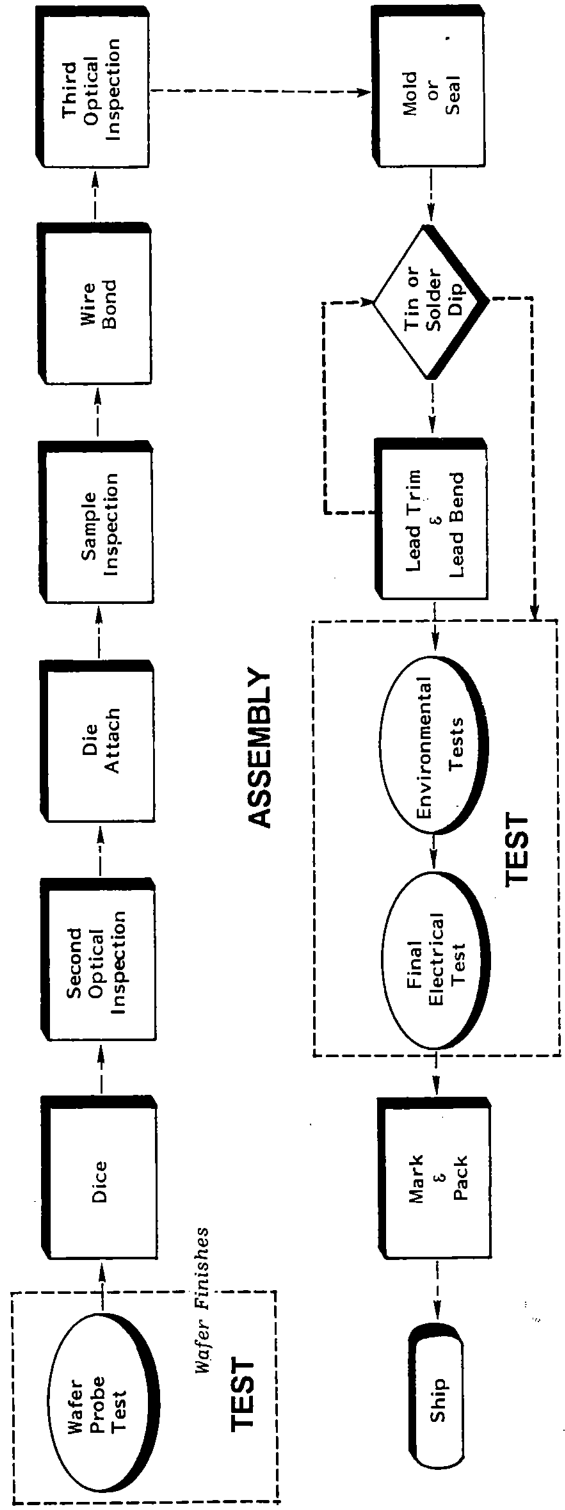
THE SEMICONDUCTOR TEST AND ASSEMBLY PROCESS



Source: VLSI RESEARCH INC

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Figure 5.1.1-2

After dicing has been completed, the dice are delivered to a second optical inspection station (second op)†. Here, they are checked for physical damage from dicing.

Additionally, complex patterns on the metal and passivation layers are also checked. The dice are next removed from the film, placed on a lead frame and bonded to the lead frame (or to a substrate). The bond between the lead frame and the die is next sample inspected to ensure that the bond is functionally correct.

Wire bonding occurs following die bonding. Wire bonding serves to interconnect package leads to the wire bonding pads on the die. Wire bonds are inspected at third op. The lead frames, with their attached die and bonding wires, are then placed in a molding-press to form the package itself. Plastic is injected into the press. Upon removal, it is cured to form the plastic package. Curing and hardening is done in a cured to form the plastic package. Curing and hardening is done in a cure oven. After curing the leads are plated. Devices may be plated by either gold plating, tin dipping or solder dipping. Gold plating is seldom used anymore because of the price of gold. If the devices are to be solder dipped, they go directly to lead trim and form. They are then returned for solder dipping later.

At lead trim and form, the excess lead material is removed and the leads are trimmed and formed as a finishing step. At this point, the package is virtually in its final state; the assembly process is interrupted to permit testing of the final package. Each part is qualified and separated according to its grade at test. After the devices have been sorted, assembly continues once again for the final step—that of marking each part according to its sorted category and its part number. Devices are often stored unmarked and marked only when they are just about to ship. This allows semiconductor manufacturers more flexibility in sales. Thus the manufacturer can replace higher grade parts with a lower grade if there is insufficient inventory in low grade parts to fill the order.

The essential steps of semiconductor manufacturing are complete after marking. The packages are now ready to be packed in a protective carton and shipped to their final destination.

† Second op continues to be called 'second' even though first op has long been eliminated from assembly. Years ago, wafers were optically inspected prior to assembly. This step was known as "First Op". However, there is little need for this now. Wafers are now given a cursory visual inspection at this stage.

5.1.2 Overall Technology Trends In Assembly

The primary emphasis in assembly has been to reduce cost per packaged unit. New types of equipment have resulted in higher productivity, higher yields, lower labor usage, and lower floor space requirements—all reducing the cost per unit. These events have resulted in significant technological trends. For example, pattern recognition has been one of the major trends affecting assembly equipment. It is now offered in dicing equipment, die attaching equipment, and wire bonding equipment. Pattern recognition is important because of its ability to improve throughput and to reduce the level of manual operation. Throughput is increased because of the reduced alignment time. Manual alignment performed by an operator usually requires over two seconds. Automatic alignment via pattern recognition can be done in less than half a second. Pattern recognition also offers yield improvements. This comes about because operator fatigue errors are reduced. With pattern recognition, several systems can be multiplexed together. This reduces the need to have an operator for every system and increases cost advantages.

Aluminum thermocompression wire bonding is another important trend that is affecting the bonding segment. It offers a cost reduction by eliminating the use of gold wire for thermocompression bonding.

Almost every type of assembly equipment is being affected by these trends to lower cost by improving throughput. One specific area that is being affected by this trend is molding and marking. In molding, developments in automated equipment molding compounds and mold design are offering higher productivity. Automated trim and form equipment with multiplunger designs, quick change tracks and long life tool and dies are shaping the world of high lead count DIP and QUAD packages. Tighter tolerances are being required of the completed package than had been ever before. Shrink versions of these same packages puts even more demand on the trim and form machines. In marking, ultraviolet curing inks and laser marking are improving both throughputs and costs.

The technological trends in assembly equipment are determined by the total number and type of semiconductors shipped. Table 5.1.2-1 shows this in terms of units shipped. These are broken out by both lead count and by package type.

Package demand by lead counts are a primary determinant of wire bonder demand. This is because the throughput of a wire bonder is

TABLE 5.1.2-1

WORLDWIDE PACKAGE DEMAND
(in millions of units)

	1984	1985	1986	1987	1988	1989	1990	1991	CAGR
By Lead Count									
2-4 Lead	79848.9	79391.5	92094.2	109285.7	114730.0	119038.5	122291.4	125632.8	6.41%
5-6 Lead	1959.5	1611.6	2060.7	2494.9	2958.8	3455.7	4002.6	4648.6	17.67%
7-10 Lead	1107.0	899.1	1240.5	1396.1	1537.9	1640.2	1757.1	1900.3	8.90%
11-16 Lead	14690.9	11977.4	14760.2	17885.9	20713.2	23911.3	27564.5	32873.6	17.37%
17-24 Lead	2912.3	2244.3	2653.3	2891.2	3104.6	3269.7	3422.7	3656.7	6.63%
25-40 Lead	2767.9	2461.6	2855.0	3468.4	4295.5	5243.0	6374.4	7563.7	21.51%
41-64 Lead	830.2	683.1	616.8	848.2	1163.5	1563.1	2000.0	2508.1	32.39%
65-96 Lead	377.8	462.8	689.8	1040.2	1388.6	1783.9	2180.9	2666.2	31.05%
97-256 Lead	66.7	82.6	114.0	208.9	354.5	502.4	656.5	893.8	50.97%
> 256 Lead	3.4	3.2	2.0	3.7	6.6	11.8	20.8	36.5	78.67%
TOTAL	104564.5	99817.2	117086.5	139523.1	150253.3	160419.6	170270.8	182380.3	9.27%
By Package Type									
TO	77779.8	75103.1	86873.9	100937.0	104000.1	103711.5	104406.9	104873.0	3.84%
SIP & ZigZag	1038.1	878.3	1174.6	1542.1	1953.8	2441.5	3022.7	3802.1	26.48%
Plastic DIP	17290.1	16010.7	18718.7	21527.7	23527.2	26575.0	29259.3	32440.4	11.63%
CERDIP	2166.5	1349.0	1915.0	2054.6	2052.6	1836.0	1602.3	1410.4	(5.93%)
Ceramic DIP	2128.7	1890.3	2013.2	2151.3	1982.2	1558.6	1348.1	1254.9	(9.02%)
Surface Mount	4161.3	4585.8	6391.1	11310.4	16737.4	24297.1	30631.4	38599.5	43.28%
Plastic CC	1065.1	1563.8	1896.4	2425.1	3032.5	3780.0	4496.7	5433.6	23.43%
Ceramic CC	1128.1	1019.0	1056.8	1320.7	1686.3	2047.5	2417.1	2863.4	22.06%
SOT	148.5	397.0	920.9	3278.6	5736.5	9285.0	12106.8	15075.9	74.91%
SOIC	373.2	408.5	999.7	2116.6	3303.7	4800.2	6333.3	8114.9	52.01%
Pin Grid Array	220.0	183.8	249.9	332.6	461.8	620.7	911.6	1305.2	39.18%
Smart Card	16.6	13.9	17.8	22.5	30.0	39.4	47.7	62.0	28.40%
COB*	1209.8	999.8	1249.6	1814.2	2486.6	3724.3	4318.1	5744.4	35.67%
TOTAL	104564.5	99817.2	117086.5	139523.1	150253.3	160419.6	170270.8	182380.3	9.27%

Source: VLSI RESEARCH INC.
2252-70

* Includes wire bond, TAB, and flip chip bonding methods.

directly related to the number of wires which it must bond. This is dictated by the following formula.

$$\frac{3600 \cdot P}{T_w \cdot L_d + T_i + T_r} = \textit{Devices bonded per hour}$$

Where:

L_d = Lead count (in units)

T_w = Wire bond time (in sec.)

T_i = Handling time (in sec.)

T_r = First pad recognition time (in sec.)

P = Plant up time & productivity ratio

Consequently, as lead counts rise, bonder demand goes up substantially. For example, consider an assembly line that starts 500 thousand packages per week. For purposes at hand, assume an automatic wire bonder is used which is rated at 250 milliseconds per wire. Handling time is 0.7 seconds and pattern recognition time is one second. P is equal to 0.53. Total hours worked per week is 120 hours. The minimum number of bonders that will be needed for this line is shown below.

Lead Count	Thruput (uph)	Bonders Needed (units)	($K)
3	778	6	480
5	634	7	560
14	367	12	960
16	334	13	1040
40	163	26	2080
64	108	39	3120

The investment needed goes up substantially as lead counts rise. There is over an order of magnitude difference between a line assembling three lead devices and one assembling 64 lead devices.

Even though much fewer IC's are shipped than discretes, IC's account for most of the bonder demand. Discrete devices are usually 2 or 3 lead devices. Of the 332 billion wires bonded in 1982, discrete devices accounted for only 44%. 11-16 lead devices alone (typically SSI/MSI devices) accounted for 26% of the wires bonded. 17-40 lead devices accounted for 23%.

Additionally, IC's are the most rapidly growing segment. Also, higher lead count devices tend to grow the most rapidly. Most microprocessors and gate arrays have pin counts above forty pins. Most memory devices have 16 or 18 leads. These are among the most rapidly growing semiconductor markets.

Five lead to ten lead devices have also grown relatively well in the mid-eighties. This is due to the growth in the linear market. Most linear devices are five to ten leads. The linear market is growing for two primary reasons. First, the market for digital signal processing (DSP) devices is relatively new and fast paced. DSP devices are a combination of digital and linear devices on one chip. They use mathematical techniques such as fast fourier transforms to analyze analog signals and transform them into digital signals or vice versa. Typical DSP devices are analog filters, codecs, spectrum analyzers, modems, speech synthesis and recognition and image processors. These devices are having profound effects on the world. These devices are teaching our children to spell and read. They give robots the ability to see and hear.

Codecs permeate modern phone systems. Digital signal processing demands have become a major part of the phone system. It is more efficient to pulse-code-modulate speech signals and transmit them as digital codes through digital circuits rather than vice versa.

Another technological trend for linear devices is the need to reduce energy requirements. Solid state controls are much more efficient than are other methods.

The 1980's boom in the video market was another area that drove the linear semiconductor market. Almost 60% of the devices that went into a video tape recorders were linear. Linear devices comprised 75% of a video camera's IC's. The average for all video products is around 70%.

Devices of fewer than four lead counts are among the slowest growing semiconductor markets. These are typically discrete devices. Devices with eleven to fourteen leads are also growing at a fairly slow pace. These are typically TTL SSI/MSI devices. The TTL SSI/MSI market has been losing ground to microprocessors and gate arrays for several years.

The trend for devices by new package type is also important in determining assembly equipment demand. In particular, the packaging segment of assembly is dependent on the type of packages produced. Additionally, bonder configurations are dependent on the type of packages assembled. TO headers represent mostly discrete and op amp devices. Plastic dips are the most common types assembled since they are also the most economical. Multi-layer CERDIP's are the next in volume produced. These packages are economical and are military approved. They approach plastic in cost. CERDIP's are commonly used for TTL devices. Ceramic packages are the most expensive packages. They are used for high lead count devices such as microprocessors and for military applications. They are also used for newly developed devices which are yield sensitive and which have a relatively high price.

Chip carriers continue to replace ceramic DIP packages for high lead count applications. Chip carriers offer several advantages over DIP's. Chip carriers have lower lead resistance, lower capacitance, higher pin counts and lower operating cost. Lead forming is less of a problem with chip carriers since leads can be made larger. This is because all four sides of the package are used. Chip carriers are also smaller than dips.

One important factor driving technology is line capacity. It determines how the line will be balanced and thus how investments in assembly equipment will be distributed. In the early to mid-eighties, most semiconductor assembly lines in use were designed to average 500 thousand die starts per week. The largest lines were capable of producing 25 million parts weekly. But, even these lines were usually broken up into 500K capacity modules. So 500K die starts per week was a good average.

Unlike the wafer process line standard of one cassette per hour, assembly line capacity is not determined by magazine capacity. An assembly line will typically start eight magazines per hour. One magazine per hour is not enough capacity to justify an assembly line. This would only be 70K die per week or about 600 die per hour. Most packaging equipment has throughput in excess of this amount. Thus, the line would be unbalanced and capacity would be wasted.

Managerial reasons are most often stated as being the primary determinant of an assembly line's capacity. A typical line manager can handle up to 25 employees. An automatic line built to employ 25 people per shift will have a capacity of 500K die per week if three shifts are used. Additionally, 500K die per week is around the minimum capacity of high capacity packaging equipment.

The amount of equipment that will be needed in assembly to satisfy this weekly rate is shown in Table 5.1.2-2. The data in the table first identifies the equipment and its area of usage. It then delineates the average selling price of the equipment, its throughput, and the number of systems needed for an assembly line of 500K die starts per week. Throughputs are given as an assembly line manager would track them. That is, by taking the actual weekly throughput of a plant and dividing by the hours worked times the amount of equipment installed. This is a pessimistic way of measuring throughput. It includes everything that could possibly slow down equipment, including breaktime and downtime. For instance, a typical automatic wire bonder may have a rated capacity of 700 units per hour. However, in practice it will only achieve half

TABLE 5.1.2-2

PRINCIPAL EQUIPMENT USED IN ASSEMBLY

Item	Where Used	Average Selling Price ($K)	Thruput † (UPH)	Systems Needed Per 500K DPW
Dicing Saw	Dicing	40	1100	4
Automatic Saw	Dicing	90	1400	3
Scrubber	Dicing	10	-	1
Wafer Mounting Gear	Dicing	10	-	1
Manual Die Bond	Bonding	8	220	19
Automatic Die Bond	Bonding	60	500	8
High Speed Automatic Die Bond	Bonding	85	1500	3
Manual Wire Bond	Bonding	10	100	42
Automatic Wire Bond	Bonding	60	350	12
High Speed Automatic Wire Bond	Bonding	90	875	5
Innerlead Bonder	Bonding	85	1600	3
Outerlead Bonder	Bonding	100	3000	2
Microscope	Inspection	8	110	38
Second Op Inspection	Inspection	23	415	10
Third Op Inspection	Inspection	14	800	5
Automatic Molding Press	Packaging	250	4800	1
Manual Molding Press	Packaging	50	830	5
Molding Die	Packaging	70	-	10
Dielectric Heater	Packaging	7	-	5
Belt Furnace	Packaging	30	6000	1
Cure Oven	Packaging	12	5000	1
Deflashing	Packaging	40	6500	1
Conventional Marker	Packaging	10	600	7
UV Marker	Packaging	40	1400	3
Ultrasonic Cleaner	Bonding	1	-	1
Degreaser	Bonding	6	-	1
Lead Trim & Form	Packaging	25	2200	2

† 14 & 16 Lead Devices, includes breaktime & downtime.

Source: VLSI RESEARCH INC.
2252-73

that rate. Thus, the assembly line must have additional equipment to produce at the needed level of capacity.

A scan down the final column shows how some equipment is heavily used while others are lightly used. The bonding area of an assembly line is undoubtedly the most equipment intensive area. It is for this reason that bonding is the largest market segment of assembly. Consequently, pressure is being brought on wire bonder manufacturers to increase uptime and throughput.

Table 5.1.2-3 shows this more clearly. It gives the investment in assembly equipment that is needed by area of equipment usage for differing types of equipment technology. These technologies are for manual equipment, automatic equipment, high speed automatic equipment, and gang bonding with automatic dicing and packaging equipment. High speed automatic equipment is a new generation of automatic equipment. Typical examples of such equipment is AMI 5400 die bonder and Kulicke & Soffa's 1482 wire bonder.

Bonding equipment accounts for 54% of the investment required for an automatic assembly line. It accounts for 41% of the investment needed for a manual assembly line. When gang bonding is used, bonding only accounts for 31% of the total investment. However, there is a substantial amount of miscellaneous equipment that is needed if gang bonding is chosen. It entails extra wafer processing equipment needed for bumping wafers. This is shown at the bottom of Table 5.1.2-3. The cost of this extra equipment should be burdened to bonding since it would not be needed otherwise. When this is done, gang bonding accounts for 51% of an assembly line investment.

Another important point concerning the gang bonded line is capital investment. The total capital investment required is not that much lower than an automatic line. The higher throughputs of gang bonding do not translate into a substantial savings. Investment is only reduced by $39K or $0.15 per week if equipment is amortized over 3 years.

Automation of the assembly line continues to be the key issue affecting suppliers to this market. This is because the fully-automated assembly line of the future is just around the corner. The trend to automate assembly equipment has been consistently accepted by semiconductor manufacturers. This does not mean that machines will be bolted together and run one continuous process. It does mean that each assembly process step will be increasingly mechanized and computer controlled to execute all aspects of the process within the tool without human setup and intervention. They claim that such equipment needs less than a five percent unit cost advantage to justify automatic equipment lines. Moreover, they claim that they will pay up to two times current prices to get such equipment. The result of this is that many plants around the world are already using automatic die and wire

TABLE 5.1.2-3

TYPICAL ASSEMBLY LINE INVESTMENT REQUIREMENTS
(Balanced for 500K Die per Week)

Equipment Type	Quantity Required				Total Investment ($K)			
	Manual	Std. Auto	High Spd. Auto.	Gang	Manual	Std. Auto.	High Spd. Auto.	Gang
DICING	6	6	3	6	180	180	270	180
Saw	4	4	-	4	160	160	-	160
Automatic Saw	-	-	3	-			270	
Scrubber	1	1	-	1	10	10	-	10
Wafer Mounting	1	1	-	1	10	10	-	10
BONDING	104	35	23	20	946	1615	1120	870
Manual Die Bond	19	-	-	-	152	-	-	-
Automatic Die Bond	-	8	-	-	-	480	-	-
High Speed Die Bond	-	-	3	-	-	-	255	-
Manual Wire Bond	42	-	-	-	420	-	-	-
Automatic Wire Bond	-	12	-	-	-	720	-	-
High Speed Wire Bond	-	-	5	-	-	-	450	-
Inner Lead Bond	-	-	-	3	-	-	-	255
Outer Lead Bond	-	-	-	2	-	-	-	200
Microscope	38	-	-	-	304	-	-	-
Second Op Inspection	-	10	10	10	-	345	345	345
Third Op Inspection	5	5	5	5	70	70	70	70
PACKAGING	34	20	16	20	1194	1190	1298	1190
Manual Molding Press	5	-	-	-	250	-	-	-
Automatic Molding Press	-	1	1	1	-	250	450	250
Molding Die	10	10	10	10	700	700	700	700
Dielectric Heater	5	-	-	-	35	-	-	-
Belt Furnace	1	1	-	1	30	30	-	30
Cure Oven	1	1	-	1	12	12	-	12
Deflashing	1	-	-	-	40	-	-	-
Conventional Marker	7	-	-	-	70	-	-	-
UV Marker	-	3	3	3	-	141	141	141
Ultrasonic Cleaner	1	1	1	1	1	1	1	1
Degreaser	1	1	1	1	6	6	6	6
Lead Bend & Trim	2	2	-	2	50	50	-	50
MISC GANG BONDING EQPT	0	0	0	6	0	0	0	569
Bump Plater	-	-	-	2	-	-	-	240
Proximity Aligner	-	-	-	1	-	-	-	165
Resist Processing	-	-	-	1	-	-	-	119
Scrubber	-	-	-	1	-	-	-	20
Etch Station	-	-	-	1	-	-	-	25
TOTAL	144	61	42	52	2320	2985	2688	2809

Source: VLSI RESEARCH INC
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bonding equipment which eliminates most operator intervention. Fully automated encapsulation (molding) systems and trim and form systems have reached the market. Major U.S. companies are installing this equipment at their primary onshore locations as rapidly as possible. Workers are only needed to carry magazines from machine to machine with this equipment.

Automation of the assembly line is occurring because it is an important way to reduce costs on high volume, low margin devices, as shown in Section 5.1.3. On these parts, die manufacturing costs are usually only twenty to thirty percent of total costs. However, assembly usually accounts for sixty to seventy percent of the total costs. Additionally, high volume, low margin devices account for over 80% of all devices assembled. Consequently, automation of assembly promises substantial increases in profits for semiconductor manufacturers.

How automation will occur in assembly will be dependent on its definition as applied by semiconductor manufacturers. The semiconductor industry does not equate automation with automated mechanisms for die transport. That is only one aspect of many. Instead, the semiconductor industry is virtually unanimous on the following definitive points concerning automation:

- Automation means more intelligent computer controlled machines capable of better operating their own activities.
- Automation means more than automatic feeding of the machine.
- Die transport is still more efficient when done by people rather than when done by machines.

These opinions are consistently echoed throughout the world. The reasons underlying these opinions are related to the prices and throughputs and reliability of equipment. Throughputs vary significantly among the various types of assembly equipment. The line must be balanced so that the equipment is fully utilized. The equipment is expensive, so an in-line system of one piece of equipment after another would not be cost effective. The reliability of the equipment becomes a critical point because the reliability of the integrated system is the product of the reliability of the individual parts.

This balance will be highly dependent on various production parameters. Examine Table 5.1.2-4. It lists typical assembly line parameters that have been obtained and those that were believed to be evolving in the early to mid-eighties by end-users. As mentioned

TABLE 5.1.2-4

ASSEMBLY LINE VARIABLES

Parameter		1983	1988
Die Starts per Week	(K units)	500	2000
Products Processed	(units)	50	25
Lead Frame Types	(units)	10	2
Number of Die per Lot	(K units)	10	80
Number of Lots per Run	(units)	4	8
Number of Die Collets Used	(units)	50	25
Number of Wire Types Used	(units)	1	1

Source: VLSI RESEARCH INC.
2252-76

previously, a typical line in 1985 assembled 500K die per week. It handled an average of fifty products. Most of these can be assembled on common lead frames—about ten products for each lead frame. However, each product will usually require its own die collet for die attaching. Only one type of wire is typically used on an assembly line. This eliminates production control problems associated with changing wire. Lot sizes were usually about ten thousand die. Four lots are usually processed at a time.

Larger lines are usually scaled up accordingly. For example, many companies already build lines with a capacity of 2000K die per week. Such a line will process 200 products types per week and it will use 4 wire types. There are some notable differences. Such a line will continue to use the same lot sizes. Total lead frames used only increases to 14 on average.

In the future, changes in these parameters will favor automation even more. The industry expects that further advances in automation will allow productivity to increase by four times during this time frame. Thus, twenty-five workers who can now produce 500 thousand parts per week will be able to produce over two million parts per week in 1988. Additionally, the number of product types produced on each line will increase in this time frame. As semiconductor companies grow larger they will lose economies of scale by the non-dedication of lines to more products. This will require equipment to become more flexible.

How it will create flexibility will be highly dependent on existing automated plant configurations. There are several existing automated facilities from which inferences about future lines can be drawn. Some of these are at National Semiconductor, TI, Hitachi, Fairchild, NEC and Toshiba. The National Semiconductor, NEC, Fairchild and TI facilities emphasize intelligent equipment. These are typical of what can be done with equipment available today. But they use people to carry magazines. They are all dominantly magazine-magazine oriented. These companies are not investing heavily in die transport mechanisms. However, they do feel that increasing reliability in equipment will enable serial in-line automation ultimately.

Hitachi's and Toshiba's assembly lines are, for the most part, in-line. The in-line portion starts at die bonding and finishes with completed packages. The only steps left are testing, during marking and solder dipping (if needed). The actual flow of die is very similar to that of a conventional automated line. Wafers are conventionally diced on film carriers. A second optical inspection is then performed. Information concerning good die is added to a map stored on a floppy disk. This disk will already have a map of electrically good die. These are mapped at wafer probe by the tester. The floppy disk and the cassette of diced wafers are then transferred to the die bonder. The die bonder reads the map and directs the bonding head directly to good die for bonding. Lead frames are then directly transferred to a wire bonder. A fully automatic third op is completed after wire bonding. Then, lead frames are automatically transferred to a fully-automatic molding system. Packages are completely deflashed and deburred. Leads are trimmed and formed. Assembly is finished at that point.

This, combined with concepts from other companies generates a fairly clear picture of the assembly line of the future, as depicted in Figure 5.1.2-5.

It is important to note that there are five distinct islands of automation in such a line. These are dicing, die bonding, wire bonding, molding and trim and form. Second optical inspection, and lead finishing will continue to remain separate from the line. Few semiconductor manufacturers feel that second optical inspection will be incorporated into automated lines. The reasons most commonly given are that second optical inspection throughputs vary significantly depending on the type and grade of product assembled. An in-line system cannot be balanced unless the line is dedicated to a few product types. Consequently, it is better to keep second op separate.

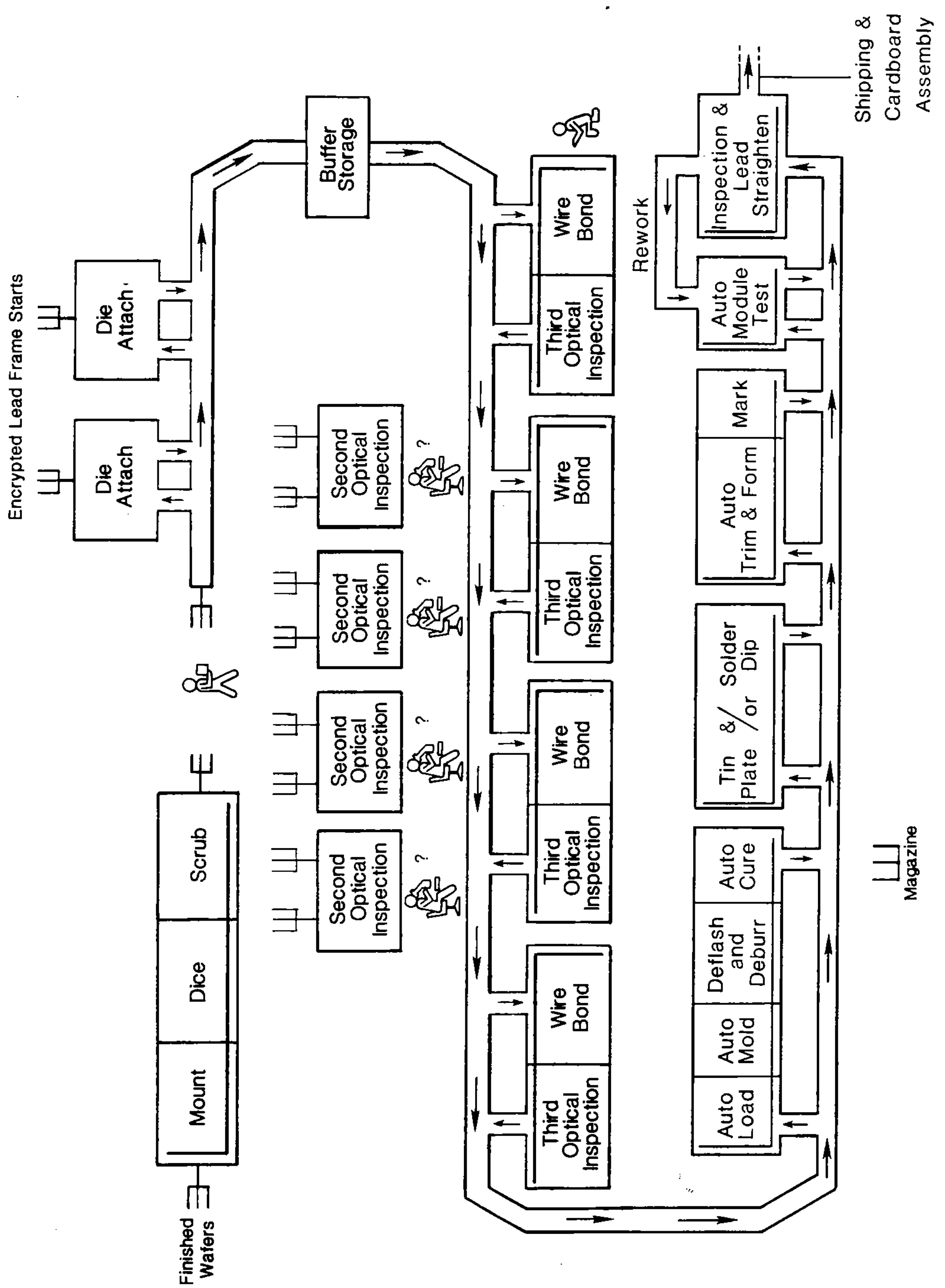
There is a significant issue concerning the viability of automatic inspection methods. In some cases automatic inspection is already being used. This is most common for high volume and low technology devices such as SSI/MSI parts. However, the inspection is usually limited to a cursory check for an ink dot and four corners on the die. VLSI devices are still too complex for automatic inspection. Consequently, a variety of equipment will continue to be used in this area.

The issues which cause finishing to be kept separate are related to the semiconductor market itself. Semiconductor users have need for both tin plated devices and solder dipped devices. Consequently, most assembly lines must have accommodations for both. Tin plating requires that devices be still in lead frame form. Solder dipping requires that devices have leads already trimmed and formed before dipping. Consequently, most automated lines will end after deflash and deburr. Several die bonders and wire bonders will be required in order to keep up with molding and dicing operations. There is a buffer storage added between die bond and wire bond. This allows the bonder island to prepare for incoming devices. Encrypted lead frames enter the plant at die bond. Codes on lead frames and mylar carriers identify the lead frame type and the device type. The bonders can then be automatically set up using programs that it has stored previously from a CAD system.

An almost universal opinion exists that rework will be eliminated in future wire bonding operations. Third optical inspection will evolve as a self-testing mechanism for wire bonders. Consequently, it can be expected that third op will become a part of the wire bonding system,

Figure 5.1.2-5

ASSEMBLY LINE OF THE FUTURE (1986-1991)



Source: VLSI RESEARCH INC.

much like the die bonder self-test systems. These systems are designed so that the bonder will stop-on-fail without any operator attention. The machine will then self diagnose itself and alert the production control host that it is down.

Note that an ever-present maintenance person is shown at the wire bonder. Semiconductor manufacturers feel that bonder maintenance is a serious limitation to automation. Consequently, future lines will be designed such that production will not be halted if any one system is down. Material will pass by equipment via the portways shown in Figure 5.1.2-5. Material will move off the portway to operating equipment. It will move back to the portway once it has been processed. If a tool is down, material will bypass it and move to one which is running. Such lines are commonly referred to as serial in-line.

Devices are then automatically transferred to a molding station. After finishing, an indexer will be needed for devices which need to be solder dipped. These can then be transferred back for trimming and forming leads.

Another technological trend is toward information management. A substantial amount of information will need to be passed through this system. This information concerns where the dice are in the line, and what their identification is. This information will be tracked via lead frame coded labels. It will include data concerning the device type so that equipment can be automatically set up. Additionally, data which ties the lead frame to the original wafer and lot will also be kept for later analysis. Many applications require absolute traceability, e.g. military, medical, and any high reliability application areas.

An archival host processor must be available to interface to each piece of equipment. One of the most important tasks of the archival host computer will be to schedule and route jobs. For example, an assembly line capable of one million die per week will have about 12 million die being assembled at any one time. Jobs will need to be scheduled and routed to minimize inventory costs of the finished parts.

Recipe management and execution is a task which will continue to stay with the equipment. The purpose of recipe management is to ensure that each magazine of dice receives each process step correctly. Most automatic equipment already has this capability. Most users want it to stay that way. They demand that assembly equipment be able to function independently of a host processor.

Not withstanding that requirement, cell or host processors will keep track of the recipes loaded into each automatic machine and have the ability to down load new one's when the need arises. This keeps the line running with minimum human intervention. The independent execution allows the line to keep running when the cell or host is not immediately available. Users want this type of operation.

Cleanliness will also be an issue in future assembly lines. In 1985, air cleanliness was typically class 8000. It was class 5000 in bonding. Some companies operate in a class 100 environment already. By 1988, air cleanliness is expected to reach class 3000 for the industry as a whole. Moreover, 57% of those interviewed foresaw a distinct need for environmentally enclosed equipment.

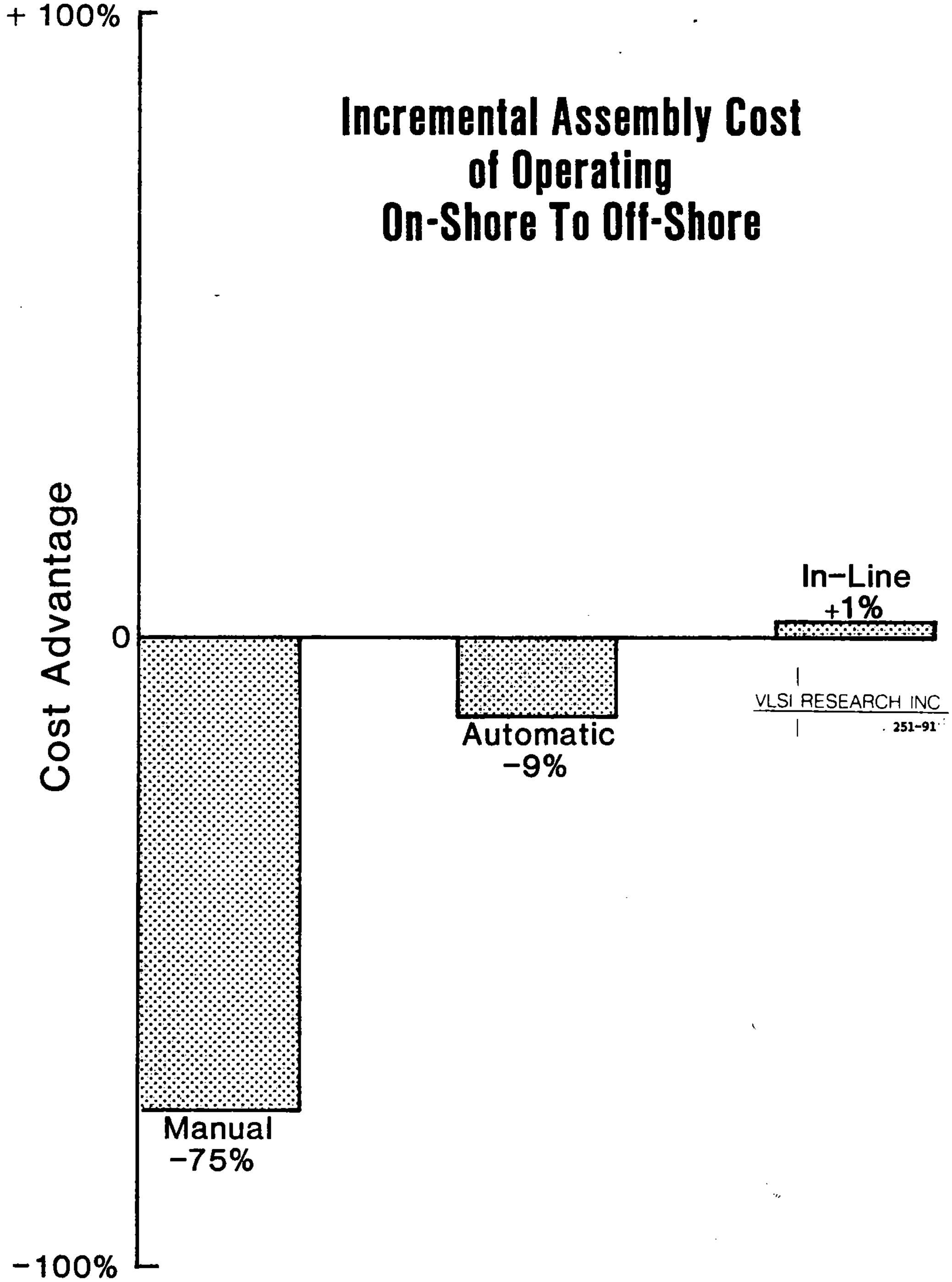
Technological trends toward automation are brought by the pressure to do assembly onshore. Currently, assembly operations are predominantly based offshore, principally in the Far East. Historically, cheap labor costs have been the driving force of such offshore assembly operations. However, as inventory and transportation costs began to rise, the savings of offshore assembly declined. Labor for non-automated assembly in very large plants only requires 10% of total costs. This caused importance of labor as a determining factor in assembly plant location to diminish. With the overriding issue of labor costs removed, other non-quantitative reasons for on-shore assembly gained more visibility.

There are security and political instability issues which tend to favor onshore assembly. Foreign governments may be here today and gone tomorrow. Furthermore, weather is not a major problem for most onshore sites. There can be quicker turnaround times for onshore plants. This allows better customer service. Inventory costs are lower for onshore plants since there is less work in process. Freight costs also present an important tradeoff. When high lead count ceramic packages are required it is no longer economical to assemble offshore. Additionally, wage premiums do not have to be paid to U.S. managers and technical personnel when onshore assembly is used.

Fully automated assembly plants can be shown to offset the labor advantages obtained in the East. This is shown in Table 5.1.2-6. The costs are still 75% higher when operating manual equipment on-shore in the mid-eighties. However, this disadvantage drops to 9% for operating automatic equipment on-shore. This drop is mostly attributed to reductions of labor cost. For in-line equipment, it costs 1% less when assembling on-shore as compared to offshore assembly. This may seem small but its benefits are actually much larger since inventory costs were not included in this analysis. A minimum of four days additional inventory is needed for off-shore assembly. This adds a minimum of a penny per package.

In addition to making on-shore assembly more cost effective, automation is the driving force behind equipment changes. This is because of automations cost advantage in the mid-eighties is shown in Table 5.1.2-7. This table examines cost over the operating lifetime of an

TABLE 5.1.2-6


+ 100%
Incremental Assembly Cost
of Operating
On-Shore To Off-Shore
Cost Advantage
0
In–Line
+1%
VLSI RESEARCH INC
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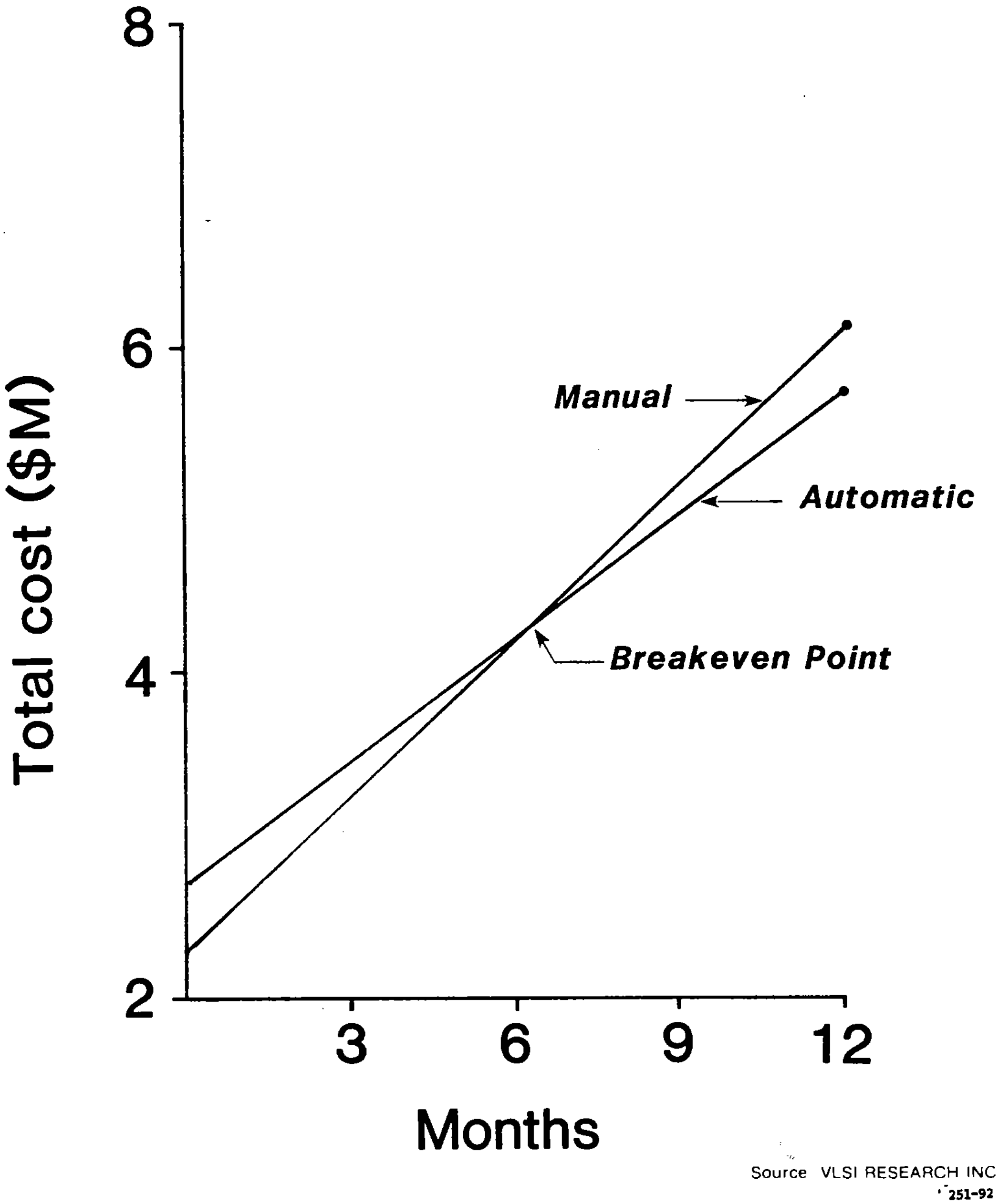
Automatic
−9%
Manual
−75%
−100%

TABLE 5.1.2-7

Automation's Cost Advantage



assembly line. The initial start-up cost for automatic equipment is higher than that for manual equipment. However, on-going operating costs are lower for automatic equipment. It takes only 6.3 months for automatic equipment to pay for itself. In a year, automatic equipment is already approximately 6% more cost efficient.. The advantage of using automatic equipment increases to almost 15%, or about $2M over a 3 year period. This cost savings will almost buy the equipment for another automated line. These factors will have a tremendous impact on the market share of automated equipment.

5.1.3 Factory Economic Models

The level of equipment automation purchased is dependent upon factors such as number of devices produced and complexity of devices. Table 5.1.3-1 shows the investment difference between a manual line and an automatic line to be $665K. This represents a savings of only $4.26 per week. However, the additional labor and floorspace required for the manual bonding line far outweigh the equipment savings. This is due to the additional 78 pieces of equipment required for the manual line. Additional labor costs alone add up to over $10 thousand per week. This cost is for an off-shore facility. In the U.S., labor accounts for $60 thousand per week more. Table 5.1.3-1 breaks out the costs of assembling a 16 lead plastic package for each type of assembly line technology. High speed automatic assembly is seen to be the most economical method. It offers a 10% cost advantage over gang bonding and standard automatic methods. This advantage is gained by lower labor and floorspace requirements. Over $300 thousand can be saved per year by using high speed automatic assembly equipment. It is also clear that automatic equipment is more economical than is manual equipment.

TABLE 5.1.3-1

UNYIELDED OPERATING COST MEASURES FOR ASSEMBLY

Line Type		Manual	Standard Automatic	High Speed Automatic	Gang
General Parameters					
Price	($K)	2320	2985	2688	2809
Operating Lifetime	(Years)	3	3	3	3
Installation Costs	($K)	116	149	134	140
Maintenance Rate	(%)	15	15	15	15
Floorspace Requirements	(Sq.Ft.)	14000	8850	6090	8300
Floorspace Costs	(¢/Sq.Ft./Hr.)	0.5	0.5	0.5	0.5
Labor Requirements	(Persons/Hour)	113	25	20	32
Labor Rate	($/Hour)	1.10	1.10	1.10	1.10
Throughput	(UPH)	4167	4167	4167	4167
Material Consumption	(UPH)	4167	4167	4167	4167
Material Costs	(CPU)	5.3	5.3	5.3	6.1
Fixed and Variable Costs in Cents per Package†					
Equipment		3.1	4.0	3.6	3.8
Labor & Overhead		3.0	0.7	0.5	0.8
Maintenance		1.3	1.7	1.6	1.6
Floorspace		1.7	1.1	0.7	1.0
Materials		5.3	5.3	5.3	6.1
TOTAL COST (Cents per Package)		14.4	12.8	11.7	13.3

† 16 Lead Plastic

Source: VLSI RESEARCH INC
251-19

5.1.4 Competitive Environment in Assembly Equipment

More than 100 companies participate in the assembly equipment market. Collectively, their sales reached $824 in 1988, and are expected to surpass $1.7B in 1993.

A list of all major competitors is given in Section 5.1.9. The list is segregated by market served, and is kept current.

Shinkawa is once again ranked number one in the total assembly market, having recently displaced Kulicke & Soffa.

Shinkawa held the number two spot in 1986, while Disco held the number three position. Both competitors have gained market share from Kulicke & Soffa.

Other major competitors are ASM, General Signal, Towa, Kras and Yamada.

Fairly turbulent demographic trends have occurred as a result of the international competition for the assembly equipment market. These demographic trends have been characterized by rapidly shifting shares in the international marketplace. Table 5.1.4-1 shows market share for 1984 and 1986. North American assembly manufacturers held 42.5% of the worldwide market share, while Asian manufacturers held 46.3% and European manufacturers held 11.2% in 1986.

TABLE 5.1.4-1

DEMOGRAPHIC DISTRIBUTION OF ASSEMBLY EQUIPMENT SALES
(by percent of seller's shipments, worldwide)

Equipment Type	*North America*		*Asia*		*Europe*	
	1984	***1986***	***1984***	***1986***	***1984***	***1986***
Dicing Equipment	33.8	19.4	61.1	76.3	5.1	4.3
Bonding & Inspection	45.5	44.4	35.7	40.7	18.8	14.9
Packaging	51.5	45.8	40.5	45.1	8.0	9.1
TOTAL	47.3	42.5	39.7	46.3	13.0	11.2

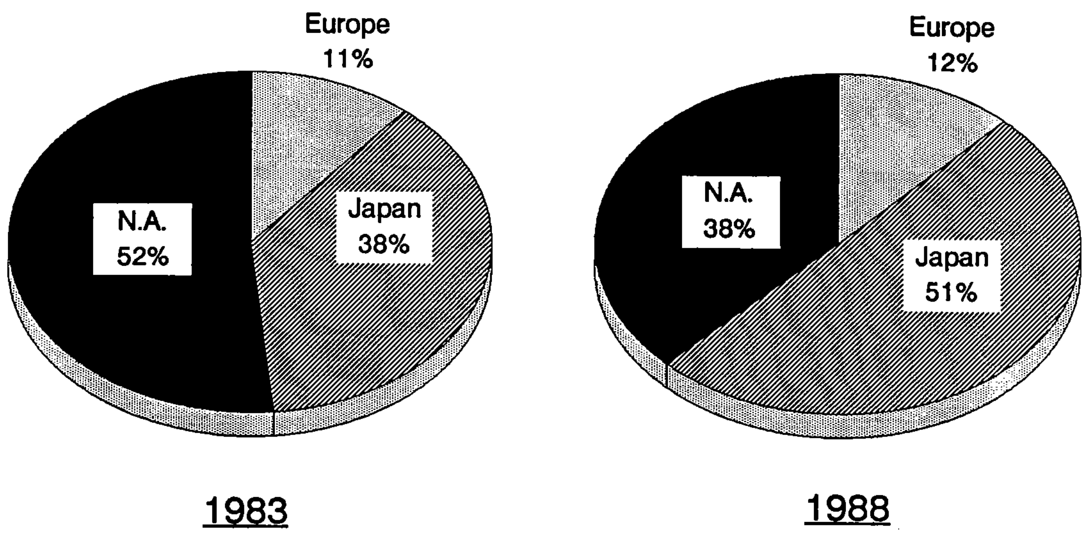
These trends have been driven by technical innovation. The Japanese emerged strongly in the mid-seventies and captured a large portion of the market share. This trend was spearheaded by Shinkawa and its automatic wire bonder. In 1977, the Japanese had reached a par with American manufacturers. Only two percent of the market share separated American manufacturers from Japanese manufacturers.

But by 1980, American manufacturers were ahead by almost thirty percent—controlling almost sixty percent of the market share. In 1980, Japanese suppliers provided only thirty percent of world sales. Kulicke & Soffa lead this drive with its invention of the digitally controlled wire bonding head. Meanwhile, European suppliers began to enter strongly with a new generation of die bonders. Nevertheless, by 1981, market share had begun to shift back in favor of the Japanese. Automated packaging equipment and dicing saws drove this trend. In addition, Japanese semiconductor companies continued to invest heavily in automated assembly during the downturn. American semiconductor companies did not. Hence, Japanese equipment companies gained worldwide market share.

In 1981, United States assembly equipment companies began to increase their worldwide market share once again. Once business turned, American semiconductor companies began to invest heavily in new assembly capacity. This offset the market share gains of the Asian equipment companies in 1981. The 1985 recessionary period favored both North American and European companies. Japanese semiconductor companies cut back heavily on equipment expenditures. This lowered the worldwide share of Japanese equipment companies. In 1986, the recession began to take its toll on North American and European assembly suppliers. Market share that had been won from Asian suppliers in the previous year was quickly eroded. Asian manufacturers actually captured an additional 6.6% over that lost in 1985. However, by 1988 Shinkawa had once again pushed ahead of Kulicke & Soffa, causing the Japanese to regain the top market share position. Figure 5.1.4-2 shows historical demographic market share.

TABLE 5.1.4-2

OVERALL ASSEMBLY EQUIPMENT MARKET SHARE



5.1.9 Assembly Equipment Database

Section 5.1.9 provides a listing of competitors in the assembly equipment market. Current competitive data for these competitors is provided in each of the following sections:

5.3.9 Dicing Equipment
5.4.9 Bonding & Inspection Equipment
5.5.9 Packaging Equipment

The most recent projections for each market are given in Section 1.9.5 of Volume 1.

TABLE 5.1.9-1

MAJOR SUPPLIERS OF ASSEMBLY EQUIPMENT

Company	*Dicing*	*Bonding*	*Packaging*
3-S Phoenix	-	•	-
Adcotech	-	•	•
Advanced Semiconductor Mat'ls (ASM)	•	•	•
Alteq	-	•	-
Alphasem	-	•	-
Amedyne	-	•	-
American Tech Manufacturing (ATM)	-	-	•
Applied Imaging	-	•	-
ARBO	-	-	•
Aremco	•	-	-
Associated General Labs	-	-	•
Atumaku Giken	-	•	•
Automated Laser Systems	-	-	•
B. Grauel	-	-	•
Benchmark	-	-	•
BTU International	-	-	•
C.A. Lawton	-	-	•
Cone-Blanchard	•	-	-
Chuo Riken	-	-	•
Dai-Ichi Seiko	-	-	•
Daichi Seiki	-	-	•
Dainippon Screen	-	•	-
Delvotech	-	•	-
Dicing Technology	•	-	-
Die Hard Engineering	-	-	•
DIAS Automation	-	•	-
Disco Abrasive Systems	•	-	-
Dr. Tresky Engineering	-	•	-
Dusan	-	-	•
Dynablast	-	-	•
Eastern Marking Machine	-	-	•
Electrobert	-	-	•
Elmont International	-	•	-
Emhart	•	•	-
ESC	-	-	•
ESEC	•	•	-
Ewald	-	•	-
Excellon Micronetics	-	•	-
Farco	-	•	-
Fancort Industries	-	-	•
Finmac	-	-	•
Fuji Advanced	-	•	-
Fuji Seiki	-	-	•
Fujiwa	-	-	•
General Signal	•	•	•
Gluco	-	-	•
GTI	•	-	•
Heller Industries	-	-	•
Hepco	-	-	•
Himi	-	-	•

Source: VLSI RESEARCH INC
2202-348W

TABLE 5.1.9-1

MAJOR SUPPLIERS OF ASSEMBLY EQUIPMENT

Company	*Dicing*	*Bonding*	*Packaging*
Hitachi	-	•	-
Hollis Engineering	-	-	•
HTC	-	-	•
Hughes	-	•	-
Hull	-	-	•
Hybond	-	•	-
Idea	-	•	-
Ideya	-	-	•
IMI	-	•	-
Integrated Circuit Automation	•	-	-
J.D. Sprout	-	-	•
Jade	-	•	-
Kaijyo Denki	-	•	-
Karl Suss	•	-	-
Keller Technology	-	•	-
Kohtaki	-	-	•
Koyo Lindberg	•	-	-
Kras	-	-	•
Kulicke and Soffa	•	•	-
Lapmaster	•	-	-
Lauffer	-	-	•
Laurier	-	•	-
Loadpoint	•	-	-
Loomis Industries	•	-	-
Lumonics	-	-	•
Markem	-	-	•
Mechanization Assoc.	-	•	-
Mech-El	-	•	-
Mesa Technology	-	•	-
Micro Bond Technologies	-	•	-
Minitron	•	-	-
MTI Corporation	-	-	•
NEC	-	-	•
New Dynamics	-	-	•
Nihon Avionix	-	•	-
Nihon Dennetsu Keiki	-	•	•
Okamota	•	-	-
Orthodyne	-	•	-
Pasadena Hydraulics	-	-	•
Penn Research	-	-	•
Pennwalt	-	-	•
Polaris Electronics	-	-	•
PolyMold	-	-	•
Probe-Rite	-	•	-
Quantrad	-	-	•
Radiant Technology	-	-	•
Research Instruments	-	-	•
Sakai Mfg.	-	•	•
Scientific Sealers	-	-	•
Semiconducotr Equipment Corp.	•	•	-

Source: VLSI RESEARCH INC

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TABLE 5.1.9-1

MAJOR SUPPLIERS OF ASSEMBLY EQUIPMENT

Company	*Dicing*	*Bonding*	*Packaging*
Semprex	-	-	•
Shibuya	-	•	•
Shinkawa	-	•	-
SLEE	-	-	•
Speedfam	•	-	-
Solid State Equipment	-	-	•
South Bend Lathe	-	-	•
R. Howard Strasbaugh, Inc.	•	-	-
Superwave	-	-	•
Systemation Engineered Products	-	-	•
Tamura Seisakusho	-	-	•
Taylor Winfield	-	-	•
Tekara	-	-	•
Teledyne TAC	-	•	-
Terra-Universal	•	-	-
Texas Instruments	-	•	•
TESEC	-	•	•
Thompson General	-	-	•
Tokyo Seimetsu	•	-	-
Tokyo Sokuhan	-	•	-
Tool and Die Masters	-	-	•
Toshiba Seiki	-	•	-
Towa	-	-	•
Tru-Mark International	-	-	•
Ultrasonic Engineering	-	•	-
Unitra	-	•	-
Universal	-	•	-
U.S. Laser Corp.	•	-	•
View Engineering	-	-	•
Viking Semiconductor	-	•	-
	-	-	•
W.T. LaRose	-	-	•
Wakatsuki	-	-	•
Watkins-Johnson	-	-	•
Wheelabrator	-	-	•
West Bond	-	•	-
Yamada	-	-	•
Zftm	-	•	-

Source: VLSI RESEARCH INC

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Notes