Automatic Chip Placement: One Solution, User-Benefits, and Future Development

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Abstract

Flexible, automated chip (die) placement is a complex and ever changing requirement in the micro-electronics industry. This evolution is a function of electronic packaging technologies which are continuously maturing. Today, multi-chip modules (MCM) can incorporate any combination of wire bonding, flip chip, and tape automated bonding (TAB) technologies. In fact, General Electric Co. has developed a new technology of "batch" interconnecting that has eliminated the traditional connections between the ICs and module wiring traces. Of course, traditional hybrid circuit manufacturing continues to challenge the industry. Similarly, chip-on-board (COB) on FR-4 material, which emphasizes miniaturization and improved electrical performance requires, the utilization of flexible assembly equipment.

This paper will not explore the advantages and disadvantages of the different packaging techniques (i.e., density, performance and reliability). However, it will explore the generic chip placement challenges, assembly options, one solution, and the real benefits. The paper will also address new developments in chip placement systems, including ultra-precision placement.

Chip Placement Challenge

One common element in the manufacturing of electronic packages such as hybrids, multi-chip modules, and PWB (using COB) is bare chip placement. The challenge for circuit manufacturers is to assemble complex devices at high speeds, with high consistency, and at low costs. With the latest MCMs, equipment must be capable of accurately placing bare die on substrates incorporating finer pitch and denser routing layouts than traditional thick film technologies. For microwave hybrids, die must be placed with high accuracy to minimize tuning requirements for the RF circuitry. As operating frequencies of the devices increase, accuracy will become even more critical. Similarly, hybrid circuits offer extremely efficient packaging techniques for biomedical electronics. The heart pacemaker is the most representative of this trend. The continuous trend of miniaturizing these packages results in a need for systems that place chips very accurately with minimum device to device distances.

The continuing demand by the military for improvements in electronic packaging has led to the increased use of hybrids in military and space level systems. Besides adhering to high quality and reliability standards, these hybrid manufacturers usually manufacture in a high mix/low volume environment. Consequently, product changeover on the equipment, including die bonders, must be simple and fast.

Packages utilizing flip chip die require two levels of accuracy. For solder reflow, die placement may be off by as much as half a bonding pad, since surface tensions in the molten solder during reflow will force proper alignment of the die. Although solder reflow is somewhat forgiving, system accuracies must steadily increase as bump diameters decrease. For example, flip chips with 0.003 inch diameter bumps must be placed to within ± 0.0015 inch. Other bonding processes for flip chip include eutectic, thermocompression and compression bonding. Assembly accuracies for some of these processes could be on the order of five microns. These ultra-precision die placement applications (under 0.001 inch) will be addressed in the last section of this paper (*Future Development*).

Typical problems faced by hybrid circuit/MCM/COB manufacturers include contamination, chipped and cracked die, improperly oriented die, improper location of die, and incorrectly placed die (e.g., mixed wafflepacks). Moreover, inaccurate placements are a major cause of insufficient epoxy coverage around the die. These conditions significantly impact product yield, consistency, rework, and attrition. Moreover, improper die placement negatively impacts the next process step -- I/O interconnect. This process might be wire bonding (hybrid/MCM/COB), solder reflow (flip chip), or laser/photo-lithography.

The generic challenge in automating die placement is dealing with the complexity and variety of circuit types. These electronic packages are being used in the military, communications, computer, automotive, instrumentation, and consumer markets. Anticipated annual growth rates for some segments such as communications are expected to be over 10% during the nineties. Accordingly, the variety and volume of these packages will vary among the different industries.

Hybrid circuits consist from one to over 200 die with a significant number of different components -- silicon-based die, Gallium Arsenide (GaAs) die, ceramic/tantalum capacitors and surface mount resistors. Furthermore, components vary in size from 0.2 mm (0.008 inch) to 17.5 mm (0.700 inch), and they have complex, near symmetrical, and some very unique patterns. These parts must be analyzed, picked, oriented, and placed on both printed wiring boards (PWB) and thin/thick film substrates of varying material (ceramic, silicon, etc.). An east coast hybrid manufacturer is challenged with building some very complex circuits. For example, one hybrid has up to 169 components and 40 different die types (see figure 1).

Each automated process is highly dependent on the quality and throughput of the previous operation. According to one source, die placement inconsistencies negatively affect automatic machines. Automatic pull-test machines require consistently placed bonds, and wire bonder performance is significantly enhanced if die locations are consistent. Manufacturers sight the reliance of fast, accurate machine vision processing to build consistent, reliable hybrids.

High quality die bonding is already a major concern for these more progressive circuit manufacturers. Machines specifications now contain requirements for six sigma levels in production. This single digit parts per million (ppm) defect level presents a tremendous challenge for die bonder equipment vendors.

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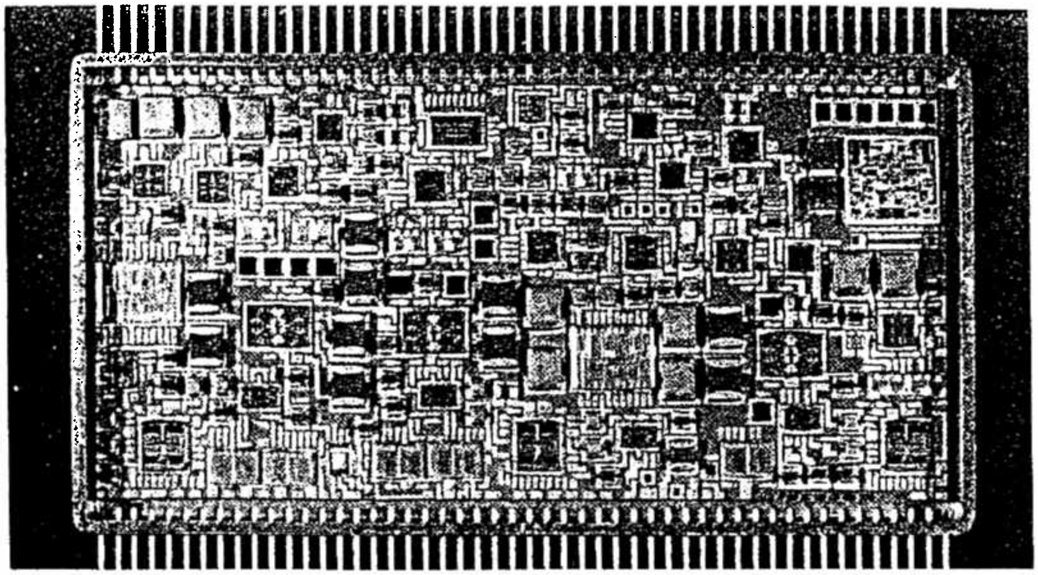

Figure 1. Complex, high density hybrid circuit

Assembly Options

A company interested in procuring die bonders faces a large pool of equipment vendors. Depending upon the application and the type of manufacturer, this list can be narrowed down considerably. Machine throughput, flexibility, reliability, cost, accuracy, process control, level of automation, capacity, and remote operation are important considerations.

The range of die bonders range considerably. At one extreme, humans manually pick and place die with the use of vacuum pens and microscopes. At the other extreme are fully automated systems with CAD interface for the teaching of placement locations.

The market for manual and semi-automatic die bonders is still significant. For example, smaller contract houses or research facilities do not need (volume) or cannot always afford fully automated systems. Vendors for this level of equipment include Westbond, Kulicke & Soffa (K&S), Semiconductor Equipment Corp., Laurier, and Hughes Aircraft. However, when economically justified, fully automated die placement will force the manufacturer into a higher level throughput, and in many instances, a higher quality level of production.

The fully automated die bonding market can be segregated into various segments. At one end of the spectrum are the high speed, dedicated die bonders from companies such as Assembly Technologies, Kulicke & Soffa Industries, Force Systems, ESEC, NEC, Shinkawa and Toshiba Seiki, to name a few. These machines typically pick from wafer(s) using ink dot recognition or wafer mapping protocols. They place die in different package types; however, the most common output is multiple lead frames. The flexibility for these machines is to handle (gently) a variety of these lead frame types. New developments for this sector will be more flexibility in picking and placing chips to/from different locations, handling standard and flip chip die, placing with higher accuracies, and dispensing with novel techniques. For example, Dynapert recently announced a system which can pick from up to six different wafer types. Still, more flexibility is required for packages with numerous component types typical in many hybrid, COB and MCM packages. Machines of this type fall on the other end of the automated die placement spectrum -- flexible, accurate, high capacity die bonders.

One Solution

One commercial solution for automated die bonding in the micro-electronics marketplace is the MRSI-501 Automated Die Placement System (see figure 2). The placement accuracy is ± 0.002 to 0.003 inches and two degrees in theta. However, the same system places flip chips to within ± 0.0015 inch. The system's throughput rate is 400-450 die per hour for vision-guided placements and 900 die per hour for direct pick and place (such as from linear feeders).

The system's host computer is a PC/AT. MRSI selected this computer because it has been established as an industrial standard. Also, it is versatile in real-time control and adaptable to available communication standards. The major workhorse, the MRSI Vision System, is based on a 512 X 512 pixel resolution, 256 grey scale level, vision package.

Figure 2. MRSI-501 Automated Die Placement System

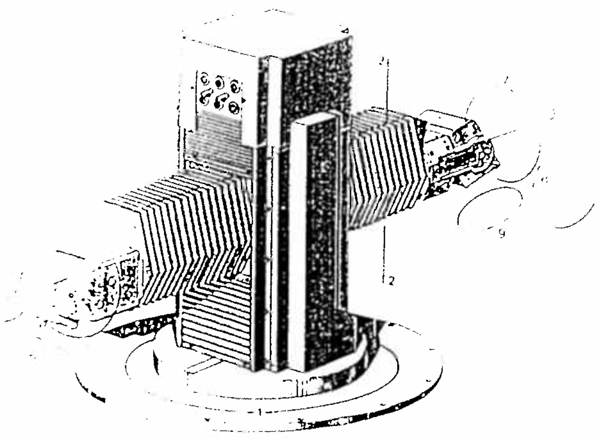

Figure 3. Five axes cylindrical robot

The MR-03 cylindrical robot is the handling device which has been configured with five (5) degrees of freedom (see figure 3). The first axis provides a 340 degree rotation of the robot arm. The second axis provides a vertical travel of 5.3 inches, with 0.00015 inch repeatability. The third axis controls the extension of the robot arm and manipulates the radius from 10 inches to 17.5 inches. The remaining two axes (six and nine) control the rotation of the vacuum pickup tool on each wrist. The MR-03 robot was selected for its high precision and speed, unique configuration, large working area, and low maintenance requirement.

Two cameras, one with high and the other with low magnification, are mounted on each of the robot's wrist. The magnifications are optimized to cover a range of part sizes and to provide enough detail within a pattern to resolve and decipher orientations of nearly symmetrical parts.

The system is programmed to recognize die that are in any orientation and position within a wafflepack cavity. If any pocket of the wafflepack is empty, the system will detect the condition and move to the next pocket. If the pocket contains a die that is incompatible in size (misplaced or chip outs) or up-side-down, it will skip it and process the next pocket. The system can also pick epoxy or eutectic pre-forms from wafflepacks. The system treats these parts like ordinary die. Eutectic pre-forms are used in some applications, including microwave, for heat sinking reasons. First, a pre-form is placed on the substrate; then, the die is stacked on top of it.

Very common in the industry is multiple sourcing of the same component. With *alternate die capability*, the system is able to match a pattern with parts from different vendors that are visually different. This operation is done automatically by the system. The system's database (library) stores alternate die information.

The vision system is also capable of detecting any die located in black, ESD wafflepacks. With some vision systems, the chip gets "lost" in the background. However, one solution is to use bright field illumination to locate the die and dark field illumination to determine the orientation. The system automatically switches the light sources.

To accommodate some users, the system can be equipped with automatic tip changing tools. In most cases the system can pick and place all the required components using the two on-the-wrist vacuum collets. However, some manufacturers require multiple size tips with different materials. In addition, the tip changing capability facilitates the use of inverted pyramid collets for eutectic scrubbing.

An up-facing camera can be utilized to increase the placement accuracy of certain die. For many micro-wave applications, chip placement must be extremely consistent to minimize and maintain wire bond lengths. Placement accuracies can be enhanced by bringing the chip over a camera after picking. The system can determine the location of the chip on the vacuum collet and calculate the final placement location. Either chip edges or component features can be used for image analysis. The latter method is advantageous when applicable. One example is the use of ground vias in MMIC GaAs chips. The vias correlate to top-side chip features; consequently, they are excellent reference marks.

The up-facing camera is also used for flip chip bonding. Once a chip is picked up, it can be moved over the third camera for image analysis of the bumps. Then, the system can place the die with its new location information.

The vision system also processes fiduciary marks on the PCB or substrates to compensate for any misalignments in feeding or positioning. Accordingly, the system will process each individual pattern of multi-up substrates (i.e., snapstrate).

A compliant vacuum pick-up device virtually eliminates damage to small delicate chips including GaAs with air bridges (programmed pick-up offsets provided, also). Compliancy also increases the tolerance to local unevenness of wafflepacks, substrates, and components. Force detection is built into the head enabling the user to pre-select a placement force for each type of die. This feature helps ensure that epoxy is properly displaced beneath a part prior to curing. In addition, a static eliminator helps discharge any static that may accumulate on the plastic vacuum pick-up tip.

The system can be configured with any combination of tape feeders, stick feeders, wafflepacks, gel-packs, and wafers. For wafers, equipment manufacturers have recently developed unconventional means for preparing die for pick-up. One such method is to place a stretched wafer on a "gel-pack" like surface (rough). After pulling vacuum from below, the die are released from the tape. Through wafer mapping software, the equipment picks only "good" die from the wafer.

The system can also interface with a flexible substrate feeding device (see figure 4). Users can specify trays, magazines or elevators to suit their environment. The automatic substrate loading/unloading can provide significant increases in system autonomy.

The production cycle is as follows:

1. Cameras attached to robot capture image of substrate (i.e., pad or fiducial marks).
2. New placement locations calculated.
3. Robot moves appropriate camera over wafflepack cavity and captures image of die.
4. Location and orientation determined, coordinates transferred to robot.
5. Robot picks part with vacuum tip.
6. Robot places part with pre-selected gram load.
7. Repeat steps 3-6.

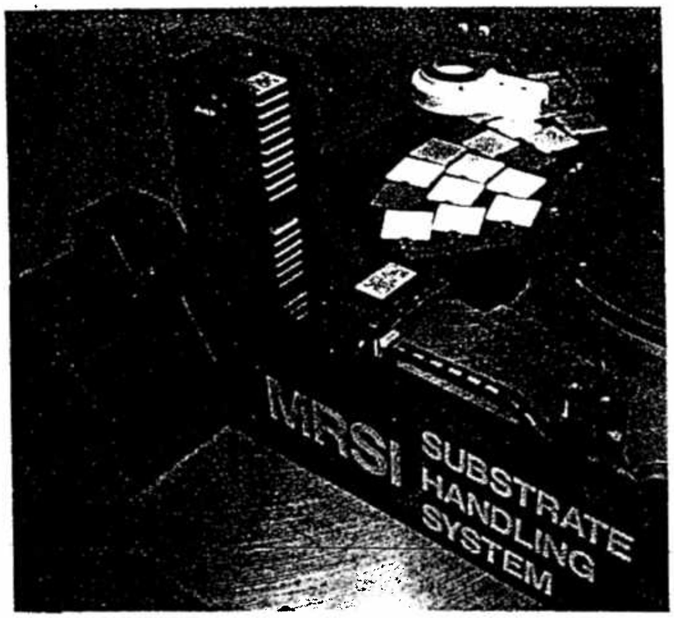

Figure 4. Automatic substrate feeding system

User Requirements

A major U.S. defense contractor is looking at hybrid assembly from the microwave production standpoint, but a significant portion of these requirements are shared by the hybrid circuit and PWB industries in general.

The production of microwave hybrid assemblies requires special performance characteristics for automated component placement. These requirements stem from the complexity and performance characteristics of these devices which offer greater demands in terms of component variety and placement accuracy. The major requirements for typical microwave hybrid assemblies have been outlined as follows by one manufacturer:

1. **Positional Repeatability:** Component positional repeatability must be maintained in order to minimize tuning requirements for the RF circuitry. As the operating frequencies of the devices increase, this repeatability will become even more critical.

When specifying requirements for positional repeatability, the theta (rotational) specification must also be factored into the requirements. For example, two degrees of rotational repeatability on the placement of a 0.100 inch square component adds 0.00171 mils of variation to the x and y components of positional repeatability.

2. **Component Types:** The type and range of components used in microwave hybrid assemblies demand flexibility from the automated component placement system. The variety of components present in a single microwave hybrid design include silicon integrated circuits (ICs), GaAs ICs, chip resistors, diodes, and capacitors, ceramic capacitors, and tantalum capacitors. Current designs include parts ranging in size from parallel plate chip capacitors 0.010" square up to GaAs RF integrated circuits over .350" in length.

In order to accommodate the variety and size range of these components and assure placement repeatability, the placement system needs to utilize machine vision systems with multiple fields of view. In addition, the variety of components and the wafflepack types needed for these component demand that alternative lighting sources be available. By using florescent ring lighting and collimated TTL (through the lens) lighting, vision recognition capability is greatly expanded and reliability is enhanced.

3. **Special Component Handling Requirements:** Force control during the pickup and placement of the semiconductor die is critical to assure that no damage is done to the die surfaces. This is especially true for GaAs components that are very brittle by nature and therefore, easily broken. By using the combination of *strain gages at the vacuum tips to monitor the applied force* and *high resolution z-axis controls on the pickup arm*, the pick/place forces can be adequately controlled to virtually eliminate handling damage.

Another characteristic of certain GaAs components is the existence of "air bridges" on the surface of the device. The air bridges act as electrical crossovers on certain circuits which can be easily damaged by errant handling of the device's top surface. To minimize the potential damage caused by conventional pickup tools (flat face), it is advantageous to avoid direct contact with the air bridge by teaching a user-specified pickup location on the surface of the device.

4. **Component Presentation Methods:** The system must accommodate the many different ways in which components may be presented to the automated component placement system. The most common method of packaging semiconductor devices are in wafflepacks or gel-packs. Another less common method of presenting these components for hybrid assembly is through the use of expanded wafers. This method of loading the semiconductor wafer (mounted on the film frame used during die separation) directly on the automated placement system is much more common in the semiconductor industry. However, wafer loading can be advantageous where devices are extremely fragile and are prone to handling damage, as is the case for GaAs RF ICs. Other presentation methods needed (for capacitor components) are linear vibratory feeders and/or tape reel dispensers.

5. **Substrate Alignment:** The last requirement for automated component placement systems is the ability to compensate for misaligned substrates and/or packages onto which the components will be placed. Substrate misalignment, as well as variation in the alignment of the top layer artwork to the substrate, can be corrected for by utilizing machine vision. The machine vision system should be capable of imaging a variety of substrate materials and configurations. Additionally, the system may also be required to perform imaging of the substrates in the hybrid package if component placement is done at the package-level assembly.

System Configurations

Because each end-user has different requirements, the system configuration must be flexible and modular. One example of an application is as follows:

- 30 waffle pack stations
- (1) 8 mm and (1) 12 mm tape reel dispenser for feeding ceramic and tantalum capacitors
- Expanded wafer presentation feeders
- Switchable collimated and florescent ring lighting capable of imaging artwork on thick film, thin film, and multi-layer thin film substrates, and components in both black (conductive) and white waffle packs (refer to figure 5)
- Pick and place cycle times ranging from five to fifteen seconds, depending on the size and complexity of the component (e.g., multiple windows)
- Alternate die capability
- Programmable placement head force control, ten to eighty grams
- Programmable pickup location on components (air bridge protection)
- User-selectable visual verification of placements

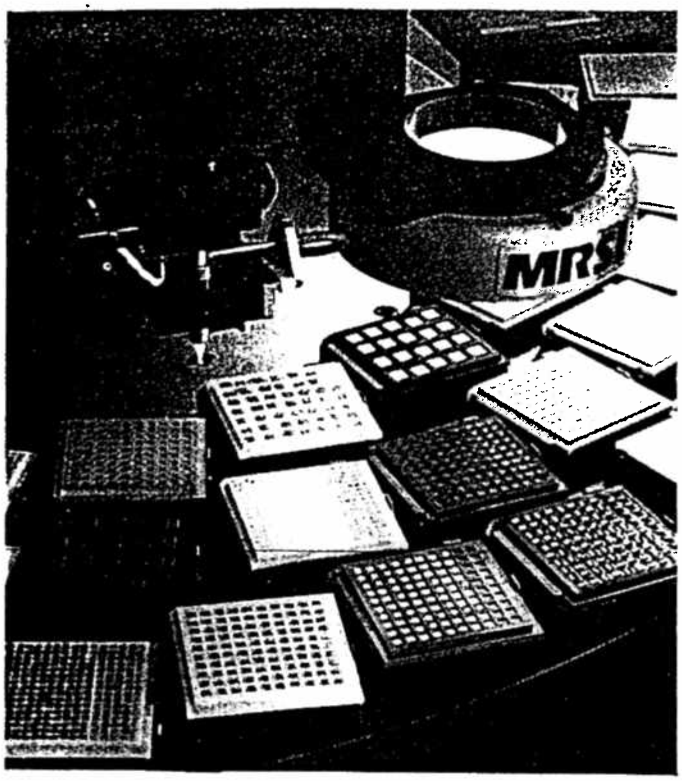

Figure 5. Multi-color wafflepacks

Special configurations are also possible. For example, the MRSI-1002 consists of two MRSI-501 robots, an input and output system consisting of magazines, elevators and linear feeders, and a heated platen to partially cure populated hybrids. A total of 114 wafflepack stations, coupled with 15 linear feeders, allows the customer to build a minimum of 100 hybrids without replacing wafflepacks. Assembly interruptions for reloading of wafflepack stations are minimized with this approach. The only operator intervention during the assembly process is the loading and unloading of magazines containing twenty substrates.

Initial loading of the waffle pack stations for one customer, as well as replenishment during the assembly process, is controlled by a unique computer-controlled kitting process. The system energizes the appropriate light emitting diodes and directs the operator to specific locations in both the custom dry boxes and the system. This technology, coupled with bar code labels located on the bottom of the wafflepacks, ensures that parts are correctly placed at specific robot locations.

This manufacturer also successfully integrated bar code readers (labels located on the bottom of the wafflepack) with an x-ray system, a computer-aided die storage and retrieval system, and the robotic placement system.

When die are received (from vendors), they log all appropriate data entered into a data base. Each wafflepack is scanned with a bar code reader and then x-rayed. The x-ray system counts the die and stores the actual die count in the data base under the wafflepack bar code label. Next, the parts are placed in a special stainless steel magazine and stored in custom dry boxes. To aid the operator, a computer system energizes a light which designates the appropriate dry box location. Because wafflepacks are only opened at the robot station, operators are never required to handle the actual die. Furthermore, the die attach system is housed in a class 100, vertical laminar flow station with full ESD protection. These system features and logistics result in contamination-free die.

Real Benefits

For a major hybrid manufacturer, automatic die placement has proven its ability to repeatedly locate and accurately place die. Improvements over the last two years, outlined in chart A, include 300% increases in die attach rates and an excess of 200% in wire bond throughputs. Increased wire bond throughput is a direct function of consistent die placement locations.

Process Improvements

300% increase in die attach rates.
Over 200% increase in wire bond throughputs.
Increased automatic pull test rates
Improved final test yields

Chart A

The implementation of automated assembly equipment has resulted in reduced production costs and formidable increases in throughput and yield, according to a leading manufacturer. These benefits become extremely important in a batch production environments with over 200 different hybrid circuits.

For one military contractor, a totally integrated system approach assembles product that is virtually defect free with a substantial/significant reduction in labor. Other advantages of the system include 1) real time, accurate inventory control, and 2) complete hybrid-as-build traceability. This process is controlled automatically with no operator input.

Still another 501 user reports that automatic die placement results in consistently accurate and precise placements. In a production run of circuits with 169 placements and 40 different components, the user experienced "zero die orientation or die-related defects." Moreover, the robots ability to maintain placements from one hybrid to another has "greatly enhanced their wire bonding operation." By keeping placements consistent, they have reduced pattern recognition time and have been able to maintain consistent wire heights on all of their products built by the robot. Consequently, this manufacturer has improved its quality levels, reduced rework, and increased throughput for this operation.

A manufacturer of microwave circuits describes the benefits of an automated die placement system in terms of reduced material attrition and reduced rework. As a result, the overall first-pass cycle time will be reduced, significantly. Material attrition savings represents the area of greatest cost savings due to the high cost and fragility of the GaAs MMIC devices. Furthermore, this user of fully automatic die bonders anticipates cost savings of 10:1 in reduced material attrition alone. In addition, they will reduce the amount of rework required to re-orient misplaced components and replace damaged components by a factor of ten. When considering rework time into the overall first-pass cycle time, the automated component placement system will effect a net cycle time reduction of 50%. In addition to these direct cost savings, the automated process will also improve cycle time of the automated wire bonding operation, since variations in component placement, including the height of the component's surface, will be greatly reduced in comparison to existing manual and semi-automated processes.

Future Development

Already, systems are assembling circuits using components mounted with a fluxless solder reflow process. This process includes placing a solder preform (usually a gold/tin alloy) on a substrate or package and precisely positioning the component onto the preform. Ideally, this pick and place operation would need to be integrated with the actual solder reflow process equipment to eliminate part handling between placement and reflow. Extra handling might cause unwanted movement of the components and preforms on the substrate.

Some companies are exploring the potential of placing substrates directly into carriers and onto lead frames with the automatic die bonder. The attachment vehicle will either be epoxy or solder. This added system capability would minimize additional handling and equipment requirements.

Certain companies are also expressing interest in fully automatic, multi-die chip placers with eutectic bonding capability. For ultrasonic bonding, conventional transducers from companies such at Uthe Technology, Inc. could be packaged in existing automated machinery.

The capability to down load part or all of the required assembly data to the pick and place machine from a host computer may be beneficial in factory applications where a large product mix (with relatively small volumes) exists, or where multiple assembly machines are required. In addition, the assembly machine should be capable of providing visibility data for monitoring production status, such as work in process, machines errors, empty feeders, or process control data. To best implement these interface requirements, standard hardware interfaces and software protocols are needed. In particular, the hybrid industry should emulate what the semiconductor industry has implemented with SECS standards.

Ultra-Precision Micro-Electronics Packaging

The need for ultra-precision (less than 0.001 inch) die placement systems has already arrived. For example, some flip chip assemblies require accuracies of less than ± 5 microns. In fact, bonding by compressive cold solder flow require forces on the order of 100 pounds during assembly. Force is a function of the number and size of bumps. Other applications include optical detector assemblies composed of CCD linear arrays. This technology requires accuracies of less than ± 8 microns. Other optical applications require accuracies in the range of ± 4 to 5 microns. Laser diodes, printer heads, microwave, photo/laser lithography techniques are challenging equipment suppliers in providing commercially available systems for ultra-precision die bonding.

Ultra-precise, thermally stable systems and/or sophisticated vision and control algorithms are required to achieve final placement accuracies of 0.001 inch or less. Systems will utilize high resolution glass-scale encoders, laser-based displacement interferometers, and error mapping software. Some companies are now incorporating equipment similar to coordinate measuring machines to perform ultra-precise assembly tasks. These Cartesian type robots incorporate air bearings and ceramic structural elements rather than metal. However, systems utilizing metal components could use auto-calibration routines to compensate for thermal expansion issues. A system can be programmed to periodically perform this routine prior to and during production runs.

Another approach, still at the experimental stage, is a coarse/fine positioning component placement strategy. Coarse positioning is done with an industrial material handler or robot. Fine positioning is accomplished using a precision micro-positioning device attached to the end of the robot. Vision analysis through a camera mounted at the end effector determines alignment error.

Equipment vendors are responding to the ultra-precision assembly market with manual, semi-automatic and automated machines. However, some in-house R & D departments are developing their own systems, including manual versions, until they increase their confidence level in external vendors.

Conclusion

Die placement is very critical to the manufacturing process, and the use of state-of-the-art automatic machines can make a major contribution towards achieving manufacturing excellence in an extremely competitive environment. Higher quality, lower cost products, greater customer responsiveness, higher margins, an enhanced reputation for quality, earlier deliveries, faster inventory turnover, and accelerated cash flow are all benefits of a successful implementation of automated die bonding.

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