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AUTOMATION IN ELECTRONIC ASSEMBLY

Flip Chip Assembly is as Easy as 1, 2, 3

Reliable estimates put total flip chip production volume at over one billion units for 2000. Most are being used today in low-priced consumer products, such as calculators and watches, where flip chip on board (FCOB) and flip chip on flexible substrates (FCOF) are the preferred applications. The computer and telecommunications markets are also showing good demand for flip chip in package. These high-end applications include microprocessors, ASICS (application specific integrated circuits), and microcontrollers, which are predominantly flip chip in package (FCIP) with ceramic substrates migrating to laminates, mostly of the built-up-material (BUM) variety to handle the high number of I/Os.

According to the Prismark report on the state of the industry (Reference 1), flip chip arrays have entered the infrastructure phase. Key barriers, such as bumping and high density interconnect, are being eliminated due to the sheer number of new suppliers and advances in technology and reliability data. The line that has traditionally differentiated first level from second level packaging is blurring for flip chip manufacturers. This trend is expected to continue in the next two to three years as known good die techniques become less costly and new materials are developed and tested, such as reworkable underfills and printable flux/underfill material. Volumes for FCIP and FCOB also are increasing (Reference 2).

With these factors in mind, how does a company establish an integrated high-volume flip chip assembly line, meet clean room and precision placement requirements, and retain the flexibility needed for the future? This article examines equipment and process considerations for a high-volume flip chip assembly line that would cost approximately $5 million to $7 million and

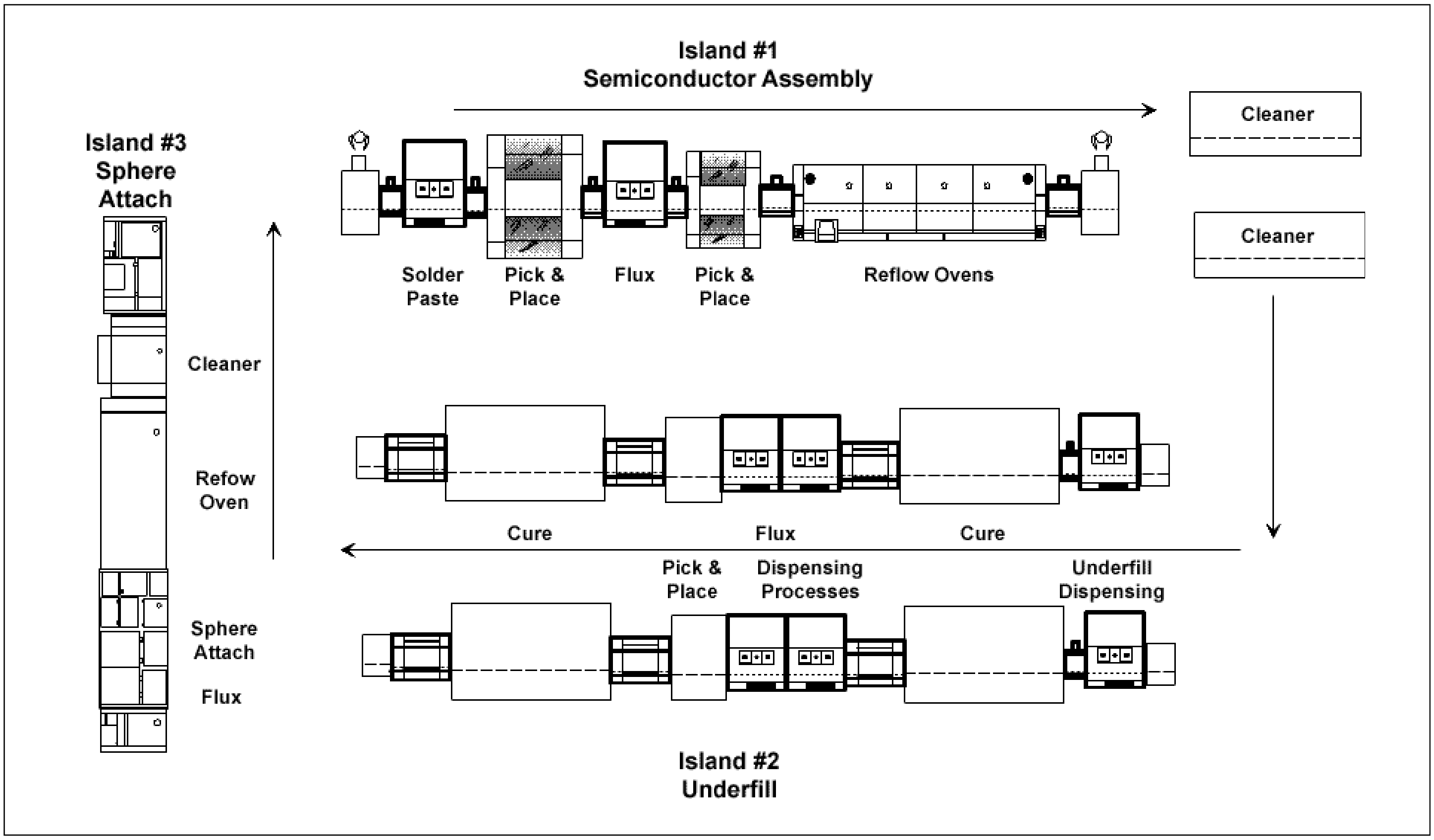


Figure 1 - Flip Chip Assembly Line

occupy roughly 2,000 square feet (*see Figure 1*). The line is segmented into three distinct functional islands: semiconductor assembly, underfill, and sphere attach. A product flow matrix is shown in *Figure 2*.

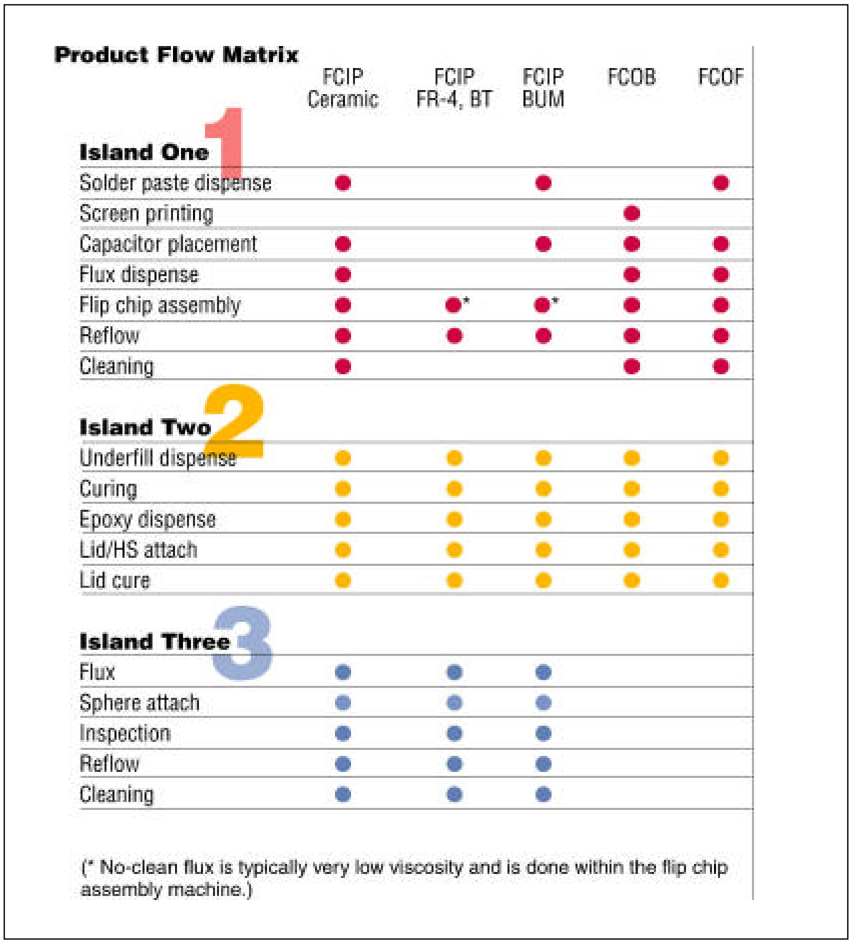
ISLAND ONE
Semiconductor Assembly: Equipment Considerations

The layout of the first island in the flip chip assembly line is shown in *Figure 3*. Operations include solder paste and flux dispensing, picking and placing using machines capable of extreme accuracy and repeatability, reflowing, and offline cleaning (if required). This configuration is capable of handling carriers for ceramics, singulated substrates, flex cables, and printed circuit boards for FCOB or laminate strips. Board handling and conveyors must be optimized for each application.

In this production scenario, capacitors are assumed to be a requirement. Just as there are many types of capacitors, there are many types of capacitor attachment methods. These include epoxy, eutectic solder, or high-temperature solder for bumped arrays, and low inductance capacitor attach. The attach material can be sprayed on or screened on; the latter method is typical of FCOB. If capacitors are not required, the configuration of this first island can be simplified by eliminating solder paste or screen dispensing and one pick-and place-machine.

Since it is difficult to predict the number of capacitors to be placed, the process should be optimized for maximum flexibility. This can be achieved by choosing machines with the precision and versatility to place capacitors as well as flip chips. Though it will be more costly in the short term, it ensures flexibility for the future.

Flip chip placement poses unique challenges for vision systems. Standard lighting typically does not provide sufficient contrast between the metal pads and the light-colored ceramic substrates around it. Polyimide flexible tape also poses imaging problems due to insufficient contrast between the flex material and the copper/metal traces. However, special lighting systems are available that can deliver optimum contrast for even the most demanding materials,



Product Flow Matrix

	FCIP Ceramic	FCIP FR-4, BT	FCIP BUM	FCOB	FCOF
Island One 1					
Solder paste dispense	●		●		●
Screen printing				●	
Capacitor placement	●		●	●	●
Flux dispense	●			●	●
Flip chip assembly	●	●*	●*	●	●
Reflow	●	●	●	●	●
Cleaning	●			●	●
Island Two 2					
Underfill dispense	●	●	●	●	●
Curing	●	●	●	●	●
Epoxy dispense	●	●	●	●	●
Lid/HS attach	●	●	●	●	●
Lid cure	●	●	●	●	●
Island Three 3					
Flux	●	●	●		
Sphere attach	●	●	●		
Inspection	●	●	●		
Reflow	●	●	●		
Cleaning	●	●	●		

(* No-clean flux is typically very low viscosity and is done within the flip chip assembly machine.)

Figure 2 - Product Flow Matrix

including white ceramic substrates and flex.

Greater demands are also made of machine positioning systems. While flip chip pitch continues to decrease, pick-and-place machines using leadscrew shafts with belt drives have already reached their limits at pitches of 200 microns. In addition, this type of machine typically generates contaminants at levels between 15,000 and 20,000 particles equal to or larger than 0.5 microns per cubic meter. Only linear motor-driven machines are capable of meeting both the accuracy and cleanliness requirements of flip chip assembly, with some generating as few as 558 particles per cubic meter (Reference 3).

Flip chip throughput is related to multiple factors. Key determinants include the number of spindles on the machine, the capability of the machine's vision-on-the-fly system, and the feeding method. Semiconductor chip feeding options include waffle packs, surf tape, tape and reel, and wafer handlers. A critical decision involves the choice of wafer handler versus waffle packs. Waffle packs are indicated when the chip requires several sorts, either for speed (microprocessors, SRAM) or for high-end memory. Waffle packs also should be chosen when the wafer yield is less than 75%.

Wafer handlers, however, are preferred over waffle packs when the wafer yield is in the 75% to 85% range. More specifically, if the assembly is done at the same facility, a 75% yield level indicates the use of wafer handlers. When the assembly is done at another site — requiring additional freight costs — the higher yield at the 85% level makes wafer handlers more cost effective.

The best heat distribution for the reflow process comes from ovens using forced convection technology. Flip chips requiring cleaning are best handled in separate cells using centrifugal force; this approach is more aggressive and more efficient than inline sprays. Total price of equipment for a line configured as shown in *Figure 3* is approximately $1.5 million, with throughput in the range of 1,200 to 1,500 units per hour.

ISLAND ONE
Semiconductor Assembly: Process Considerations

For eutectic applications the flip chip bump will have an under bump metallurgy (UBM) of electroless Ni-P/Au plating or electroplated Cr/CuCr/Cu/Au, NiV/Cu, or Ti/Cu/Au and a bump that will be screened or electroplated. Typical eutectic on laminate will use a low viscosity/low solid flux and will not require cleaning.

Flip chips on ceramics are reflowed at a higher temperature, although fluxes tend to "char" at those temperatures, which makes them more difficult to clean; this typically requires an offline batch centrifugal cleaner. Substrate materials are ceramic, FR4/BT, and BUM with microvias. Detailed review of these topics is beyond the scope of this article, but those considering flip chip assembly should be aware of the importance of solder mask registration for flip chip on laminate and FCOB applications, as well as the importance of precision placement accuracy and repeatability for substrates with pitches of 150 microns or less.

Figure 3 - Island One in Flip Chip Assembly Line

ISLAND TWO
Underfill:
Equipment and Process Considerations

The long term reliability of a mounted flip chip device largely depends on the quality of the underfill material between the chip face and the substrate (*see Figure 4*). Underfill encapsulants improve reliability primarily by reducing localized solder bump fatigue strains induced by the coefficient of thermal expansion mismatch between the silicon die and the substrate to which it is attached. Properly dispensed and cured underfill uniformly disperses the localized fatigue strains over the entire encapsulated assembly, yielding a 30- to 50-fold increase in solder joint life. Island Two (*see Figure 5*) includes underfill.

The three most critical variables of the underfill process are dispensed volume accuracy, temperature control over parts and fluid, and management of the parts data. The use of "closed-loop" dispense process control is the best method for managing these variables and ensuring that underfill material has been properly dispensed. A log file can also be built, allowing for part traceability and SPC charting.

The key to volumetric control of underfill fluids is to use a true volumetric displacement pump. Linear positive displacement pumps meet this requirement by using a piston to displace precise volumes in large and small shot sizes. These pumps are a significant improvement over rotary or auger systems, which are better suited for solder paste and other high viscosity fluids. The low viscosity and short pot-life fluids used in encapsulation processes require a precision pump that is not dependent on viscosity for output flow rate. Valves in these pumps also have the best abrasion resistance and lowest cost of ownership.

Closed-loop temperature control is another key to process success. Using proportional integral differential (PID) controllers, a thermocouple provides feedback for an algorithm using current temperature and previous rates of temperature change; control is stable and repeatable. In a "lights out" manufacturing environment, the system must automatically check temperatures prior to dispensing and record this data in the SPC log file.

Flexibility to choose the heating and cooling methods that take advantage of heat transfer mechanisms is also critical. While radiant heat may be appropriate for a laminate substrate with bottom side components, contact or convective heat may be more appropriate for ceramic and other components, which may also require clamping or part hold-down. Risks from upstream or downstream process delays can be minimized by using the same heating method in pre- and post- dispense areas as in the dispense station.

Lights out manufacturing also requires a robust vision system. It must quickly evaluate

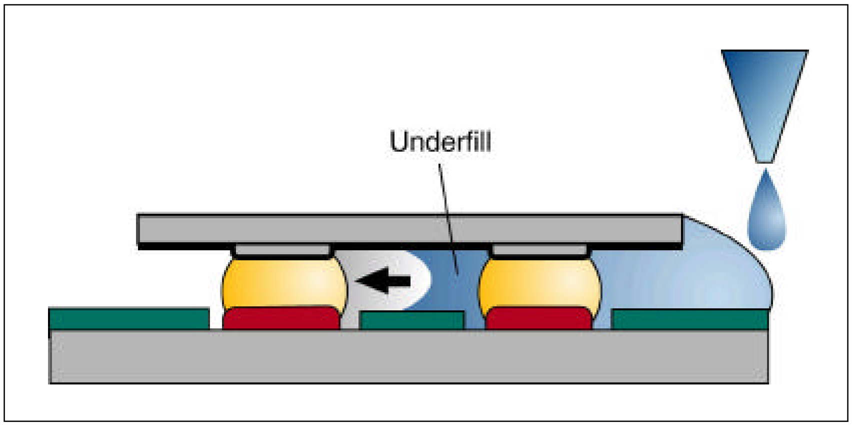


Figure 4 - Underfill between Chip and Substrate

presented components, then precisely dispense and/or properly log bad components. Since the variety of parts presented in the dispensing step can be broad, vision algorithms with edge detection and auto-correlation are required. Programmable lighting is often the only way to ensure detection of key features before dispensing.

FCIP assembly often includes processes such as thermal interface material dispensing and lid sealant dispensing and curing. These dispensing processes are developed and managed using closed-loop process control methods similar to those used for underfill. High yields and throughput ranging from 500 to 1,000 units per hour are typical when all closed-loop process controls are in place.

ISLAND THREE
Sphere Attach: Equipment Considerations

The increased use of flip chips in device packaging has resulted in reduced size and increased density of the packages. Both affect the sphere attach process and the equipment used. Key aspects include material selection, precision, increased density, and reduced sphere size.

Because of the increased number of I/O on the package, increasingly complex substrates have been required. However, substrate material selection can influence the choice of equipment and its performance. These substrates also increase dimensional variability on a proportional basis both within the substrate and from substrate to substrate. The equipment must then dynamically accommodate this variation, which is best accomplished through the use of vision guidance that allows the machine to dynamically alter its positioning system to compensate for local and whole substrate variability. Features on the most advanced sphere attach machines allow for step-and-repeat processing to minimize local variability. This allows for more precise ball-to-pad registration rather than averaging the placement across the entire substrate. This issue is amplified by the smaller size and pitch of spheres, coupled with the increased density and larger panel sizes. The material variation and decrease in feature size directly increase the

Figure 5 - Island Two in Flip Chip Assembly Line

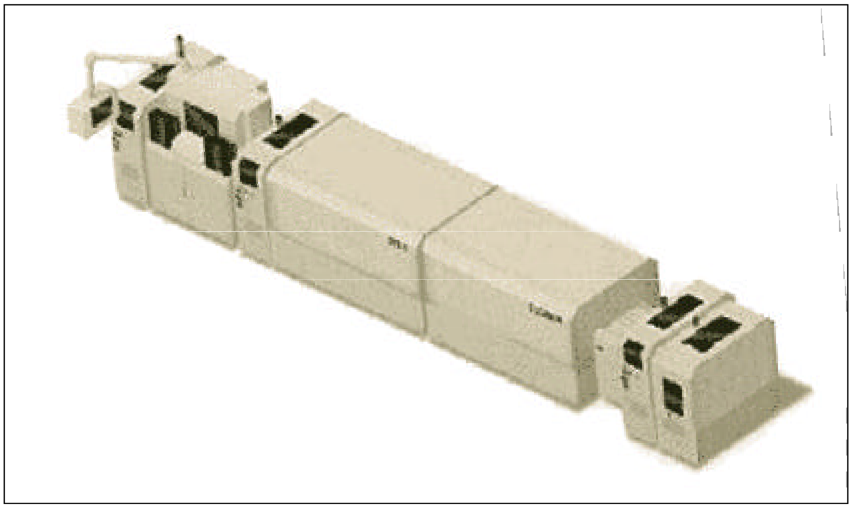


Figure 6 - Island Two in Flip Chip Assembly Line

precision needed by the sphere attach system to precisely deposit flux and attach the sphere.

Material selection in the form of array versus singulated parts also impacts equipment selection, as singulated parts require different features on the sphere attach equipment to provide positioning capability. This can be accomplished by using active tooling, which provides for a reference position to be created through the use of cam action between the parts and the machine. By creating a reference location, the parts can be processed either in batch or in step-and-repeat fashion.

ISLAND THREE

Sphere Attach: Process Considerations

Production solder sphere attach is best performed in an integrated in-line fashion, which takes advantage of tightly integrated material handling, assembly, and processing equipment. *Figure 6* shows a typical line configuration. Steps include substrate feeding, flux deposition, sphere attachment, reflow, and cleaning. Other configurations are possible, depending on the chip feeding method. These setups may include singulated parts in JEDEC tray handling and strip array substrate processing with post-mount inspection after sphere attach and before reflow. Post mount inspection checks sphere presence/absence as well as ball-to-pad measurements; this is augmented by in-process detection, which performs missing, stuck, and excess sphere detection in real time during the processing of the substrate. Escaping defects are minimized down to 6 sigma levels.

In ceramic substrate sphere attach applications, solder spheres typically have a high tin content to compensate for thermal conditions to which the package is exposed. This sphere is joined to the substrate via eutectic paste that wets to both the substrate and the sphere. High-tin spheres can be attached to the ceramic by placing them directly onto a pasted substrate or into graphite boats with paste deposited onto the sphere surface; the substrate is then placed over it.

In plastic substrate sphere attach applications, a drop of flux is deposited on the substrate's solder pads before sphere placement using a pin transfer method; this allows for batch deposition of flux onto all pads at once or by step-and-repeat. Vision guidance is used as before. Changes in volume and surface area of the flux deposition are done by changing pin shape and penetration into the flux bed.

CONCLUSION

These three "islands of automation" offer several options for handling the continually increasing number and variety of flip chip packages, bumping metallurgies, substrate material, and handling scenarios; these include laminate strips, singulated substrates in carriers or Auer boats, and others.

Those considering the purchase of a flip chip assembly line will typically meet with as many as 12 suppliers before generating a tentative layout, estimated pricing, and material handling scenarios. By combining leading-edge technology, process expertise, and an integrated approach, the time required to prepare a flip chip assembly line proposal can be reduced. Start-up problems and the technical risks from having multiple suppliers also can be reduced. The approach outlined in this article drastically reduces the number of suppliers and lead time associated with purchasing, start-up, and qualification of a flip chip assembly line, either in package or on board.

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