Automation requirements for die bonding process

To make the appropriate equipment decision, OEM engineers need to take a hard look at the advantages and disadvantages of installing either a semi-automatic or automatic die bonder when process development and follow-on low volume production runs are involved.

The capability requirements for die bonding equipment that can handle over time a variety of area array package interconnections (flip chip, chip scale) can be wide ranging. One of the process engineer’s biggest challenges is the different flip-chip designs that keep coming and the corresponding means that may be required in handling the attach process like solder reflow, polymer attach, eutectic, etc. Depending on design, placement precision of $\pm 12\mu$m will suffice. With others, $\pm 5\mu$m or better may be required. Today, there are commercially available semi-automatic die bonders that are capable of placing flip chips within $\pm 5\mu$m and that feature broader flexibility in operating cycles.

When comparing the speed of a semi-automatic with that of an automatic, it is important to look beyond the machine’s uptime throughput rate and consider the time required for and the complexity of the set-up involved with the run. Such things as teaching a fully automatic die bonder to correlate the chip and the target site on the substrate and to handle such parameters as range of magnification and z-motion can be time consuming. For example, it is

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not at all uncommon for the set-up routine on automatics to take the better part of a day compared to as short a time as 15 minutes with semi-automatics. So, if you are only going to run a small number of chips, you can have the set-up of the semi-automatic system accomplished and the chips run in the time it would take just to get the automatic ready to run the chips.

Aside from choosing a semi-automatic machine for lower capital investment and ease of setup reasons when short runs are involved, one needs to consider the fact that there are semi-automatic die bonder designs available today that can have capabilities added to them for performing laser diode and eutectic die bonding as well as flip-chip bonding.

Basic requisite features
Regardless of the high density interconnect application, the basic platform should provide some means (after die targeting and pickup) of achieving alignment of the die with the substrate site, applying bond load and adding process heat.

Alignment should be accomplished by means of a video system which uses a cube beam splitter for simultaneously viewing (in the case of flip chips) the die and substrate images. However, because the video system will not allow the operator to observe the actual bonding process in real time, it is sometimes desirable to have a magnifying system such as a pivoting direct-view microscope both for monitoring the chip placement process and troubleshooting (especially for eutectic die and laser diode attachment). The mounting arrangement of a combination cube beam splitter and a pivoting direct-view microscope on a semi-automatic laser diode bonder is shown in figure 1.

The ability of the cube beam splitter in presenting the bumps on the flip chip superimposed over the pads on the substrate is critical to the alignment process when dealing with micro flip chips. Fiber-optic illumination should be provided to assure proper viewing in the presence of different light levels. A video camera with motorized zoom lens for optimized viewing over a range of magnification rounds out the minimum features needed on the platform for achieving pick-up and alignment. Note that with such a semi-automatic system no set-up is required whereas with an automatic system, the alignment process is accomplished via a pattern-recognition system which, incidentally, needs to be taught.

Regardless of whether the platform is semi-automatic or automatic, it needs to be equipped with the appropriate bond load controls for the application at hand. For example, when solder is used, all that needs to be done after the chip has been dipped in flux is to apply just enough load (50g to 300g) to cause the chip to properly sit on the substrate. With epoxy and adhesive applications, both bond load and time become an issue. And with these applications, the chip needs to be held at a load of up to 10kg while curing takes place. Other application examples where precise bond load control is required include runs with small delicate chips and certain cases where the bond loads must be different at each point in the cycle (e.g., one load at pick-up, another at flux dip and another at placement).

In the case of flip-chip solder reflow applications, a separate oven may be used or you may wish to accomplish reflow on the same machine that places the die. If you choose to go the latter route, the
machine needs to be equipped to deliver the heat in one or more ways, depending on the application. One example is via a heated die tool, an elevated temperature stage with a set point or some kind of spot heating tool, such as a hot-gas heating nozzle. Note that with the latter spot heating capability you will be able to heat one chip at a time and do rework (figure 2). An automatic machine can provide the same level of heating capability. However, in the case of rework it is not practical to use an automatic system.

System-level capability
Before describing some of the add-on features that are available, the application environment in which the bonding system will operate needs to be considered (flip-chip bonding being prevalent). This will help determine the level of capital investment needed and provide an insight into the kind of add-ons that may be desired. For example, there are low-cost semi-automatic table-top starter units available that are designed for companies just getting into flip-chip attachment. Figure 3 shows an example of one of these entry-level die bonders (Level 1). The units provide an appropriate amount of alignment precision, controllable bond load and heating capability. The design shown delivers placement accuracy of \( \pm 12 \, \mu m \) and can be used (optional sizes available), bond load of 50g to 300g (2kg option available), a manual or motorized flux tray, and has a throughput rate of 120 placements/h.

A scanning video feature is accessible via an adjustment knob on the cube beam splitter, allowing operators to pan back and forth half-an-inch in each direction off the center when working with large flip chips having various bump sizes and pitches. Examples would be smaller or larger than 0.1mm in diameter and distances of less or greater than 0.15mm. The x-y precision slide table is equipped with pneumatic brakes and the pushbutton-activated z-motion initiates the placement cycle. The substrate holder includes a micrometer-adjusted x, y and \( \theta \) stage. Options that can be added to the basic platform include a heated stage capable of 3,500°C operation and a hot-gas spot heating system.

A recently announced optional feature offered by one of the semi-automatic die bonder manufacturers is an attachment to one of its flip-chip bonder models for removing flip chips that have been bonded with the new reworkable underfill materials. The new semi-automatic rework attachment is particularly suited for those flip-chip processes involving the new reworkable single-step combination underfill/flux materials, including the new no-flow reworkable underfills. The attachment includes a focused chip heat source, a heated stage with substrate holder, a chip grabber, a microscope for alignment, a control box with internal computer and power supply, and provision for site clean-up. It should be noted that while this capability adds versatility to the semi-automatic platform, it simply would not be practical to include it on an inline automatic system.

For more demanding applications, such as gold bump flip-chip attachment and related laser diode attach-
ment, more control of temperature, pressure and machine cycling is needed. Multi-use designs, such as that shown in figure 4, represent this next level (Level 2) in capability and complexity. These semi-automatic table top designs feature a combination cube beam splitter and pivoting direct viewing scope and are aimed at firms who need more operating capability such as greater bond load control and who need more system versatility for doing low-volume production runs involving gold, solder, adhesive, or stud-bumped flip chips as well as laser diodes and eutectic die.

Such systems are capable of aligning and attaching die sizes usually from $3.87\,\text{mm}^2$ to $645.16\,\text{mm}^2$ with $\pm 5\,\mu\text{m}$ placement accuracy at a throughput rate of up to 120 placements/h. Standard options offered include a motorized rotating collet, motorized sweep (for easy perimeter viewing) and rapid heat pick-up head. The latter option is particularly suitable for thermo-compression bonding. The rapid heat head is used to either heat the flip chip to a preset temperature or rapidly ramp the temperature at a controlled rate and then hold it for precise periods of time at multiple temperature settings. For extremely high temperature processing, the system can be equipped with a stage capable of ramping at 20°C/s up to 5,000°C or more.

Level 3 is the most demanding, requiring a machine that delivers high bond loads, the highest precision and the most versatility. This level of bonding system capability is represented by the floor-mounted semi-automatic die bonder shown in figure 5. The system is targeted for use by research labs and process development departments who need versatile cycling capabilities and a large stage area to carry out prototype development and characterization studies involving a host of cutting-edge technologies, including laser diodes and next-generation laminate circuits.

The bonder delivers $\pm 5\,\mu\text{m}$ in placement precision of die sizes from $6.4516\,\text{mm}^2$ to $645.16\,\text{mm}^2$ and spot heating capability via hot gas. The machine features elevated stage temperature, closed-loop bond-load control over a range of 5g to 10kg (higher loads available for applications such as chip-on-glass) and can be equipped with ultrasonic scrub for thermosonically bonding microwave flip-chip die. It provides a $38.7\,\text{mm}^2$ heated stage with 6mm motorized travel in x, y and theta, and a motorized zoom and pan viewing feature for scanning large chips at high magnification. The operating cycles are programmed into the machine and saved using a system of macros. The level 3 system must come mounted on a vibration/shock isolation table so that the stability needed for placement accuracy is assured.

Each of the described levels of system capability will give the operator maximum throughput rates of around 120 units/h. For R&D applications and most low-volume runs this is sufficient. If the production requirement calls for higher throughput, the faster operating automatics with their pattern recognition/matching features enter the buy decision process. While automatic die bonders provide the required higher throughput, they basically perform the same primary steps (alignment, bond load and heating) in attaching the die as do the above three tiers of semi-automatic bonders. But the automatics take longer to set up. Remember, in the time it takes to set up an automatic you can be finished with the chip run on a semi-automatic. And automatics cost considerably more.

The fact remains that sometimes less automation will work to your advantage because the applications really only call for a relatively low throughput, which makes possible a lower initial capital investment.●

Figure 5: For high precision, versatility and high bond load delivery requirements, Model 410 is the most suitable.