High-volume manufacturing (HVM) of chip-on-submount (CoS): challenges and solutions

By Daniel F. Crowley, Peter Cronin [MRSI Systems]

The demand for data and bandwidth continues to expand, resulting in the requirement for high-volume manufacturing (HVM) of photonics devices at unprecedented levels. This expansion, with double-digit growth rates, is driven by data consumption from cloud computing, web and mobile-based applications and storage through hyperscale data centers (e.g., Facebook, Google, Microsoft, Amazon). The data bandwidth demand from individual consumers and enterprises creates the need to upgrade long haul networks, metropolitan communication systems, and data centers.

One key photonic device component requiring HVM is the chip-on-submount (CoS). CoS devices present some unique manufacturing challenges. Application-specific die bonders have evolved over decades to address the current manufacturing demands of CoS. This article reviews the required features of a successful HVM die bonder of CoS devices.

The basics of a chip-on-submount (CoS)

The volume for photonic devices is increasing for the reasons mentioned above. Among the critical building blocks for photonic devices, the CoS devices are the core in terms of performance, reliability and required volume.

In fiber optic transmission, the laser diode (LD) CoS, also referred to as a chip-on-carrier (CoC), is the starting point of light generation and transmission, and the photodetector (PD) CoS is the ending point of the light, which is received and translated into an electronic signal. It is quite typical for a 100Gbps fiber transmission to have four sets of LD and PD CoS at a rate of 25Gbps each. Some have 10 sets at a rate of 10Gbps each. The quantity of LD CoS and PD CoS can therefore be four to ten times the quantity of final optical modules.

A common configuration of a LD CoS, includes a eutectically-bonded LD and a back facet monitoring detector, both mounted on the same submount. The quality of the joint between the LD or PD chip to the submount is one of the most critical factors for device long-term reliability. Eutectic bonding is used for a highly thermally efficient interconnect with long-term reliability. The LD CoS may include additional components, such as thermistors, capacitors and driver chips. The PD CoS typically includes a PD and may also include additional components, such as a transimpedence amplifier (TIA), and in some cases, a thermistor for temperature control. In subsequent process steps the completed CoS may be mounted onto a thermoelectric cooler (TEC) packaged in a "gold box" or TO-can package. In order to achieve the eutectic bonding of these multiple parts within the package, a temperature hierarchy of eutectic solder is frequently required. When using a TO-can package, it is common that the LD and the monitoring detector are each eutectically bonded on separate CoS and then mounted in a vertical plane just offset from 90 degrees of each other (Figure 1).

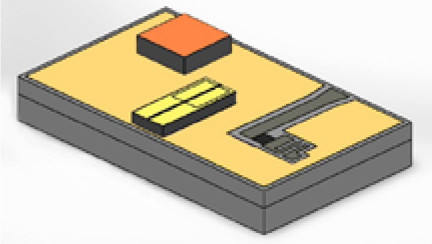

Figure 1: LD CoS.

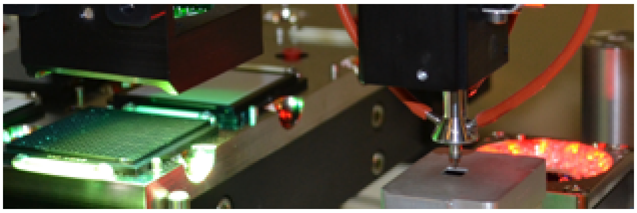

Figure 2: Eutectic bonding stage.

Die bonder requirements for HVM of CoS

The majority of die bonders offered today have evolved for generic semiconductor packaging applications. While these semiconductor die bonders may be well-suited for the die bonding requirements of semiconductor packages, they lack the specific unique features required for successful HVM of CoS.

Another approach to solving successful HVM of CoS is to use dedicated highly mechanical die bonders. While these dedicated mechanical solutions can offer high speeds, they often do so by sacrificing flexibility, reliability and machine delivery times. Any changes in the CoS design or type of the devices being assembled result in expensive and time consuming retooling costs.

The best solution is an application-specific specialized die bonder for HVM of CoS that is able to deliver high speeds while maintaining flexibility. This is best achieved with a standard, flexible, high-speed system that can be easily reprogrammed for new device designs and types. This approach results in shorter delivery times for standardized machines. Short machine delivery times are important to allow customers to scale production rapidly. A HVM CoS die bonder should include many parallel processing features to maximize throughput. The following is a summary of the unique features of a CoS-specific HVM die bonder.

Eutectic bonding optimized for CoS. Because of high power requirements, small component sizes, and the need for the elimination of materials that outgas, many components are attached with a eutectic die bonding process. The CoS substrate sizes are small, typically less than a few millimeters. A small form factor eutectic stage is needed to provide ultra-fast temperature ramping, and ultra-fast cooling cycles. A closed-loop, low-mass, high-power, pulsed heated eutectic stage is required. Stable temperature control and cover gas flow must be optimized throughout the eutectic process. Additionally, the eutectic station must be fully programmable, tailoring the process for a specific bonding recipe. Faster speeds, higher yields and repeatable quality are the outcomes (Figure 2).

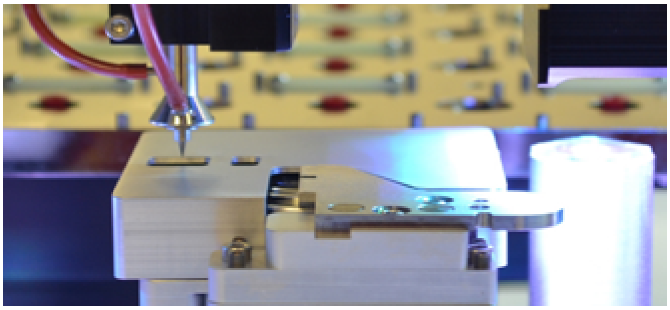

Figure 3: Epoxy stamping well.

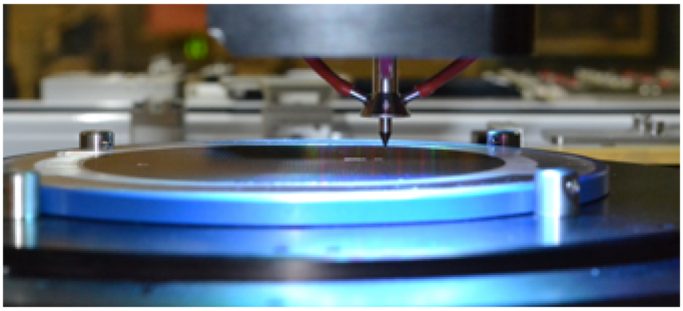

Figure 4: Wafer handling.

Eutectic bonding is the process of using a solder alloy as a third material to form a continuous bond between two components. In the case of CoS, this often means two gold-plated materials being joined by gold-tin solder. When performing eutectic die bonding, the temperature of the assembly is brought up to just above the melting point of the solder. As the solder liquifies, the chip is placed with controlled force. The part is then cooled to below the reflow temperature and the eutectic bond is complete. During the time that the part is subjected to heat, it is important to control the atmosphere. Eutectic bonding is usually performed in an inert environment to prevent oxidation of the bonding surfaces. A 95-5% nitrogen-hydrogen mix should be used so that hydrogen is present for use in the formation of the bond.

Epoxy deposition. CoS components are small and consequently require very small epoxy dots for successful epoxy die attach. Components, such as 200 micron laser diodes, require very small volumes of conductive epoxy with an exact dimension. Epoxy coverage with no voiding and controlled, thin bond lines is critical to maximize thermal transfer, mechanical strength and minimize stresses. Squeeze-out must be controlled to prevent shorting or bridging, and epoxy must be placed in precise locations to maximize yield.

There are two basic methods for applying epoxy to accomplish the task described above. These include stamping (pin transfer or daubing), and syringe fluid dispensing. The selection of deposition method will largely depend upon the properties of the epoxy used and the minimum dot size required. Factors such as silver grain size, material viscosity, thixotropic index, and packaging methods will all influence the decision on the material deposition method. Often for CoS, the solution is stamping because the process requires dots smaller than 200 microns.

Stamping is used to create very small epoxy dots by touching down in epoxy at the stamping well and then transferring the material onto the substrate. Dot size is determined by the epoxy thickness at the well and the stamp tool profile. In the stamping process, a reservoir of epoxy is presented in a grooved well. The well is rotated so that the material is passed under an adjustable height wiper blade. The height of the wiper blade should be precision adjustable using a micrometer adjustment. The rotating stamping well can have multiple grooves to accommodate multiple types of epoxy.

Stamping does not have to be limited to the transfer of single dots. Gang-arrayed (multiple) stamping tools can be employed to transfer an array of dots simultaneously. These gang stamp tools have multiple points that place the same pattern of dots with each touchdown. This is useful for increased throughput and for precise control over the pattern.

Tool profile is another critical factor of stamping to consider. Tools can be designed with a spherical tip or a flat tip depending on the shape and size that is desired for the dot. When combined with good control of epoxy thickness in the well, the right stamp tool can produce repeatable dots of a very specific height and diameter.

Syringe fluid dispensing is an alternative to stamping. The feature typically includes high-resolution servo driven, positive displacement pumps, for the most accurate dispensing of dots, lines and areas. A precision time/pressure pump can also be used depending on the application, materials and process requirements. Material flow is enhanced by a chamfered design in the needles inside the wall, with the chamfering toward the needle tip. This reduces surface tension, provides for more precise control, and also reduces clogging (Figure 3).

Small die and solder preform handling expertise. CoS components, such as laser diodes (LD), photodetectors (PD), capacitors and thermistors, are commonly as small as 200 microns square and require special handling. Solder can be pre-deposited on some devices such as the LD die. When solder is not pre-deposited, solder preforms are used. These solder preforms require the same precision handling as small die.

Presentation methods include waffle pack, Gel-Pak™ and wafer. Wafer handling must be optimized for the CoS die. These small, thin and fragile die must be delicately picked from the wafer tape to avoid damage. Synchronized movement of the pick head and the ejection needles must be used. By using servo-controlled synchronized systems, yield is increased by avoiding die damage. This is of particular concern for thin, fragile materials and die with internal and surface features. Both LD and PD die are made of fragile III-V compound semiconductor materials, such as GaAs- and InP-based materials that require delicate handling (Figure 4).

The use of programmable closed-loop force feedback, is required to enable delicate handling of these devices. Die must be picked and placed with controlled forces as low as 10 grams. The crystal facets on edge-emitting laser diodes and receptor areas of PDs must not be touched by the bonding tools because the devices can be damaged. Custom vacuum collets are used to avoid touching sensitive areas.

High-precision placement at high speeds. When manufacturing optical components, such as CoS, placement accuracy is a basic requirement. Throughput is only meaningful with achieved accuracy. When manufacturing optical devices, which will couple light, high yield is only achieved with a high-precision, stable machine. The device and epoxy placement location, in the case of epoxy die attach, must be controlled for high yield. Placement accuracy as low as 3 microns at high speeds is needed for CoS and is achieved through the use of linear motors and encoders combined with a thermally and mechanically stable platform.

Parallel processing is used to achieve high speeds. Parallel processing examples include multiple pick-and-place heads, "on-the-fly" tool changing, parallel vision alignment, material handling, and multiple bonding stages with parallel loading and unloading.

Advanced vision and lighting optimized for CoS. Another major feature of HVM CoS is machine vision, a critical factor for accurate placement and required to achieve micron-level accuracies. The vision system must align the die features to substrate fiducials ensuring repeatable and precise placement. The alignment of the laser chip to a photo diode is critical. This requires the ability to perform feature recognition of the LD and PD to ensure proper light coupling.

Figure 5: Multi-colored lighting.

Machine vision is used for alignment of components with bottom features and flip chips. An upward facing camera captures the image of the die feature on the vacuum collet prior to placement. The integrated vision aligns features on the bottom of the device prior to placement.

Optimal lighting conditions are needed for die recognition and for alignment. Multi-color lighting is required to successfully image process a wide range of materials and enable optimum imaging of low-contrast components. Multi-colored (i.e., red, green and blue) ring lighting is a powerful tool when processing challenging alignment surfaces (Figure 5). Lighting intensity must be programmable and include both ring and collimated lights for a complete lighting solution. It also must be possible to individually program optimal light settings for each die and substrate fiducial alignment.

Summary

This article reviewed the challenges and the required die bonder features for successful HVM of CoS devices. HVM of CoS is an important and challenging problem requiring unique capabilities from the die bonding system. A HVM CoS die bonder should include many parallel processing features to maximize throughput. By combining the features discussed, an application-specific standardized die bonder will deliver a flexible solution, which maximizes product yield, throughput, and process control, to ensure a successful solution for HVM of CoS. This approach also results in fast machine delivery times. Fast machine delivery times allow CoS manufacturers to scale production rapidly, to meet the market demands.

Biographies

Daniel F. Crowley received his MS degree in Industrial Engineering from Purdue U. and BS from Northeastern U.; he is VP of Sales at MRSI Systems; email Dan.Crowley@mrsisystems.com

Peter Cronin has an MS in Manufacturing Engineering from Boston U. and is the Director of Applications and Service Engineering at MRSI Systems.