Advanced eutectic packaging for volume manufacturing of photonics, microwave and RF electronics

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Increasing demand for data and bandwidth requires high-volume manufacturing of photonics and RF electronics at a level we have never seen before. This accelerates the continuing adaptation of full automation and the improvement of processes in advanced eutectic packaging for volume production as well as advanced product designs. This article presents the most recent advances in the areas of automation and the eutectic processes particularly for the challenges facing photonics and RF electronic components and microwave modules. These advances result in high-precision, high-throughput, improved yield, and new products for the component and module manufacturers.

There is an interesting metaphor between the telecommunication industry and America's railroad system. By way of reference, in 1850 there were 9,021 miles of tracks, and by 1916, that figure had escalated to 397,014 miles. During the first wave of backbone railroad development between big cities, there were not enough goods and people that were carried by railroad. The railroads overbuilt the system and then paused to wait for demand to catch up. Then gradually, along the railroad routes, new train stations were built, and new shops were opened. They built more short distance routes to reach small towns, villages and farms. Finally, commerce expanded beyond the railroad system's capacity, forcing another cycle of build-up to start. History has shown that driving forces emerge over time producing continual cycles of change.

In recent years, the telecommunication industry has entered its own cycle of change with a rapid expansion phase driven by various macro technology and economic factors. We all remember the last cycle ended with the dot-com bubble bursting around 2000. Although it should be noted, this last cycle did create a great legacy, with a major deployment of long haul infrastructure during that period of time. This has set up a great foundation for the current expansion of metro and access networks to access individual consumers and enterprises worldwide. This expansion with double-digit growth rates is driven by data consumption from web- and mobile-based applications.

Cloud computing is transforming traditional business models as the multi-nationals from IBM to Cisco grapple with new business models that rely on mobile-based devices and the internet. Increasing mobile data streaming through wireless and cloud-based computing and storage through hyperscale data centers result in demands for increasing capacity, particularly in data communication areas, including wireless and data center infrastructures. In return, the data bandwidth demand from individual consumers and enterprise creates the need to upgrade long haul networks, data centers and metropolitan communication systems. Just a few data points worth noting include IDC's forecast of data growth, which predicts the industry is on track to hit a data size of 35 zettabytes, or 44 times 2009 numbers. Some analysts claim data traffic on mobile devices is growing at 61% annually. Right now, we are in a cycle with a relatively healthy balance between the pull of consumer demand and the push of infrastructure construction.

Photonics and RF electronics have always been on the frontier of network infrastructure expansion. Recently, the transition to 10Gps to 40Gps and then 100Gps/200Gps/400Gps optical network systems enabled an array of new generations of photonic components such as laser chip-on-submount (COS), micro-iTLAs, 100G/200G/400G modulators, intradyne coherent receiver (ICR), 100G CFP2-ACO, and QSFP28+ transceivers. Wireless base station build-out needs critical components, such as RF power amplifiers, made with GaAs or GaN. Most of these products have multiple dies bonded on a common platform or base plate inside a metallic package.

Typical bonding processes include both eutectic and epoxy materials. Eutectic bonding is one area of particular interest to photonics, microwave and RF electronics due to the need for a clean, highly thermally efficient process and for long-term reliability. This article, therefore, specifically focuses on the challenges and automation solutions related to eutectic processing.

Challenges in volume manufacturing

The forecasted volumes for the new generation of photonics and RF electronic components are unprecedented. This demand level increases the pressure for lower cost manufacturing. However, with the trend of increasing labor costs in popular manufacturing bases, such as in China, it becomes necessary to use a much higher level of automation in the industry. In addition, the higher precision equipment required for advanced packaging with higher density, demands automaton because manual and semi-automatic processes are much less effective both from a cost and a quality perspective.

Given these demands and this environment, the challenges include: throughput and accuracy, handling delicate materials, the ability to handle a large and diverse component inventory, stability requirements of 24/7 operations, the scalability needs once demand takes off, and finally, the market requirements surrounding traceability of parts. Each of these challenges is described in more detail in the sections below.

Throughput and accuracy. Automation will always deliver higher levels of throughput compared with manual or semi-manual operations, in any sector. Specifically, in the world of die attach, automation can have 3x to 10x of throughput compared to its manual counterpart depending on the exact process. On the other hand, the throughput is only meaningful with achieved accuracy. With the technological advancement of component products and new processes, for example, silicon and InP photonics integrated circuit (PIC), we see the 5µm pick and place accuracy (±3σ, the current main stream) moving to requirements of 3µm (±3σ) accuracy or better, specifically in photonic and imaging applications.

Handling delicate materials. III-V materials such as thin GaAs, InP and GaN dies require delicate handling. The crystal facets on edge-emitting laser diodes, the top emitting surface of vertical-cavity surface-emitting lasers (VCSELs), and other active areas must not be touched by the bonding tools because the devices can be damaged. It is even more critical when flip-chip bonding is required. Because all GaN RF transistor die are typically very thin and have a large aspect ratio, the force and pressure control is crucial in picking and placing the die. It is very useful to have a real-time, closed-loop feedback in the force and height control when long-term reliability is an issue.

Managing multiple parts with various sizes. Optical and RF applications frequently require handling a large range of devices from small to large, as well as odd shaped. Many of the devices used in packages are small, including laser diodes and monitoring diodes. Thin metal preforms must be oriented and delicately handled. These preforms are tedious to manually handle. Increasingly, extreme aspect ratio devices are used for arrays. These devices can have an aspect ratio as extreme as 15:1. The housings may also be odd shaped, with small housings of large packages with protruding connectors and pins. Flexibility is key for an automatic machine to be able to perform a variety of die attach processes on one platform. The ability to handle a large number of component types from 150 micron diodes to large odd-shaped lids and attach them eutecticly, with epoxy or with thermocompression, is a tremendous advantage over manual or semi-automatic assembly.

Stability. Volume manufacturing often requires 24/7 operations or overnight operation with minimal operators. The automatic equipment stability becomes critical in order to avoid or minimize errors and thus loss of materials and productivity. The system stability can be tested through rigorous steps, but more importantly, the platform needs to be proven in the field. A reliable automation supplier with competent local technical services and expertise in photonics, microwave and RF applications is key for success.

Scalability. In today's dynamic market, it's not just about being first to market but it's also about having the capability to scale quickly and safely when higher volume is demanded. How quickly can your manufacturing partner scale production? Increasingly, product cycles are measured in months rather than years. Markets change quickly demanding that all vendors in the supply chain react quickly. It is important to have a product and a process that is scalable, because it often makes a difference between the vendors who dominate and those who do not. Short product cycles mean frequently changing production lines. Manufacturing systems need to be suited for dedicated high-volume manufacturing, yet flexible enough to allow small lot production and changeover between designs.

Traceability. Traceability is required for device tuning and component selection at integration. For these reasons, it is important to track individual die lot and serial number information with the serial number of the device being built. Manual record keeping of this pedigree information can be time-consuming, tedious, and vulnerable to human error. Automation equipment must continually compile information and export to log files for later inspection. This should enable all relevant information to be delivered with the completed product.

Fully automatic eutectic bonding

While the volume manufacturing of photonics, microwave and RF electronic components present some unique requirements and challenges, there are attractive solutions, which involve cost-effective automation to reduce manufacturing costs and increase capacity. The rest of the article will review how the eutectic process and characteristics can solve these problems.

Solder reflow eutectic bonding. 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 optoelectronics, this often means two gold-plated materials being joined by lead-tin, gold-tin, or gold-germanium solder. To achieve this bond, typically, a solder preform is placed on one component - usually a carrier or sub-mount - and then the second component, often a microwave monolithic integrated circuit (MMIC), photodetector or laser chip, is placed on the preform. The temperature of the assembly is brought up to just above the melting point of the solder either by heating the base on which the assembly rests, or by flowing heated gas over the assembly. Just as the solder liquifies, the chip is placed with controlled force. The part is cooled to below the reflow temperature and the eutectic bond is complete (Figure 1). Depending upon the device type and construction, scrubbing may be used during the placement process.

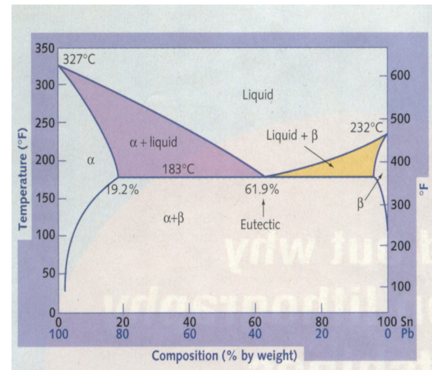

Figure 1: Eutectic transitions for a given metal composition—in this case, tin-lead.

The scrubbing step consists of applying a vertical force to the chip while also applying a lateral force. The chip is usually moved three to five mils in the negative, and then in the positive x or y direction for several cycles, and then possibly in the alternate direction as well. Rotational scrubs are sometimes employed. Scrub parameters consist of amplitude, speed, and frequency in the x, y, and theta directions. Parameters are determined by process requirements such as the surface area of the chip or the mass of the carrier and process constraints such as proximity to adjacent die. Scrubbing is done as a component of the process of forming a common material (bond) among the three materials. Forcing out air reduces voiding. Also, the solder is better distributed across the die, and the pressure assists the diffusion process.

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 (Figure 2). A 90-95% nitrogen-hydrogen

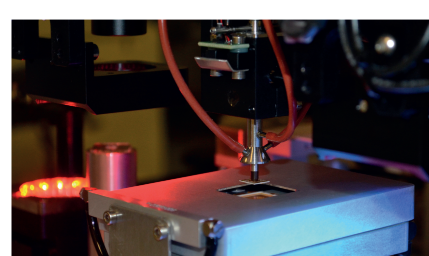

Figure 2: A pulse-heated, fast-ramp eutectic stage.

mix can be used so that hydrogen is present for use in the formation of the bond.

From the perspective of the equipment manufacturer, control of the eutectic process involves several key elements and processes. These include the ability to accurately control the temperature of the device, to accurately control contact forces, to introduce a scrub to break through the oxides, to introduce energy to spike the temperature and to mix the various metals contained in the solder, to provide an inert atmosphere with cover gas or a fluxing agent with cover gas, and to control cooling and collets.

Thin GaAs and InP die require delicate handling. The crystal facets on edge-emitting diodes, as well as the surface of the emitting implant on vertical-cavity diodes and other active areas, must not be touched by the bonding tools because the devices can be damaged. Table 1 illustrates the sort of delicacy required.

Force

- 15-20g for .020 square die
- 40g for .050 square die
- 80g for.070 square die

Scrub

- Typically .003 to .008 inches in X, Y, or both directions
- Usually 3 to 5 cycles

Table 1: Handling requirements for thin GaAs and InP die.

Solder Alloy Melting Points

- Pb38 -- Sn62 183° C
- Au80 -- Sn20 280° C
- Au88 -- Ge12 356° C
- Au97 -- Si03 363° C
- Au06 -- Pb94 304° C
- Au82 -- In18 451° C

Table 2: Different metal compositions have specific reflow profiles.

Multiple die eutectic bonding. Some advanced photonics devices require multiple dies, bonded on a sub-mount or carrier—all by eutectic bonding for a range of purposes, such as high thermal conductivity, high reliability, and special hybrid integration. A more complicated tunable laser chip on a carrier may include other additional components such as capacitance for bandwidth optimization. Sometimes other mechanical components for fiber alignment may also need to be bonded through eutectic bonding on the same carrier where the laser sits.

In order to achieve the bonding of multiple parts within a package, a temperature hierarchy is frequently required. To achieve this temperature hierarchy, fast ramping heated workstations are used. There are many reasons for a temperature hierarchy. For example, a monitoring diode may need to be eutecticly bonded to a spacer at one temperature (for example, gold-germanium at temp Y) and the subassembly (monitoring diode and spacer) may then need to be bonded to a substrate using a lower temperature solder (for example, gold-tin at temp X). The substrate may then need to be mounted to a package utilizing a lower reflowing solder (e.g., lead-tin at temp Z)(Table 2). This fast ramping is achieved by utilizing a low-mass hot plate.

In-line eutectic processing. In-line eutectic provides a means to achieve high production volume. By utilizing a progressive hot plate system that indexes through heat zones, eutectic die attach is performed on the same "boat" or carrier that transports parts through the conveyer line that loads and unloads automatically. Strict temperature control is achieved by indexing parts through pre-heat, assembly, and post-heat zones. Temperature profiling of each heat zone enables fast processing of high-mass parts. High throughput is achieved by limiting the temperature ramping time at the bond station. All temperature zones are under a cover gas of nitrogen and hydrogen mix to prevent oxidation of the heated parts (Figure 3).

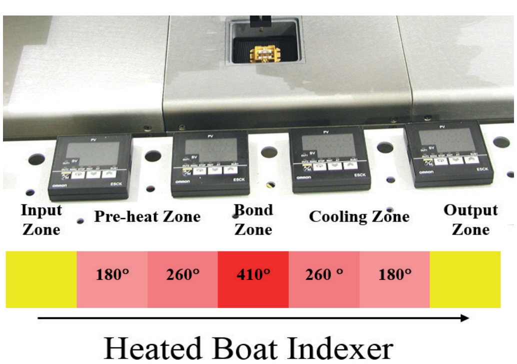

Figure 3: In-line eutectic die bonding.

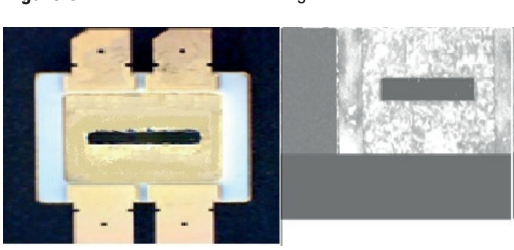

Figure 4: Eutectic package (left) with Sonoscan inspection results (right).

For gold-silicon eutectic, the vision system aligns the package and then picks and places the die, using a scrub action (variable amplitude and frequency) to accomplish the eutectic bonding. A heated cover gas of hydrogen and nitrogen is present over the bonding area. For solder reflow eutectic bonding, such as gold-tin (Au/Sn) attach of gallium arsenide (GaAs) and gallium nitride (GaN) die, the system aligns the package and picks and places a preform onto the heated package (if required, the preform can be pre-deposited) (Figure 4). The die is then picked and placed, while the temperature at the bonding position is ramped using a pulse heated eutectic stage and scrubbed (variable amplitude and frequency) to accomplish the eutectic reflow. The boat is indexed to the next substrate position and the above process is repeated until all the boat positions have been bonded. As the indexer transfers the boat, the parts are incrementally cooled by passing over a cool down zone. When completed, the indexing conveyor transfers the boat to the output magazine loader. Finally, there is a capability that sits above any die eutectic bonding process: an advanced vision system, which is discussed below.

Advanced vision systems. Machine vision is critical for accurate placement. Having a proven ultra-accurate machine platform that is mechanically and thermally stable, with no cantilevered parts, is a baseline to achieve accurate device placement. In addition, the accurate alignment of device fiducials is required to achieve micron-level accuracies. Many other key features are required for accurate final placement.

Local and global vision alignment is used for nested substrates and feature alignment. The software must allow the user to align die relative to substrate fiducials, die edges, or features of previously placed die. The alignment of the laser chip to a photo diode or a

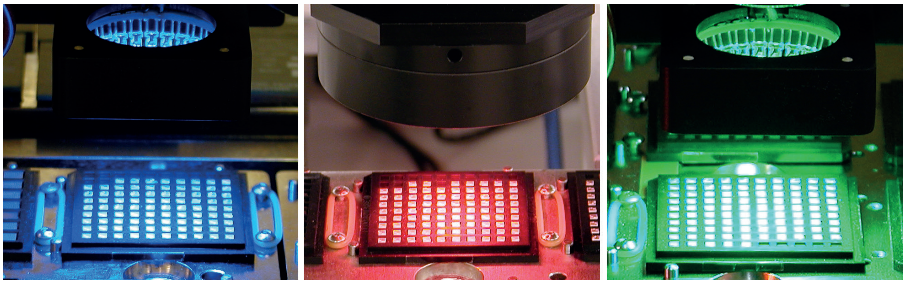

Figure 5: Programmable lighting intensity and color.

lens to a VCSEL are common photonics examples. Another example is the alignment of a critical die, such as with MMICs and beam lead diodes. This capability ensures repeatability and precise alignment of optical and microwave devices.

Multi-colored lighting is required to successfully vision process a wide range of materials. Tricolor (i.e., red, green and blue) programmable lighting provides the capability for processing challenging alignment surfaces, such as gold traces on alumina (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.

Advanced vision must rapidly perform robust substrate fiducial alignment regardless of material contrast and detect and orient die over a full 360°. Both pattern recognition and boundary trace tools provide a complete solution to locate the die center, edges, or application-critical features. This enables fast, error-free processing of complex assemblies.

The optics and camera system must include multiple magnifications for both upward and downward facing cameras. Machine vision is used for alignment of component 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. Software, hardware, lighting and optics are integral. One example is the manufacturing of a photodetector. The downward facing camera first aligns a feature on the substrate package. The upward facing camera then aligns the lens on the bottom of the die, and the system places and bonds the device.

Summary

This article discusses the recent trends in the demand of the communication market, the needs of photonics, microwave and RF electronic devices and processes, and the technology advances of automation in eutectic die bonding. The recent proliferation of mobile-based applications and cloud-based computing and storage, drives higher demand in bandwidth, making photonics and RF electronic devices among the most critical components for communication infrastructure expansion. The high-volume production and more advanced products require high speed, high precision and reliable automatic die bonding solutions for a successful manufacturing environment. The integral parts of these solutions are equipment performance, dedicated software applications, advanced vision systems, process understanding, and technical support services.

Biographies

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