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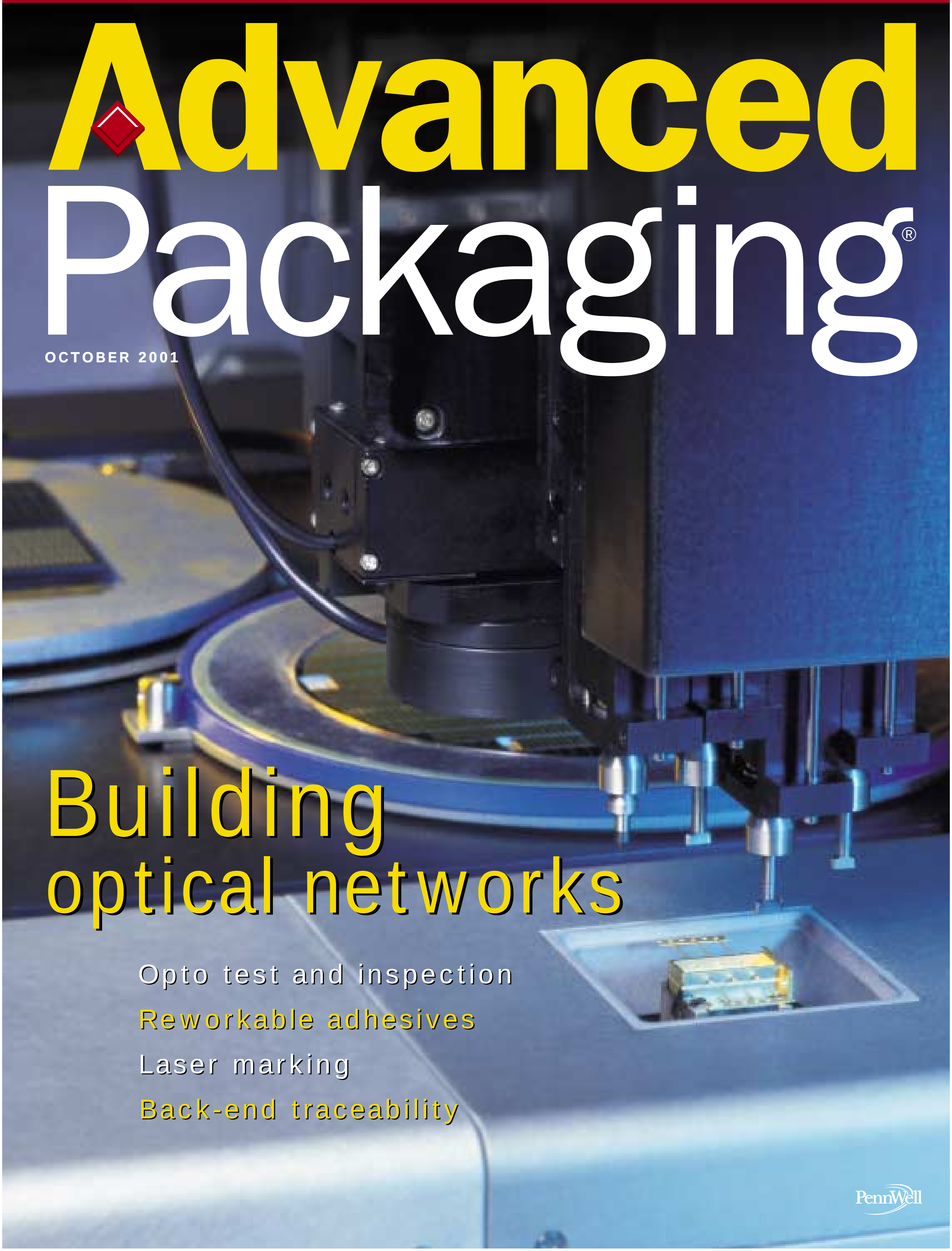

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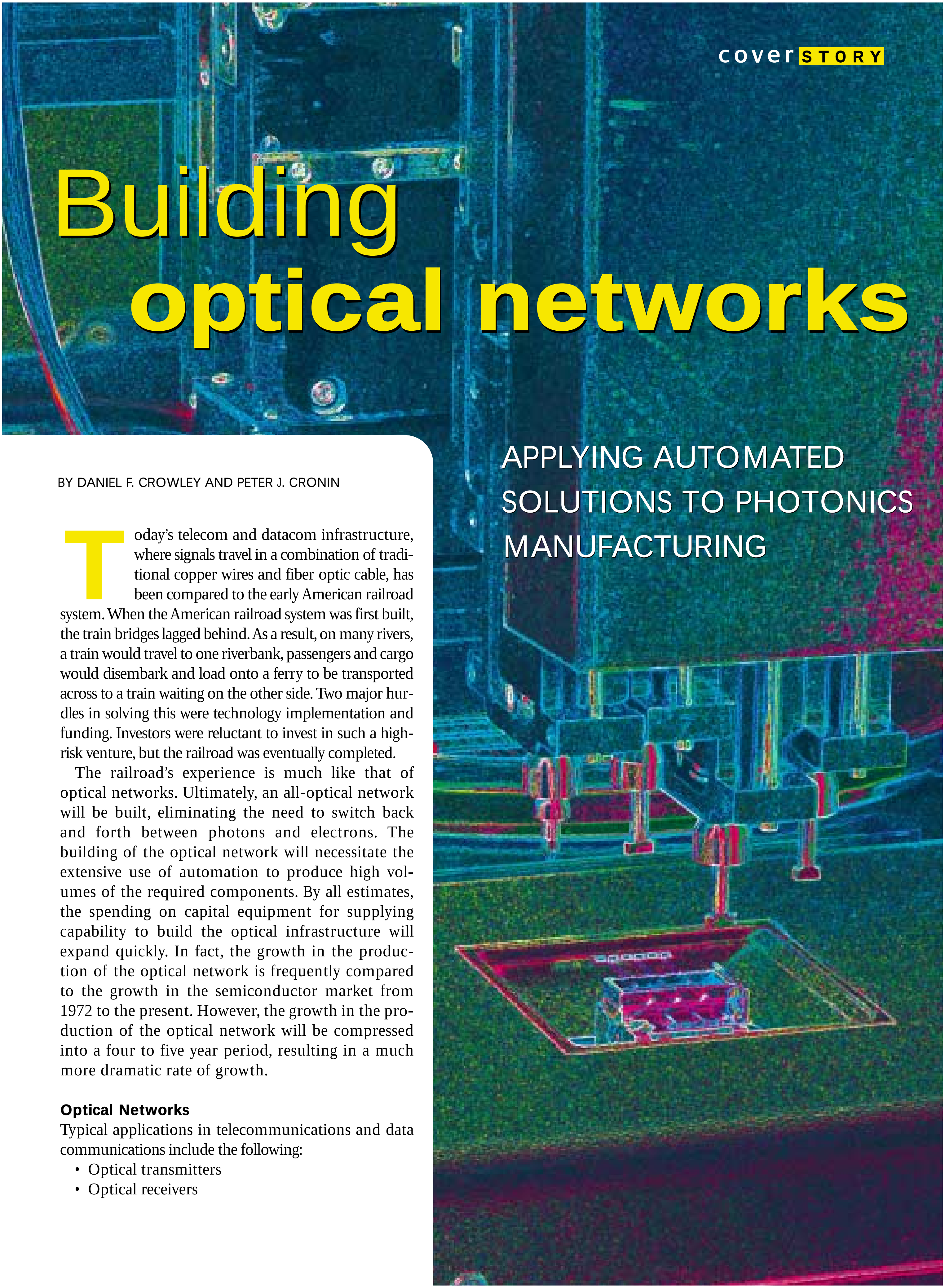

Building optical networks

APPLYING AUTOMATED SOLUTIONS TO PHOTONICS MANUFACTURING

BY DANIEL F. CROWLEY AND PETER J. CRONIN

Today's telecom and datacom infrastructure, where signals travel in a combination of traditional copper wires and fiber optic cable, has been compared to the early American railroad system. When the American railroad system was first built, the train bridges lagged behind. As a result, on many rivers, a train would travel to one riverbank, passengers and cargo would disembark and load onto a ferry to be transported across to a train waiting on the other side. Two major hurdles in solving this were technology implementation and funding. Investors were reluctant to invest in such a high-risk venture, but the railroad was eventually completed.

The railroad's experience is much like that of optical networks. Ultimately, an all-optical network will be built, eliminating the need to switch back and forth between photons and electrons. The building of the optical network will necessitate the extensive use of automation to produce high volumes of the required components. By all estimates, the spending on capital equipment for supplying capability to build the optical infrastructure will expand quickly. In fact, the growth in the production of the optical network is frequently compared to the growth in the semiconductor market from 1972 to the present. However, the growth in the production of the optical network will be compressed into a four to five year period, resulting in a much more dramatic rate of growth.

Optical Networks

Typical applications in telecommunications and data communications include the following:

- Optical transmitters
- Optical receivers

- Switches
- Amplifiers
- Filters
- Micro-electromechanical systems (MEMS)
- Photo detectors
- Laser submounts
- Lenses
- Multiplexer (MUX) and demultiplexer (DEMUX) sub-components
- Tunable devices
- Couplers.

The automated manufacturing of these photonic components presents some unique requirements and challenges. These include the need for proper handling of small delicate parts, high-precision placement and meeting time-to-volume pressures. Automated solutions for dispense, assembly and integration can be applied to reduce manufacturing costs and increase capacity.

Eutectic bonding is an area of particular interest for photonic applications because of the need for high reliability and excellent heat transfer. For these reasons, and because epoxies often cannot be used because of their outgassing characteristics, eutectic bonding is commonly used. Turnkey solutions for eutectic bonding, including in-situ eutectic bonding, in-line eutectic bonding, and reflow eutectic bonding in a chamber, are discussed here.

Solder alloy	Melting point
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 1. The wide range of solder alloy melting points demonstrates the need for composition-specific reflow profiles.

Photonic Challenges and Requirements

Delicate parts handling: Thin gallium arsenide (GaAs) and indum phosphide (InP) die require delicate handling. Active areas, such as the crystal facets on edge-emitting diodes and the surface of the emitting implant on vertical cavity diodes, must not be touched by the bonding tools because the devices can be damaged. These areas are critical, because they are where the beam is emitted and are also where heat is concentrated. Damage results in the inability to dissipate heat and leads to destructive device overheating.

High precision: Devices need to be placed with a high degree of precision, because the optical path must be aligned to minimize the scattering of light. While active alignment is frequently done at the final stages of assembly when aligning the fiber to the package, this task can be minimized by accurately aligning the individual components during assembly. One example of a critical alignment is in aligning an edge-emitting laser to the submount; if the front edge of the chip overhangs the submount, the device does not have a good surface to dissipate heat, resulting in overheating and device failure. On the other hand, if the laser does not reach the edge of the submount, then the light signal is reflected off the submount and the signal is scattered.

Small and odd-shaped devices: Optical applications frequently require handling of a wide range of devices, including typically small laser diodes and monitoring diodes. Thin metal preforms must be oriented and handled carefully. High aspect ratio devices are also challenging, with some array devices having aspect ratios as extreme as 15 to 1.

Design for manufacturing: As in the semiconductor industry many years ago, first-generation photonic devices are not necessarily designed for volume manufacturing. Frequent challenges include a high part count, devices placed at various angles and levels, and mixed technologies in a single part — including various eutectic processes (i.e., different reflow temperatures using multiple metal compositions to achieve a temperature hierarchy, as shown in Table 1), thermally cured epoxy, and epoxy cured by ultraviolet (UV) light.

Time to volume pressures: In today's dynamic market, it is necessary to not only bring a design to market quickly, but also to consider time to volume production. It is important to have a product and a process that are scaleable — it often makes a difference between the vendors that achieve extreme success and those that 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.

Need for material traceability: Traceability is required for device tuning and component selection at integration. It is also required by Telcordia standards. For these reasons, it is impor-

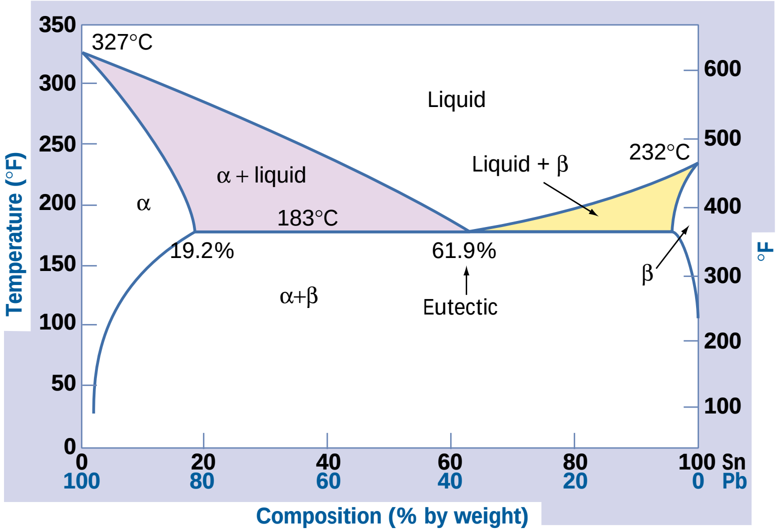

Figure 1. A phase diagram shows the eutectic transition for a given metal composition, in this case, lead-tin.

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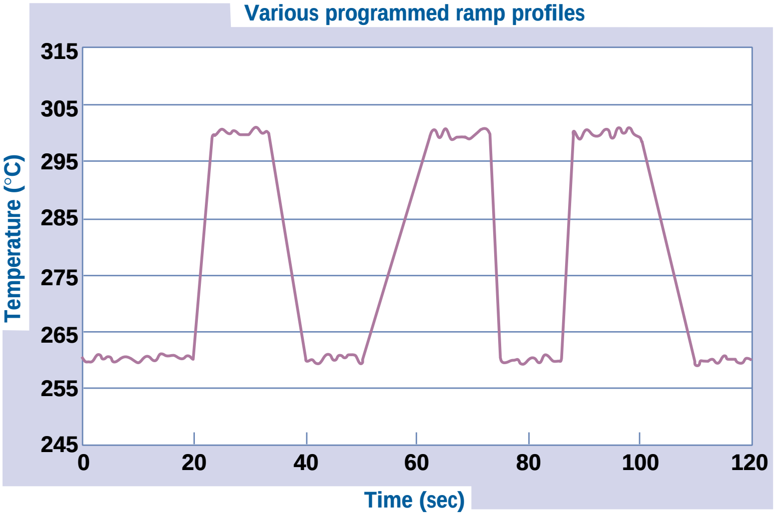

Figure 2. Various fast programmable ramping and cooling options are available for eutectic bonding.

tant 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 should be able to take in this information automatically and deliver it with the completed product.

Manufacturing Solutions

While the automated manufacturing of photonic components presents some unique requirements and challenges, these processes can be cost-effectively automated to reduce manufacturing costs and increase capacity. Automated packaging solutions for dispense, assembly and integration provide significant benefits. Eutectic bonding is one area of particular interest in photonics because of the need for a clean, highly thermally efficient process. Epoxies are often not used because of the requirement for heat dissipation from high-power devices with a small surface area and because of the inherent outgassing characteristics of polymer epoxies. Other aspects of assembly equipment that serve as solutions for photonics components include placement accuracy, the use of machine vision and the ability to handle a variety of forms of material inputs.

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 submount, and then the second component, often a MMIC, photodetector or laser chip, is placed on the preform. The temperature of the assembly is brought to a point just above the melting point of the solder (Figure 1) either by heating the base on which the assembly rests, or by flowing heated gas over the assembly. Just as the solder liquefies, the chip is placed with controlled force. The part is cooled to below the reflow temperature and the eutectic bond is complete. Depending upon the device type and construction, scrubbing may be used during the placement process.

The scrubbing step consists of applying a vertical force to the chip while moving it laterally. The chip is usually moved about 100 microns in the negative and then 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 by process constraints, such as proximity to adjacent die. The benefits of scrubbing include forcing out air, which 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 a nitrogen environment to prevent oxidation of the bonding surfaces. A 90 to 95 percent nitrogen-hydrogen 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, accurately control contact forces, introduce a scrub to break through the oxides, introduce energy to spike the temperature and mix the various metals contained in the solder, and provide an inert atmosphere.

Force
• 15-20 g for 0.5 mm square die
• 40 g for 1.25 mm square die
• 80 g for 1.75 mm square die
Scrub
• Typically 75–200 microns in X, Y, or both directions
• Usually 3 to 5 cycles

Table 2. Typical handling requirements during eutectic bonding.

Heated Workstages

Control of temperature is an important aspect of the eutectic bonding process. Differing part sizes and materials necessitate temperature profiling of the process. Although the eutectic point for pure gold/tin is 280°C, some amount of process development is necessary to find the precise temperatures that should be used for dwell and reflow temperatures. The dwell temperature is the temperature at which the part is held until the part is placed. Once the part is placed, the temperature is quickly brought up to the reflow temperature. The most effective and efficient processes have dwell and reflow temperatures that are close enough that fast ramping is possible, but far enough apart that the integrity of the bond is upheld. Parts that are of high mass require attention to ensure a fast process. Similarly, ceramic parts or others composed of materials that are poor thermal conductors pose related challenges. Parts with small surface areas but with high mass are poor thermal conductors and therefore must be carefully profiled.

Typically, in photonics, a laser die can be mounted to a submount, or a submount can be mounted to a bench, with the substrate material held to the hotplate with vacuum. Some parts need additional tooling, such as mechanical clamping, to facilitate the integration of clamping with a stand-alone hot plate. This kind of clamping and extra handling must be compatible with the requirements of the thin GaAs and InP die. Table 2 illustrates typical handling requirements.

Figure 3. Inverted pyramid collet for eutectic bonding.

Implementation

In-situ bonding: A flexible system developed for eutectic bonding supports direct gold-silicon eutectic and eutectic reflow using gold-tin and gold-germanium preforms. The system uses programmable (up to 450°C) closed-loop temperature control for eutectic bonding. For the process of direct gold-silicon eutectic die attach, the system places the die with an inverted pyramid collet (Figure 3) and simultaneously scrubs (variable amplitude and frequency) to accomplish eutectic reflow. A heated cover gas of H_2/N_2 mixture is blanketed over the hot plate. For gold-tin or gold-germanium reflow, the machine first places a preform onto the package. The die is then scrubbed (variable amplitude and frequency) to accomplish the eutectic reflow. Small and irregular shaped submounts are clamped with custom mechanisms to ensure positive locating and bonding.

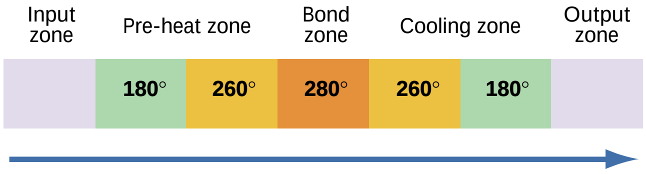

Figure 4. Indexing through a progressive hot plate.

Reflow chamber: In a reflow oven, the placement parameters are different from those of epoxy-based processes. The accurate stacking (dry) of preforms and components, as well as the gentle transfer of these assemblies to an oven, are particularly important, because there is no surface tension to hold the devices in place. With other types of attachment, the medium can be in a liquid form, which helps to hold the pieces in place.

In-line eutectic bonding: An in-line eutectic bonding process provides a means to achieve both fast times to market as well as fast times to high production volume. By using 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 line. Strict temperature control is achieved by indexing parts through pre-heat, assembly and post-heat zones (Figure 4). Temperature profiling of each heat zone enables fast processing of high-mass parts. High throughput is achieved by limiting ramp time in the assembly zone. All temperature zones are under a cover gas of nitrogen and hydrogen to prevent oxidation of the heated parts.

Temperature hierarchy: To achieve the bonding of multiple parts within a package, a temperature hierarchy is frequently required. Fast ramping heated workstations are used to accomplish this. There are many reasons for a temperature hierarchy. For example, a monitoring diode may need to be eutectically bonded (e.g., Au-Ge) to a spacer at one temperature, and the subassembly (monitoring diode and spacer) may then need to be bonded to a substrate using a lower temperature solder (e.g., Au-Sn). The substrate may then need to be mounted to a package using a lower reflowing solder (e.g., Pb-Sn). This fast ramping is achieved by using a low mass hot plate.

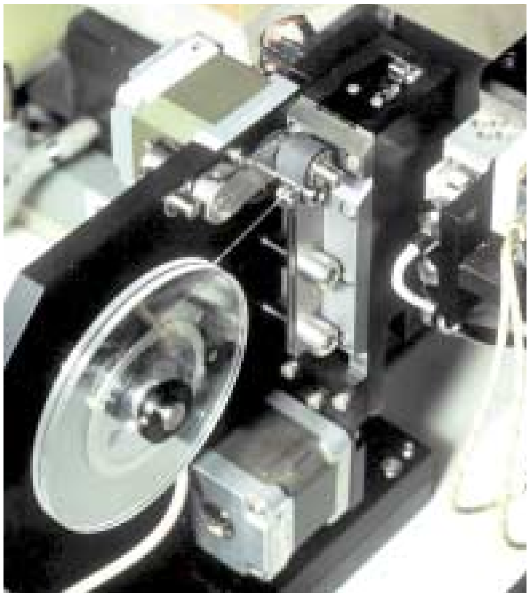

Figure 5. Eutectic solder preform feeder.

Preform handling: The handling of delicate solder preforms is an extremely tedious task when done manually. A great benefit is gained through automating the presentation of preforms to the assembly equipment. Several options exist for their handling, including waffle pack, tape-and-reel (pre-packaged in 8-mm feeders from the preform vendor) and preform feeders (Figure 5).

Solder preforms can be presented for eutectic bonding by offering automatic preform feeding. A preform feeder can handle reels of solder and cut a variety of preform sizes for immediate pick and place during the assembly process. The feeder uses a guillotine mechanism to cut the preform while it is held over a vacuum hole for positive location by the pick and place tool. The process is optimized by programming the cam-driven blade and the stepper motor for control of indexing. The use of such a feeder eliminates the tedious task of manually cutting and transferring preforms to waffle packs. Increasingly, the use of pre-deposited solder is used. This provides many benefits, including eliminating a difficult assembly step and giving better control of the solder volume deposited.

Accuracy: Placement accuracy is paramount in photonics assembly. Laser die demand extreme accuracy for heat dissipation and to minimize reflection. Photodetectors must be placed in line with the beam. Passive elements frequently offer very small apertures that must be aligned for beam transmission.

To achieve this level of accuracy, automated assembly equipment must begin with the appropriate platform, ideally one that is built from materials that are stable regardless of temperature or humidity fluctuations. This can be achieved with granite or advanced polymers. For motion control, linear motors with optical encoders can be used for rapid and accurate movements with high precision. Cantilevered robots can suffer serious losses in accuracy and speed. Integration of machine vision combines the accuracy of the machine with the ability to accommodate variably presented parts. For practical use in automated assembly, the system design must be such that frequent calibration is unnecessary.

Vision: Machine vision is the critical link between a potentially very accurate assembly tool and randomly presented parts. Advanced vision allows multiple lasers located on the same submount to be referenced and placed relative to each other in one axis, and relative to the front of the submount in the other axis.

Machine vision systems must be robust both in how they find components and how they reference the assembly. Effective visions systems can quickly find and align parts no matter how they are presented in waffle packs over a full 360 degrees. This is important to avoid the need for prealignment of die by operators and to ensure that all of the good die that are presented are actually used. Particularly in photonics, there is a need to find distinct die features before the die is picked. Submounts and lasers have an orientation that plays into how they are placed. An example of a challenge that must be met by a machine vision system is to bond a laser submount to a bench, and then using machine vision, pick a photodetector submount and place it so that the detector diode is properly aligned to the previously placed laser submount. In this case, global alignment is used to place the laser to the bench, and a local alignment is used to place the photodetector relative to the laser.

Another feature required of machine vision is the use of an upward facing camera for alignment of component feature and flip chips. The camera captures the image of the die feature on the vacuum collet before placement. The integrated vision aligns features on the bottom of the device before 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.

Material inputs: High part counts and product mixes are typical in photonics. Thus, it is necessary that automation equipment is robust in terms of handling the input of materials. Most commonly, materials are presented in waffle packs, Gel-Paks, or directly from wafers.

Assembly equipment is often used in line with other equipment. An epoxy dispense machine might be placed before the assembly station, and an oven or wire bonder might be placed downstream. This provides an additional material input possibility because butterfly packages or benches can be fed to the assembly work cell on boats. In this case, the package can be lifted from the boat to an assembly station, or the components can be brought from the waffle packs and assembled right in the boats. In-line systems are frequently more dedicated to a particular product but provide increased throughput.

Conclusion

Automating the assembly of photonics devices and components is readily achieved with equipment available today. Automation is necessary in photonics to achieve the high throughputs and yields that the maturing market demands. The accuracy necessary for photonics is now available from established equipment suppliers. This equipment can enable manufacturers to go from concept to market with full automation and high yields, thus bringing about rapid advances in meeting the demand for bandwidth and progressing to the idealized all-optical network. AP

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