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AUTOMATED TECHNIQUES IMPROVE MICROWAVE-MODULE ASSEMBLY

Automated assembly provides better module quality and higher production yields while reducing costs.

THE assembly of advanced packages has become a critical factor in today's electronic manufacturing environments. In particular, microwave modules have some unique requirements that demand extremely-precise dispensing and placement, delicate handling, and well-controlled curing (or reflow). These needs can be satisfied by applying automated manufacturing techniques to the assembly of microwave modules (Fig. 1).

1. A typical microwave component that can be manufactured by automated methods is the T/R module used in phased-array radar systems (Photo courtesy of Raytheon Co., Quincy Operations, Quincy, MA).

Similar to classic analog and digital hybrid circuits, microwave-module manufacturing started out as a manual, labor-intensive procedure. Two significant factors make the automation of microwave circuits more difficult than that of hybrids:

1. Microwave circuits contain extremely-delicate GaAs dice, with these fragile parts being as thin as 0.002 in. They also have delicate features called air bridges which are located on the top surface and serve as electrical crossovers (Fig. 2). With thicknesses of two to three microns, the air bridges must not be damaged during handling. In addition, some GaAs microwave monolithic integrated circuits (MMICs) contain ground vias, which are holes that penetrate from the bottom of the die up to the back surface of the circuitry. Vias can present problems during solder reflow and handling if the process is not controlled properly.

2. Many microwave-module tolerances necessitate machine-placement accuracies of ±0.0005 in. This results in consistent gaps between adjacent components as intended by the RF design engineer. However, the tolerances of the components must also be minimized. For example, a gap of ±0.002 in. can be obtained only if placement tolerances are held to ±0.0005 in. and chip size is held to ±0.001 in. With this chip-size tolerance and a placement accuracy of ±0.002 in., a gap of 0.005 in. is needed between the two chips to ensure that one chip is not placed on top of another.

Variations in gap lengths during manual attachment leads to a variable wire-bond length. The wire bond is a series inductive element for which the RF designer assumes a nominal value to be absorbed into the circuit design. Variations in this inductance perturb the nominal RF performance of the overall microwave module. This condition leads to worse standard deviations of key parameters across a family of modules. As a result, operators must perform a labor-intensive RF tuning

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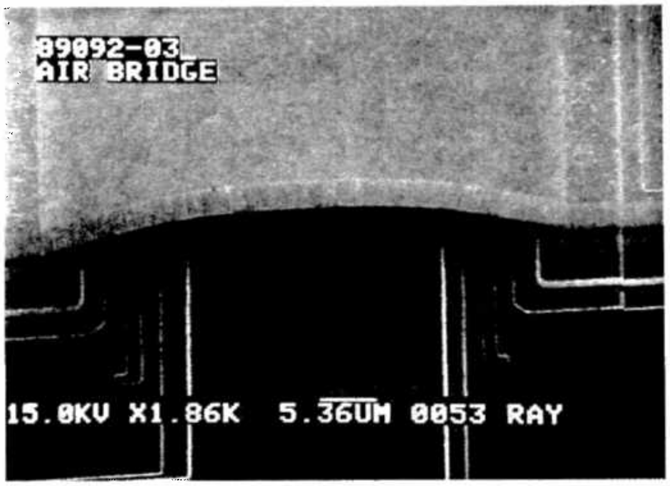


2. Air bridges, which provide electrical crossovers in MMIC applications, have thicknesses of two to three microns, requiring extreme care in handling (Photo courtesy of Raytheon Co., Advanced Device Center, Andover, MA).

process to compensate for inaccurate placements.

The attachment method of dice to carriers or housings depends on the power and frequency of the device (i.e., heat-sinking requirements). Components are placed either into epoxy (wet placement) or onto solder preforms (dry placement). A third method is a direct-attach approach, where components/preforms are reflowed during placement with manual eutectic bonders.

The epoxy-attach method requires the application of consistent, even layers of conductive material, as well as extremely small dots. The inspection criteria for military microwave packages, including the transmit/receive (T/R) module, is MIL-STD-883. One important guideline is proper epoxy coverage under the die and filleting at the outside edges of the die. The thickness of dispensed epoxy, material characteristics (e.g., viscosity and particle sizes), and placement force will dictate the final bond line, coverage, and filleting. Components as small as 0.010 $in.^2$ and as thin as 0.002 in. magnify the challenge.

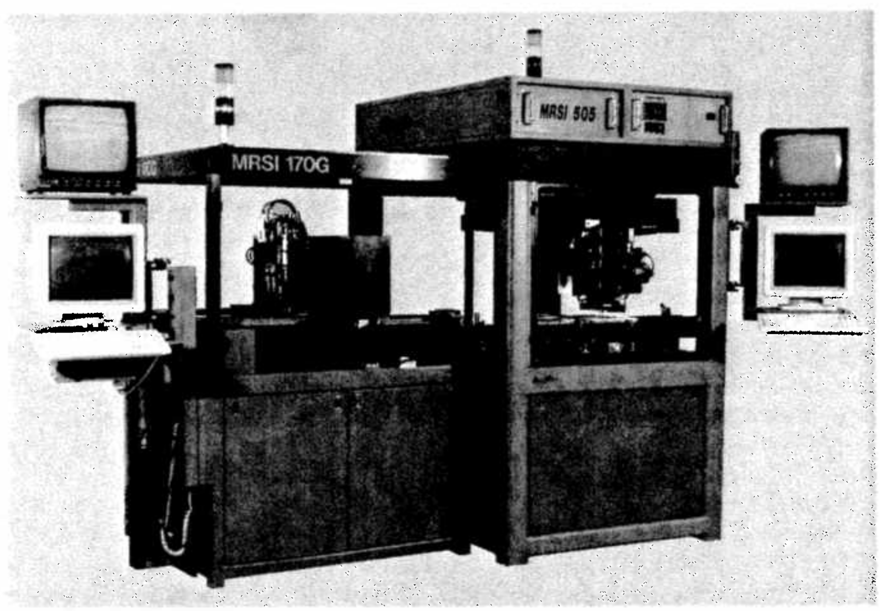
Similar bonding requirements exist for solder-reflow applications. However, the placement parameters are different than those of the epoxy-based process. Solder mounting methods require the accurate stacking (dry) of preforms and components, as well as the gentle transfer of these assemblies to an oven for reflow. Unfortunately, there is no surface tension like that of wet epoxy to hold the devices in place prior to or during reflow. Some companies' processes include the clamping of these stacked components by means of dedicated fixtures.

MANUAL ASSEMBLY

Although there has been a gradual shift to automation, many GaAs-based MMIC carrier and module assemblies are still produced using manual or semi-automated methods. This requires a great deal of manual dexterity and labor. For example, the epoxy-bond line thickness must be precisely controlled to meet thermal-conductivity and RF ground-plane requirements. Also, voids in the epoxy during die attach can lead to hot spots, reducing electrical yields and reliability. Insufficient epoxy can cause poor attachment, leading to failures during visual inspection or electrical and mechanical screening, as well as catastrophic field failures. Alternatively, excessive volume can cause wicking on the sides of small or thin components such as parallel-plate capacitors. This is a primary reason for shorting with these devices.

The use of large-area die is a significant factor in reducing the cost of modules. Manually-assembled large-area die are particularly prone to cracking due to flatness, thickness, and consistency issues related to the die-attach process. Finished yields are a direct function of the capability of the manual method.

The eutectic attach processes require very precise placement of the extremely-fragile GaAs relative to the dry preforms. These solder preforms have thicknesses of 0.0008 to 0.0010 in. The preforms are often placed underneath a die in a stacking operation. Precise placement helps prevent excessive die-edge fillet spreading (both vertically and horizontally) between tightly-spaced component carriers, ceramic matching networks, and module drop-in



3. This in-line fabrication scheme incorporates the MRSI-170G automatic dispenser to deliver epoxy and the MRSI-505 assembly work cell for die attachment.

cutouts. Manual assembly becomes tedious when trying to maintain gaps of 0.001 to 0.002 in. between module parts (these small gaps greatly enhance MMIC electrical performance). Some manual solder-reflow processes also require the placement of clamps and weights on top of the stacked components to minimize voiding during the reflow process. This places an additional burden on the assembly process, as more dedicated fixturing is required.

The manual assembly process requires delicate handling to prevent damage to the air bridges on the GaAs die. Typically, operators use special die-pickup tooling, tweezers, or collets. For some solder-reflow processes, assemblers must carefully load trays of stacked components (carriers, preforms, and die) into ovens. Operators need a fairly high level of training and experience to sustain high yields on carriers and modules. Moreover, assembly operations are labor-intensive. As a result, throughput rates achievable with manual assembly are limited.

AUTOMATIC PROCESSES

Achieving greater throughputs with increasing yields requires advanced assembly equipment. The following are the minimal requirements for microwave assembly:

Placement accuracy: To minimize inductances from wire bonds and to reduce tuning requirements, the system must place critical devices with high accuracy relative to global and/or local alignment marks. Requirements for system positional accuracies approaching ±0.0005 in. are common in the microwave-module industry. Consistent achievement of this level of accuracy requires a mechanically- and thermally-stable platform. Granite is commonly used to provide this stability.

Flexibility: Devices in typical microwave modules can include silicon or GaAs integrated circuits (ICs); chip capacitors, resistors, and diodes; ceramic and tantalum capacitors; gold-plated subcarriers; solder preforms; and thin/thick-film ceramic substrates. Part sizes range from 0.008-in.^{2} diodes to 1-in. substrates and carriers. Component thickness also vary considerably. Because of these component variations, the hardware and software in automated assembly systems must be inherently flexible. Advanced and user-friendly interface menus allow fast and easy programming in environments with many different component types.

4. Eutectic solder reflow can be achieved by using an IR oven in line with the die-attach module. An automated handling device transfers assemblies to the oven.

Advanced machine vision: To accommodate the large variety of components and package types, the system needs powerful machine-vision capability. The vision system complements the optics and illumination, which are optimized for device recognition. In most applications, the vision system must quickly and accurately recognize randomly-oriented die (up to 360-deg. rotation) in waffle packs. This eliminates the need for vendors and kit-production departments to pre-orient components in optimally-sized tray pockets. In addition, the system should automatically compensate for multiple vendor sourcing of die.

Global and local fiducial alignments permit placements based on critical references. For example, local alignment allows for the matching of RF trace lines between substrates and GaAs die (to minimize and provide consistent wire lengths). Thus, the vision system must detect actual features on devices and place parts at the "local" level. For larger components and substrates, multiple fields of view are necessary.

Special illumination provides the flexibility needed for the wide range of components and waffle-pack types. What is obvious to the human eye is often problematic to the camera (i.e., vision system). Different lighting schemes, such as through-the-lens and oblique lighting, enhance critical features. Factors that determine the correct lighting include surface texture/finish, patterns, and background.

Die-handling requirements: Due to the variety of components within a microwave module, handling requirements vary significantly. For example, to ensure that delicate components such as GaAs ICs are not damaged, the system's end-effector pickup must be a sensitive, force-feedback mechanism. This allows minimal gram loading—typically 10 to 15 g. The feedback must be quick and accurate in order to minimize static and dynamic loading. In addition, the same end effector may have to place larger, heavier devices with forces of up to 1000 g in the next pick/place cycle.

With the proper handling mechanisms, some processes allow for direct contact of vacuum pickup collets on air bridges. However, some GaAs devices cannot withstand any level of direct contact. Thus, the system must pick around air-bridge features. This can be accomplished by programming optimal pickup locations or using perimeter collets that contact the die at the outside edges only.

Finally, the system must have the necessary ground points for static control. Charges as low as 100 V can damage GaAs devices. The system must provide earth-ground paths to the pickup collets, fixture trays (via conductive conveyor belts), and component presentation devices such as waffle-pack trays. Any plastic enclosures must be able to dissipate static charges.

Component feeding methods: Waffle packs and Gel-Paks™ are the most common methods of presenting microwave components for module assembly. Another technique which is more common to the semiconductor industry is direct feeding from expanded wafers. For delicate devices such as GaAs ICs, direct feeding eliminates one handling step, so no die sorting is necessary. To feed discrete components such as ceramic capacitors, the system should be able to pick from tape-and-reel and linear vibratory feeders. Substrates, carriers, and modules are typically loaded into boats or fixture trays. These trays are stacked in cassettes for automatic loading, resulting in greater system autonomy (uptime) in work-cell environments.

Volume production capability: The market for MMIC modules is expanding rapidly. Besides reduced material/component costs, another reason for this expansion is more creative assembly processes. As major programs continue their progress, the industry is seeking the capability to build a relatively large number of high-quality, high-yield modules in a short time period. Because the solution must be justified economically, the system must be able to achieve high throughputs while producing quality parts. System configurations, material handling and control, machine construction, motion control, and software all contribute to fast and accurate assembly platforms.

In some manufacturing environments, automation modules are linked. This reduces manual material handling between work cells. The preference is an in-line configuration similar to traditional surface-mount technology (SMT) lines. Hence, modules need to be compatible to standards such as those defined by the Surface Mount Equipment Manufacturers Association (SMEMA).

Dispensing: Although sometimes overlooked, dispensing is just as critical as die attach in epoxy-based module assembly. The dispensing system must use software algorithms to perform global and local alignments. Accurate sensors are needed to maintain consistent gaps between syringe needles and substrates. Positive-displacement dispensing pumps for both conductive and non-conductive epoxies must be responsive and accurate. In addition, special cleaning, purging, and autocalibration routines are needed to provide reliable and consistent dispensing without human intervention. Only with these features can a system dispense 0.001-in.-thick areas and 0.010-in.-diameter dots consistently and reliably inside modules and packages.

Solder reflow: If the attachment is achieved by solder reflow, solder preforms and components must be carefully stacked. This process requires well-controlled forces, dwell times, air purges, and speeds (both approach and retract). Static control is essential because of the possible attraction forces between very small components and the collet. After placement, the tray holding the stacked (dry) components must be gently set to the reflow module. This operation must not disturb the components that were just placed to high accuracies.

COMMERCIAL SOLUTION

Commercially-available solutions exist that can satisfy the above requirements. Today's customers are looking for turnkey solutions for dispensing, die attach, solder reflow, and epoxy cure. Depending upon the user's process requirements, modules can be configured in an in-line or stand-alone scheme.

An example of an in-line configuration (Fig. 3) includes a dual-headed dispenser for conductive and nonconductive epoxies and a gantry-style die-attach system. These modules are connected by a flexible material handling system. Substrates are pulled from a cassette at the input side of the dispenser. These substrates can be carried via boats or trays, or they can be directly conveyed. After dispensing, the parts are automatically transferred to the die-attach module. The parts are then transferred to an output cassette, a conventional belt furnace (for curing), or any in-line compatible module.

The line can be configured for eutectic solder reflow by integrating an infrared (IR) oven after the die-attach module (Fig. 4). In operation, a handling device gently transfers trays of stacked (dry) assemblies to the oven. The cover at the reflow stage then lowers to form a sealed chamber. The system can download pre-programmed temperature profiles under various vacuum or pressure states. The reflow chamber is designed to avoid disturbing the components with incoming gases. Process gases enter from under the handling fixture to minimize gas currents. After eutectic reflow and cooling, the parts are automatically removed. All process data is automatically stored.

AUTOMATION BENEFITS

Automated assembly produces more-consistent, higher-quality modules and circuits at a lower cost. Precise epoxy dispensing and die placement results in consistent gaps between adjacent components. Tighter placement minimizes wire lengths, while at higher frequencies, the modules need less manual tuning and tweaking to achieve desired performance. Testing throughput also increases. For example, Raytheon developed an automated probe station that is integrated with a specially-designed three-port test station. The station conducts more than 98,000 measurements on multiple modules and generates a pass/fail report with full numerical data in 3.5 min.

Increased production throughput of microwave modules is an added benefit of automated assembly. Initial analysis has showed throughput increases of 8 to 40 times that obtained with manual methods at some customer sites. Non-recurrent engineering used to program the equipment is often paid back in a few dozen units. Computer-aided-design (CAD) downloading capability also minimizes the costs of equipment programming. Commercial CAD translation programs are available that automatically convert numerous CAD formats into files for specific modules like the MRSI-505 assembly work cell.

Trends in some industries are toward smaller lot sizes and longer periods between identical production runs. Fast production changeover is essential. Special production runs are also typical in the defense industry. For example, suppliers must be prepared to manufacture a small order of spares (up to a quantity of five) after the last production run. This is a problem for manual lines because of costly relearning. With automation, the original programs can be recalled long after the initial production without the need for relearning.

For other applications, the trend is toward higher volumes of the same product type. Robust, high-speed modules configured in optimal layouts can be productive in both low- (batch) and high-volume environments. This ability supports those companies making a transition from military to commercial production.

Reduced rework and material scrap provide additional cost savings, especially with modules containing fragile and costly GaAs devices. Automation allows for repeatable, well-controlled handling of this class of components. Special material-handling devices also add value with solder-reflow applications. Here, the stacked (dry) solder preforms and chips cannot be disturbed after placement. The fixture tray holding these assemblies must be gently placed into the reflow oven chambers or onto reflow furnace belts. Without this handling capability, operators must perform a complete inspection of all devices prior to reflow. This inspection is needed to ensure that parts did not move during manual handling.

Automated production also facilitates real-time, accurate inventory and process control, as well as complete module-as-build traceability. Automatic material and process traceability eliminate the need for laborious paper trails sometimes laden with erroneous data input.••

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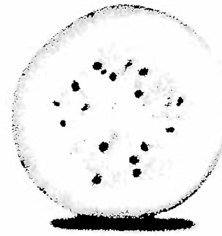
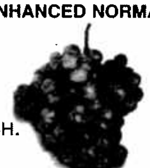
THE MRSI-505 MAKES AUTOMATED MANUFACTURING MORE FRUITFUL

THE MRSI-505 ULTRA-PRECISE ASSEMBLY WORK CELL HAS QUICKLY BECOME THE MARKET LEADER AND INDUSTRY STANDARD FOR FULLY AUTOMATIC, HIGH SPEED, ULTRA PRECISE MICRO-ELECTRONIC ASSEMBLY SYSTEMS. THAT'S EASY TO UNDERSTAND GIVEN THE MRSI REPUTATION FOR DEVELOPING SUPERIOR AUTOMATIC DIE-ATTACH SYSTEMS.



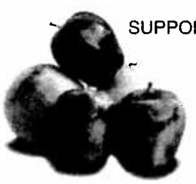
USERS APPLAUD THE MRSI-505 STATE-OF-THE-ART VISION SYSTEM WITH **360° DIE ROTATION.** IT EASILY IDENTIFIES AND ALIGNS RANDOMLY ORIENTED DIE. ADD **ENHANCED NORMALIZED GRAY SCALE** AND **AUTO FEATURE EXTRACTION**, AND IT'S NO WONDER THE MRSI-505 VISION SYSTEM IS CONSIDERED THE BEST OF THE BUNCH.



THE TERM "ULTRA-PRECISION" IS SYNONYMOUS WITH THE MRSI-505. YOU CONSISTENTLY GET **±0.0005 INCH OR BETTER PLACEMENT ACCURACY**. ALWAYS WITH FAST SETTLING TIMES RESULTING IN ***HIGH SPEED*** MANUFACTURING.

THE MRSI-505 IS **THERMALLY AND MECHANICALLY STABLE.**

A SOLID GRANITE PLATFORM SUPPORTS THE ARM FROM ABOVE, SO NO MECHANISMS ARE CANTILEVERED.



THE SYSTEM LETS YOU ACCOMPLISH MUCH MORE THAN JUST MIX APPLES AND ORANGES. IT ACCOMMODATES MANY COMPONENT ATTACH TECHNOLOGIES—EPOXY,FLIP CHIP, SOLDER REFLOW, AND TAPE AUTOMATED BONDING.

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A LARGE WORK AREA EASILY SERVES YOUR INPUTS AND OUTPUTS, NO MATTER HOW THEY'RE CONFIGURED. PICK FROM ANY COMBINATION OF WAFFLE-PACKS, GEL-PAKS, VIBRATORY FEEDERS, TAPE FEEDERS, AND EXPANDED WAFER FRAMES.

THE SYSTEM'S COLORFUL, USER-FRIENDLY, MENU-DRIVEN SOFTWARE MAKES THE MRSI-505 **VERY EASY TO LEARN AND OPERATE.**

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