Automating MEMS Packaging

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Abstract:
In anticipation of the market's growing demand for MEMS products, clearly, a high-volume, high yield manufacturing solution is the answer: Design for Automation. MEMS component designers must do the upfront work in designing their MEMS devices for volume production. The process requires care and due diligence. The value brought to the customer in lowered costs, and to the manufacturer in increased throughput and yields, translates to success all around.

In the last decade, Micro-Electro- Mechanical Systems (MEMS) have moved from the university laboratory into mainstream use in a multitude of commercial products. From automotive airbag deployment accelerometers to telecommunication optical switches, MEMS are flooding the market. New uses for these chip-level devices are being discovered everyday in the information technology, military, environmental, space based and biomedical industries (table 1). But growth rates far exceeding these estimates are expected when makers of consumer products find ways of reducing MEMS production costs, because costly manual manufacturing processes are the primary impediment. For many in the MEMS packaging industry, then, the answer has become: Automation.

Automotive	Pressure sensors Accelerometers
Aeronautics, Space and Military	Temperature sensors Chemical sensors Active flight control surfaces
Medical and Biomedical	Micronozzle injection systems Microfluidic sensors DNA testing (gene probes)
Information Technology	Data storage (read/write heads) Displays Video projectors Inkjet printheads
Telecommunications	Switches (RF/optical) Variable optical amplifiers Optical add/drop multiplexers Tunable lasers Tunable filters Inductors Resonators Millimetric wave sensors

Table 1 - MEMS applications in today's markets

Today's manual packaging techniques allow costs to be driven down only so far. Automating these packaging processes will allow component providers to further reduce costs by taking advantage of the economies of scale, reduce yield losses by eliminating the need for human touch, and increase package reliability and performance through repetitive and accurate component placement and attachment.

MEMS Packaging Challenges

The Semiconductor packaging industry has forged the path for automated component assembly, providing today's MEMS manufacturers with lessons that are directly transferable to MEMS packaging. Even with this foundation, automating a MEMS packaging process presents some unique challenges. By understanding these challenges and addressing their solutions, component manufacturers will have the knowledge they need to successfully automate their MEMS packaging process.

Component Design

For today's MEMS manufacturer, low volume and high complexity have made process automation a low priority. Consequently, many MEMS device providers never consider automation when designing their components. Although the need for full automation may not be a requirement today, up-front design for automation will reduce future redesign costs when demand for these products grows.

Designing MEMS devices for automation means ensuring they possess the precise physical features and tight manufacturing tolerances needed for an automated assembly process. Generally the machine can place parts only to the accuracy allowed by the quality of the components it is placing. For example, in the telecommunications industry where optical MEMS devices are used in switching arrays, the MEMS must be placed with a high degree of accuracy, on the order of five microns in the X, Y and Z axes, and 0.2 milliradians in Theta axis. This and other similar applications require the components to be of the highest quality.

Physical features, such as metallisation traces or fiducials, are used by the machine's automated vision system to recognize the component's location and orientation. Oftentimes the required placement accuracy of a MEMS device is with respect to its microstructure. Therefore, MEMS manufacturers should ensure that the fiducials or metallisation patterns are benchmarked to that structure. If the variance between the fiducial and the structure is greater than the acceptable placement accuracy, the required accuracy will never be met.

When placing MEMS devices relative to their edges, size variance and chip-outs cause vision-guided placements to vary outside the acceptable limit. Chip-outs from poor dicing can cause the vision system to misidentify die corners causing inaccurate theta placements. Variance in die size will cause the machine to skip parts or cause the critical microstructure to be placed inaccurately due to the edge-to- structure dimension variance. Vision systems with improved software capabilities can overcome some of these chip-outs and structural variances. However, to correct the problem before it arises requires significant attention to be paid to the wafer dicing process to ensure the highest quality methods and equipment are used.

Requirements for automation must be considered when designing MEMS devices, keeping in mind that the highest degree of accuracy is achievable with the highest quality components. By designing components for automation from the beginning, MEMS manufacturers will save critical time and money when scaling their manufacturing operation to meet increased demand.

Presentation and Handling

Due to their fragility, MEMS devices must be handled with care. The slightest shock to these devices can easily damage the microstructures causing altered performance. It is for this reason that human intervention or manual-packaging processes of such delicate components contributes to lower yield. In an automated packaging process, the need for human intervention to touch or handle these components is minimized.

Presentation of the components for assembly is often done in waffle paks or gel paks. These carriers can then either be placed on special tooling for the machine to access or can be presented automatically. Packages can be presented similarly, or can be presented in standardized process carriers on an in-line conveyor. In any case, designing the proper presentation method can minimize the need for human intervention.

Once the parts have been presented for assembly, they must then be picked and placed into the package for bonding (Figure 1). To ensure no damage occurs during this operation some automated assembly machines are equipped with as many as eight vacuum pick-up tools. Each tool can be custom designed to pick particular components in the process. Such tools are ideal for handling MEMS devices because they are designed to avoid the 'no touch' areas of the device yet provide ample vacuum to hold the part during the pick and place operation. Highly controllable force and movement trajectories are needed during the pick and place operation to carefully move the component into the package and hold it for the bonding process. In some cases the component must be turned over prior to being placed, requiring the assembly machine to have flip-chip capability. Still others require the use of a Look-Up camera to reference fiducials or features on the bottom of the MEMS device.

An automated MEMS packaging process provides an immediate increase in yield over a manual process. An automated assembly cell, capable of interacting with various presentation methods, capable of moving and assembling the most delicate of components, is the reason why.

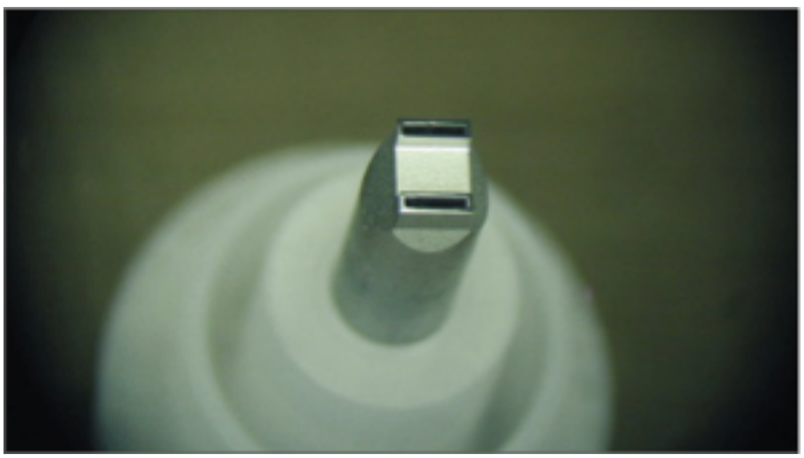

Figure 1 - Vacuum pick-up tools can be customized to pick-and-place MEMS without damaging the fragile microstructures

Attachment Method

There are three main attachment methods for MEMS packaging. While each method carries its own benefits and drawbacks, all three are typically used in MEMS packaging. In the first method, epoxy, either thermally curable or UV-light curable, can be daubed or dispensed to attach the device. Traditionally, daubing is used for dot sizes less than 0.40 to 0.50 mm, while dispensing is used for larger dot sizes and for lines, although automated nanoliter dispensing equipment is now available. Epoxy has long been used for die attachment purposes and comes in a variety of types to suit almost any application. Outgassing resulting from the epoxy curing process has been a concern when applied to MEMS packaging, because it can cause deposits to accumulate on the MEMS microstructures, inhibiting their operation. However, improvements have been made resulting in epoxies that minimize outgassing in almost any environment.

A key advantage to using epoxy is that it is very flexible in its ability to adhere components in numerous complex applications, such as stacking optical MEMS devices.

By using an in-situ UV cure, epoxy can be used to provide the support mechanism for stacking MEMS de- vices on top of each other. In-situ curing of epoxy, either thermally or by UV light, can also be used to en- sure components do not move during the sequential build until final cure is complete (Figure 2).

Figure 2 - In-situ epoxy cure performed by automated UV system

The second method of attach is by eutectic soldering. MEMS components can be attached using either a eutectic solder preform, or by having the submount pad pre-metallized with the solder alloy while the MEMS itself is metallized with Gold on its attaching surface. In deciding which method to use, cost analyses should be done on both options. Submounts with pre-metallized solder tend to result in higher throughput but are expensive. Preforms, on the other hand, result in the same quality bond but are cheaper. Preforms are also a bit more tedious to work with and slow down throughput due to an extra pick-and-place operation per die.

To perform the eutectic die attach correctly, the automated assembly cell must have the ability to not only pick and place the preforms if necessary, but must also be able to tightly control the heat pulse while the bond head holds the part in place.

Some MEMS manufacturers feel that eutectic attach is too rigid or induces stresses at the bondline that will inhibit the operation of the microstructure. However, it has been shown that using the correct eutectic solder will provide adequate flexibility at the bondline. Also, by tightly controlling the eutectic solder reflow through accurate and repeatable temperature control, the stresses at the bondline can be minimized during the attachment process. Through this control, voiding is also minimized, further reducing the bondline stresses and increasing the quality of the mechanical, electrical, and thermal characteristics of the attach.

Finally, in the third method of attach, ball bumping can be used to put small deposits of pure Gold bumps on the back of the die (via a flip-chip process) followed by a thermal-compression bond attachment procedure. Heat, force, and/ or ultrasonics are used to cause the Gold bumps on the die to diffuse with the Gold on the submount pad, creating the bond. Another method of ball bumping is to deposit solder bumps on the submount pad, place the MEMS device onto the pads, and then reflow the solder.

Placement Accuracy

MEMS devices are chip-level systems that use an electromechanical input to affect the physical environment. In some cases, such as in an optical switch, the MEMS are used to affect the light path of an optical signal. Any variation in the placement of the MEMS causes the device to improperly alter the path of the laser beam, seriously affecting the yield of the process. To achieve the proper functionality, the MEMS must be placed to a high degree of accuracy in all six degrees of freedom: X,Y,Z, pitch, roll and yaw.

Achieving accuracy to this degree requires not only quality parts, but also a machine with a high degree of control that can repeatedly place and bond the MEMS components into the package. X, Y, Z and Theta accuracies are dependent upon the precise mechanical movement of the machine and its ability to accurately provide positional feedback for movement correction. Pitch and roll, or flatness, depends on the ability to achieve co-planarity between the working surface and the die itself, and to some degree on the mechanical ability of the machine to maintain planarity throughout the vertical motion of the placement. In all cases, a machine that is highly repeatable in all of its motions can be programmed to place MEMS devices with the highest degree of accuracy required in all six axes.

The machine also ensures high placement accuracy by its ability to hold the part in place throughout the bonding process. The purpose of high placement accuracy is defeated if the machine moves the part during bonding. Whether it is in an epoxy, eutectic or thermal-compression bond, the highest degree of accuracy occurs when the part is held while the bond is made (in-situ cure/reflow).

Cleanliness

Cleanliness is a must for the packaging of MEMS devices because of the very small scale of the MEMS structures. Dust particles and moisture can seriously affect the operability of the microstructures or even cause inoperability. Whether your packaging process is manual or automated, cleanliness standards should be attained and followed to ensure the highest yield.