# Fluid Dispensing for Packaging Today's Devices

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# Fluid Dispensing for Packaging Today’s Devices

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## Introduction

Fluid dispensing systems are evolving in order to address the challenges that system-in-package (SiP) and micromechanical systems (MEMS) packages face, especially in regard to tight geometries and assembly processes. These packages, used in smartphones, have become more miniaturized, and as a result, have created added value in the market. However, they include a variety of small dies or devices inside, including RFICs, MEMS, application specific ICs (ASICs), discrete passives, and others, which are more tightly allocated in the package. The dispensing system has to dispense various fluids, including underfill, solder paste, flux, and encapsulation, into tight locations and onto smaller pads in order to fit the device size.

The packaging assembly process is also changing because of miniaturization. Packaging companies see different prospects in yield and “buy or produce” for the devices. For example, the integrated device manufacturer (IDM) usually purchases discrete passives and their yield is quite high because they are pre-tested and their assemblies are simple. The IDM produces active devices and their yield is lower than discrete passives. These different prospects guide the assembly sequence: high yield devices follow low yield devices in assembly, while testing after low yield device assembly prevents high yield device waste. Discrete passives have now become expensive because of their small, grain-like size. This makes the assembly process sequence from low yield to high yield result in even greater savings. The additional cost of the discrete devices, however, also makes the accuracy of applying the fluid even more important. Because both high and low yield devices can't be assembled at the same time, the latter have to be applied very carefully in tight spaces between the devices. Screen printing can't be used, so the solder, tacky flux, surface mount adhesive, or other fluid has to be applied in that tight space, very close to the active devices on the board. This is challenging for the dispensing system.

One of the typical MEMS devices following this miniaturization trend is the microphone, which is used in increasing volumes for mobile applications. The microphone mainly consists of a MEMS diaphragm component, ASIC, wire bonds, substrate, and metal cap with a hole. Two types of dispensing are usually done for this package: dispensing sealant between the substrate and cap, and encapsulation on the ASIC. As the package has shrunk, the diameter of the MEMS diaphragm hasn't changed because the diaphragm size is defined to capture sound. However, the size of the MEMS diaphragm die has shrunk significantly over the years. The peripheral die area of the diaphragm has decreased by 80% from 2006 to 2011, but the diaphragm area has not changed. As the MEMS diaphragm die size has decreased, the entire package size of the microphone has also been decreasing: 6 x 4mm$^2$ in 2008 to 3 x 2mm$^2$ in 2011 to 2.2 x 1.5mm$^2$ in 2013. Tighter component allocation in the overall package becomes more critical. This tight clearance requires very straight sealing lines with no rippling or waviness.

These trends create realigning and redefining requirements in the dispensing assembly process and adapting dispensing equipment and processes to produce today’s products so they function reliably and at peak performance. Some of these dispensing application challenges are: 1) Fluid dispensing for holes; 2) Small dot dispensing for flip-chip bonding and discrete passives; 3) Maintaining tight keep-out zones for underfilling; and 4) Sealant dispensing for MEMS cap assembly. This article presents solutions for the challenges these new trends create.

## Fluid Dispensing For Holes

SiP and MEMS substrates often have holes. The holes are used for through-hole device assembly and for access between inside sensors and the outside environment. These holes have angular rings with a width of 250 microns and diameters that range in size from 1.5mm down to 1mm **(Figure 1)**.

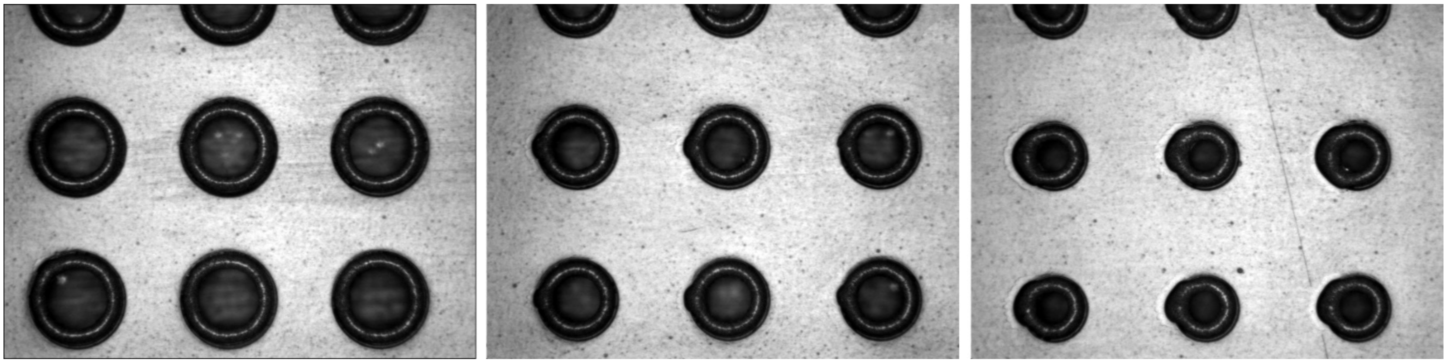



***Figure 1. Typical solder paste dispensing for different circle diameter sizes.***

In the assembly process, solder has to be deposited around these holes to hold the pin in place to make the electrical connection. Tacky flux is usually applied around the holes to prevent the components from slipping during reflow. A common way to apply these fluids is with screen printing. However, when fluid is deposited using screen printing, these holes present a real problem because fluid tends to run down into the holes. Dispensing is a good way to deposit the fluid because it can aim the fluid at specific locations around the holes; however, the holes are so small that only a dispenser that can deposit or jet very accurately placed small dots each and every time can be used. Therefore, small dot dispensing and equipment that can jet these small dots precisely and repeatably around the holes has taken on increased importance.

## Flip-Chip Bonding and Discrete Passives

Many SiP packages include flip-chip devices. The flip-chip bumps are inside the package so the bond needs to mesh with the bond on the substrate. They can be gold stud bumps, copper pillars, solders, or any material. The bump pitch and bump diameter on those flip-chips have become smaller and the package size has shrunk. In the middle of the assembly process, bonding materials such as solder and silver epoxy have to be deposited on the substrates into the tight spaces between components that have already been placed. Screen printing can’t be used because the other components don’t allow the screen to attach to the substrate. Dispensing can be used to apply the fluid, but the dispensing system has to be able to produce small dot sizes and tight location accuracy for those applications.

Another consideration is the keep-out zone (KOZ). This is the area between the components that must be kept free of fluid and contaminants. As the packages have shrunk, the KOZs have also shrunk so the fluid has to be deposited in a very thin line extremely close to the component. This is especially important when depositing underfill next to the component. High-density flip-chips on strip, where the chips are close to each other and they need to be underfilled, also pose this challenge. Small droplets need to land between the chips so the chips can both be underfilled at the same time. The fluid under the chips cannot be connected. Some of the automated fluid jetting equipment on the market today is designed especially to underfill close to the die to reduce the KOZ.

For small dot dispensing of flip-chip packages, an auger valve that can achieve 100µm +/-14µm dot diameter dispensing at 3-sigma repeatability with silver epoxy is necessary. **Figure 2** shows small dot dispensing on the top of flip-chip bumps. **Figure 3** shows the dot sizes and accuracy that can be achieved.

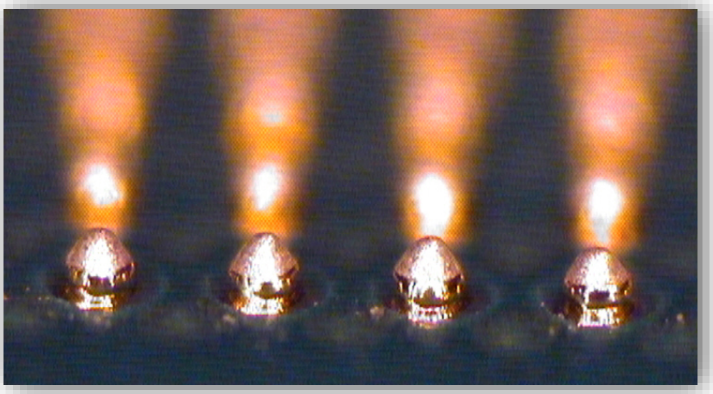
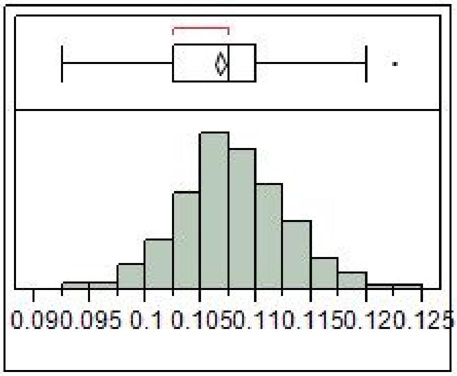


***Figure 2. Small dot dispensing on the top of flip-chip.***

Distributions

Dot Diameter (mm) on Stainless Steel Substrate_Run # 2




**Quantiles**

| | | |
|---|---|---|
| 100.0% | maximum | 0.1225 |
| 99.5% | | 0.11999 |
| 97.5% | | 0.1175 |
| 90.0% | | 0.1125 |
| 75.0% | quartile | 0.11 |
| 50.0% | median | 0.1075 |
| 25.0% | quartile | 0.1025 |
| 10.0% | | 0.1 |
| 2.5% | | 0.0975 |
| 0.5% | | 0.09251 |
| 0.0% | minimum | 0.0925 |

**Summary Statistics**

| | |
|---|---|
| Mean | 0.1066938 |
| Std Dev | 0.0047714 |
| Std Err Mean | 0.0002386 |
| Upper 95% Mean | 0.1071628 |
| Lower 95% Mean | 0.1062247 |
| N | 400 |
| Variance | 2.2766e-5 |
| CV | 4.4720514 |
| N Missing | 0 |
| Range | 0.03 |

*Figure 3. Statistical data of small dot dispensing.*

Small dot dispensing technology can be applied to small discrete passives as well. Many small discrete passives such as 0201 ($0.6 \times 0.3 \times 0.23mm^3$) are applied to SiP and MEMS packages because of their tiny size. They need a 250µm x 250µm pad size. As with flip-chip packages, these passives are assembled into these small spaces after the active devices are assembled, so small dots of fluids, such as solder, have to be dispensed on the pads with extreme precision, such as in short lines and dots ranging from 600 microns down to 250 microns **(Figure 4)**.

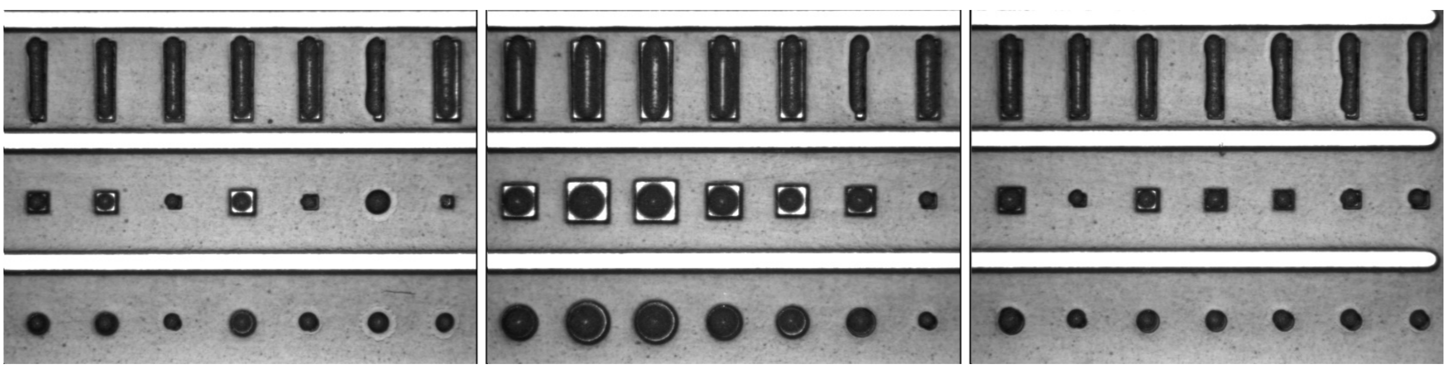


*Figure 4. Solder dispensing samples for SiP and MEMS packages.*

## Sealant Dispensing For MEMS Cap Assembly

The space, or buffer clearance, between the MEMS die and the sealing lines for attaching the MEMS cap decreased to 150µm **(Figure 5)**.

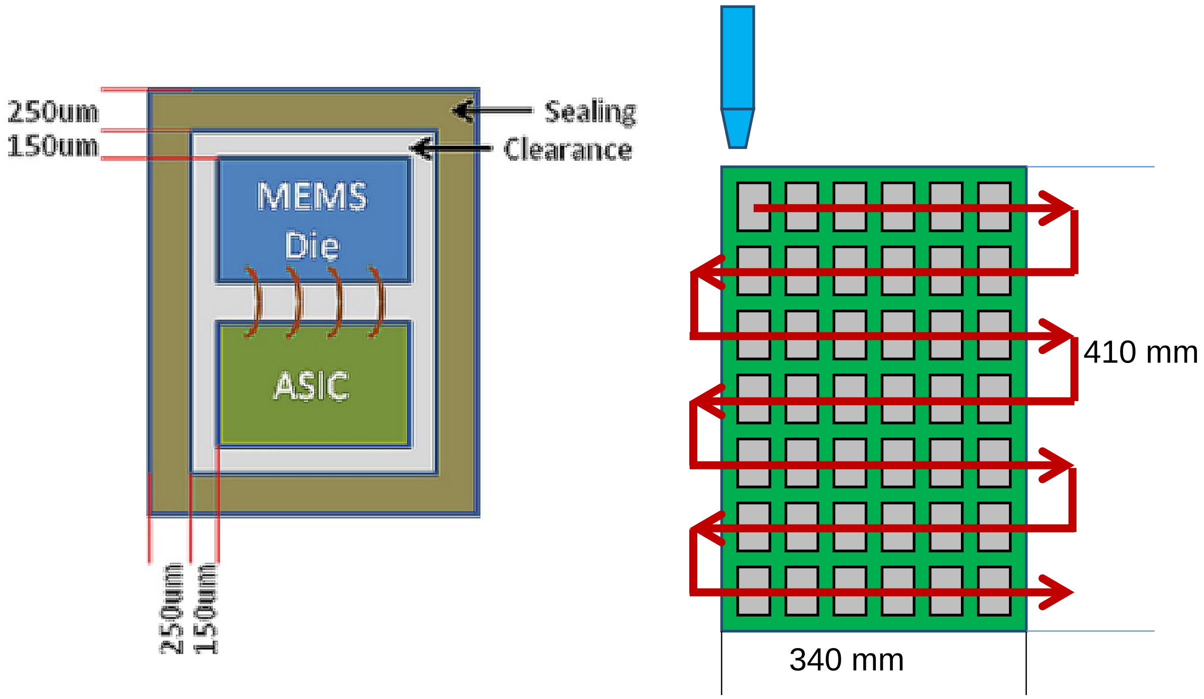



***Figure 5. Buffer clearance and sealing line dimensions in MEMS package.***

This tight clearance requires very straight sealing lines with no rippling or waviness. Deviations from a straight line path or inconsistency in the line width negatively affects how close to the die edge this line can be dispensed without risking fluid landing on top of the die or on neighboring components, resulting in product failures. Line straightness and width consistency are also important for solder paste and sealant line dispensing applications. In such applications, however, there are two additional considerations that affect fluid dispenser design and performance: oscillations (ringing) after cornering, and thin line width. Transitioning from a high speed move in one direction to a perpendicular direction causes ringing oscillations in the subsequent dispensed line caused by motion system inertia. When determining how close to the die to target a line path, ringing effects of the system at the target line speed must also be considered to avoid having fluid land on top of the die. This situation will also affect the minimum KOZ.

When using an auger valve, a consistent dispense gap between the dispenser tip and the substrate is required to achieve straight sealing lines. Maintaining this consistent dispense gap is critical to achieving smooth lines with less rippling. This is called the z-gap and is defined as the vertical distance between the fluid ejection point and the substrate surface. Achieving a minimal z-gap not only requires precise control in the z-axis motion, but also precise detection of the surface height relative to the reference z-home position. Maintaining this minimal z-gap along the dispense path requires the ability to ensure that there is minimal variation in both the surface height and the reference z-home position throughout the target dispense area **(Figure 6)**.

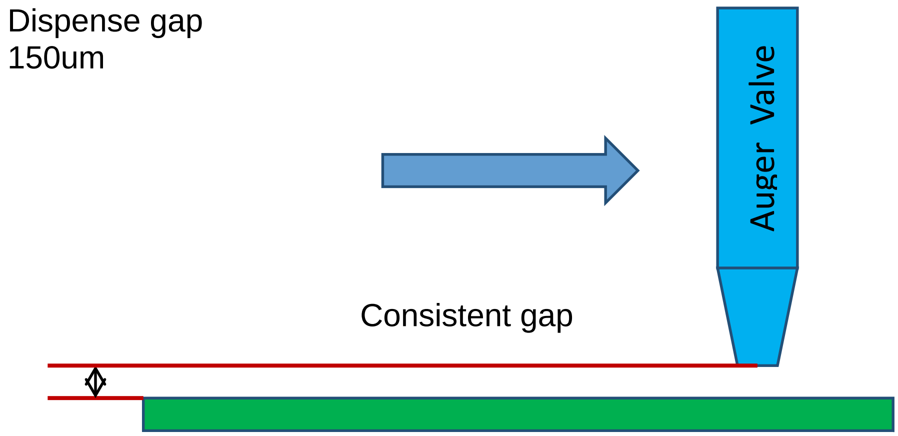



***Figure 6. Dispense gap consistency requirement.***

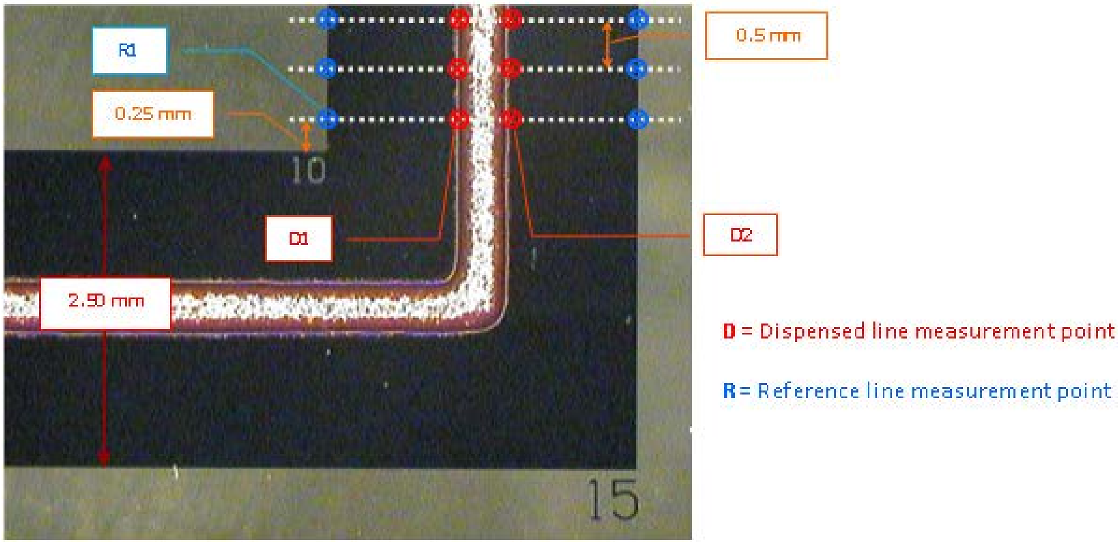



*Figure 7. Measurement method between line & reference.*

In high-volume production environments, a dispensing system needs to make sealing lines for hundreds of microphones at a time. Typically, a 250µm wide sealing line will require a 150µm dispense gap. Being able to achieve such a gap, let alone maintaining it across a substrate surface while the dispenser is moving rapidly across the area, is quite challenging **(Figure 7)**. In addition to tight control of the Z-axis oscillations, making lines that closely follow a set path requires precise movements in the X-Y plane of the dispenser head. In order to meet the needs of these applications, the dispensing system must have tight accuracy control in all three dimensions, x, y, and z. This is often accomplished through improving the stiffness of these axes.

## Dispensing System Accuracy

New dispensing systems specifically address these types of high-accuracy applications. Achievable accuracies are listed in **Table 1**.

***Table 1. Achievable accuracies for new dispensing systems.***

| Item | Specification |
|---|---|
| X and Y axis accuracy | ±40µm @ 3σ |
| X and Y axis repeatability | ±15µm @ 3σ |
| Z axis repeatability | ±15µm @ 3σ |

## Sealing Line Validation

Auger vales have been validated for line straightness by measuring the center of dispensed lines. **Figure 7** shows the measurement methodology. Placement error was determined by measuring the positional offset between the center of the reference line and the center of the dispensed lines.

$$\text{Error} = ((D1 + D2)/2) - ((R1 + R2)/2)$$

Data in **Figure 8** shows the X and Y axis accuracy that has been validated with >1.3 $C_{pk}$ with ±40µm specification limits. It was clearly observed that the lines are quite straight and corner radiuses are very small **(Figure 9)**. Dispense gap consistency is difficult to measure directly during dispensing. However, line straightness and width control are ultimately the core concern and acceptable metrics by which to judge a system's performance. These are metrics that haven't been given a lot of consideration previously and will require more testing and attention as they are a more valid measure for achieving the desired results than just speed or line width.

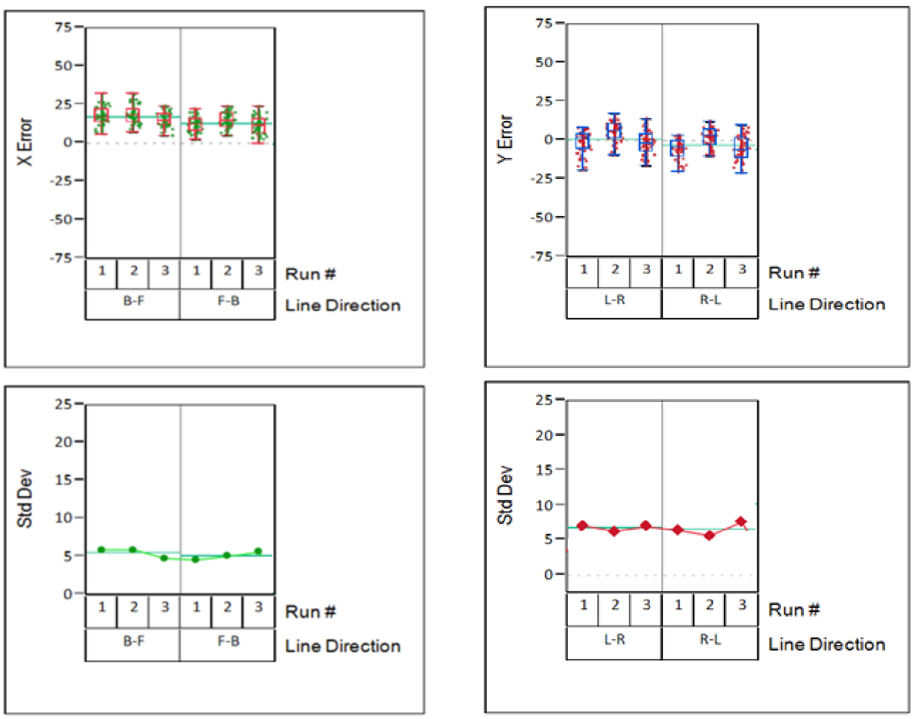



*Figure 8. Difference between line and reference in X and Y axis.*

## Summary

SiP and MEMS packaging requirements continue to push for increasingly smaller devices and packages requiring fluid dispensing continue to evolve. These conditions call for smaller volume dispensing into tighter spaces. Therefore, dispenser capabilities to achieve these targets must continue to improve and the ability to evaluate these capabilities must also evolve. Fluid dispenser accuracy must keep pace with, or stay ahead of, the market. Challenges include dispensing around holes, dispensing in tight spaces accurately and reliably, the ability to achieve tight keep-out zones, and maintaining a consistent and very small dispense gap during high speed operation to achieve a perfectly straight line during dispensing.

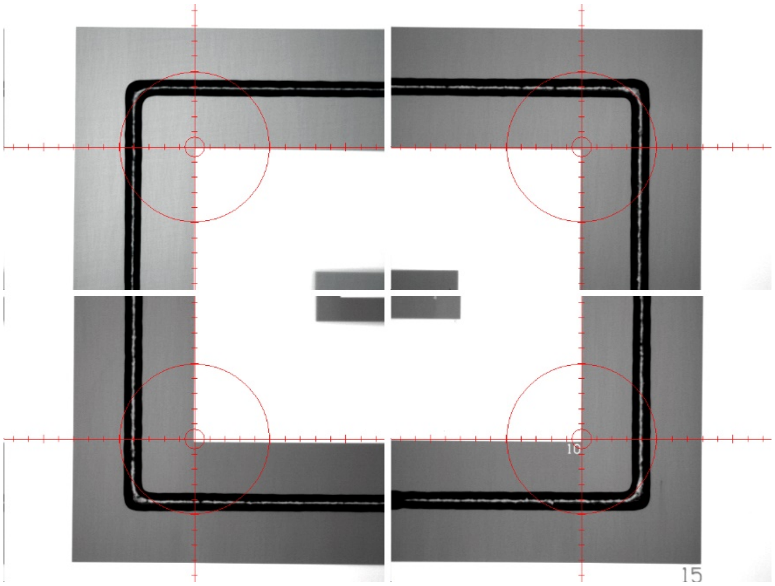


*Figure 9. Sealing lines are quite straight and corner radiuses are very small.*

The stiffer and more accurate the dispenser and ability to achieve ±40µm straight sealing lines from the target path with a >1.3 $C_{pk}$, and the ability to address the tight clearance requirement between the MEMS dies and surrounding package structures are making manufacturing of these packages possible. New test methods are being used to evaluate fluid path accuracy and z-gap control to closely reflect actual customer use. New dispensing systems have been designed to take these factors into account and compensate for them.

Dispensing systems have been redesigned so the motion system can achieve accuracy and precision in all three axes, further improving path accuracy and narrow line width control. Some of the newer systems on the market have demonstrated the ability to increase some customers' units per hour productivity by over 25%, while also reducing keep-out zones and achieving line widths and dot diameters below 200µm. Although dispensing equipment manufacturers are constantly working with customers to develop systems to build these new products, when designers look at new products and applications, it's also important for them to consider the manufacturing processes and the equipment and capabilities available to achieve them.

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## Biography

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