UNDERFILL DISPENSING FOR CHIP-ON-WAFER

Akira Morita[1], WeiWei Gu[1] and Brian Chung[1]*
[1]Nordson Asymtek, Carlsbad California 92010, USA
*Corresponding Author's Email: akira.morita@nodsonasymtek.com

ABSTRACT

The chip-on-wafer (COW) process is becoming a technology enabler with the emergence of 3D packages, stacked wafer level packages (WLP), and chip-last processes for WLP. A critical step in a COW process involves jet-dispensing underfill in interconnect space between the chips and wafer. The constant quest for increased performance and cost reduction continues to drive device miniaturization in multiple dimensions including reduction of the wafer scribe line width and the interconnect gap between chip and wafer. These tighter geometries significantly increase the complexity of underfill dispensing. It requires accurate and stable dispensed fluid volume and placement as well as sustained high throughput for mass production. This paper addresses the challenges with higher platform accuracy, smaller dot size at higher jetting frequency and longer applicator lifetime.

INTRODUCTION

Application

The COW process is rapidly becoming a critical factor in advancement of semiconductor assembly, and it is incorporated into key emerging packaging technologies such as 3D package, stacked WLP, and chip-last process for WLP. TSMC and Xilinx commercially demonstrated a COW application in a 3D package in its FPGA devices in 2011 [1]. Recent development in the Package-on-Package (POP) stacking on Fan-Out WLP (FOWLP), hereafter called as FOWLP POP, is in high-volume production with a COW process [2]. Also, chip-last process for WLP such as Amkor's Silicon Wafer Integrated Fan-Out Technology (SWIFT) [3] adopted a COW process.

COW Process

COW has several different implementations in terms of material and terminology. The configuration and process, however, can be generally described in the following:

1. Placing multiple chips on a wafer;
2. Making proper chip-to-wafer interconnections;
3. Dispensing underfill between the chips and wafer; and
4. Molding them if necessary before ball placement on the backside and dicing.

In the case of FOWLP POP, the attached chips are the molded components, and the wafer is either a silicon wafer/interposer for 3D package, a reconstituted wafer for FOWLP POP, or redistributed layers (RDL) for WLP chip-last process.

Underfill Dispensing Challenges

In semiconductor packaging, the demands for cost reduction and miniaturization challenge the COW process exponentially. Two major geometry changes should be highlighted here: the scribe line width (horizontal space between chips) on wafer, and interconnect gap (bump height) between chip and wafer are becoming smaller.

The narrow scribe-line width necessitates smaller dot sizes in combination with a sufficiently narrow jetted stream width to dispense into the gap between chips and requires higher volumetric and placement accuracy to avoid yield-limiting, die-top contamination. Figure 1 shows the overflow situation when too much underfill fluid is dispensed into tighter line widths.

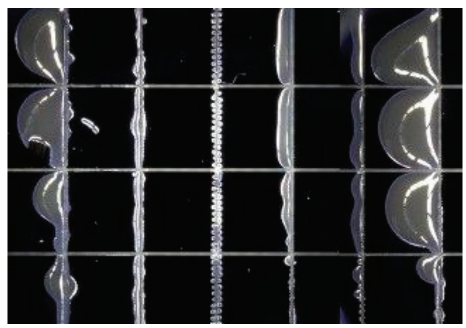

Figure 1: Underfill overflow in scribe-line width

Because work-in-process WLP is populated with known-good-die, it is a high-value product, and so underfill dispensing must be very reliable to avoid producing defects. Simultaneously, this type of underfilling requires an exponential increase in the number of jetting cycles for smaller dots. Thus, the lifetime and reliability of the jet applicator must be increased for production costs to be competitive. This paper addresses those challenges in the following sections.

FIELD PRACTICE AND SOLUTIONS

Field Practice

There are many layout variations in terms of chip numbers, geometries, production volume and so on for a COW underfill jet-dispense process. An example of the typical configuration is described below to highlight the challenges and solutions for the high-volume manufacturer.

- 300 chips on a 300mm wafer
- 350 µm horizontal space between chips
- 50 mg underfill amount per chip
- 16 µg dot weight
- 0.94 million jetting cycles per wafer
    - 50 mg x 300 chips / 16 µg = 0.94 million cycles

Higher Placement Accuracy

Jetting small dots into a narrow space requires the dispenser platform to have high placement accuracy. Figure 2 clarifies the accuracy.

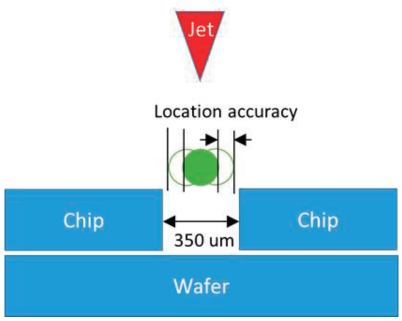

Figure 2: Location accuracy

A newly developed dispenser platform addresses these types of high-accuracy applications. With a redesigned system that includes a more robust base frame and motion system, the platform is able to achieve accuracy specifications as in Table I.

TABLE I. DISPENSER PLATFORM ACCURACY SPECIFICATIONS

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

To verify the line path accuracy, the platform with an auger valve was used to dispense line segments and measure line straightness and placement accuracy. The auger valve is suitable to measure the exact dispensing trajectory. Figure 3 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, as in (1).

$$\text{Error} = ((D1 + D2)/2) - ((R1 + R2)/2) \qquad (1)$$

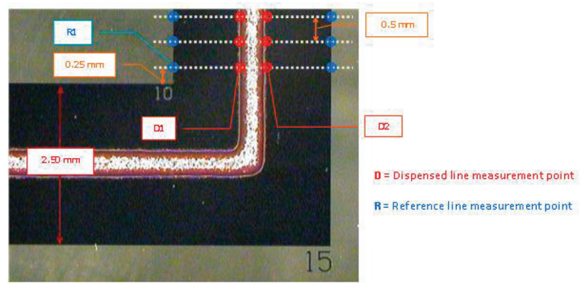

Figure 3: Measurement method between line and reference

Data in Figure 4 shows the X and Y axis accuracy of the platform has been validated with >1.3 Cpk with ±40µm specification limits.

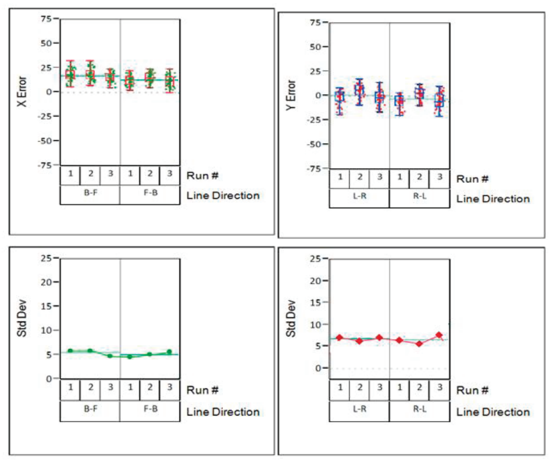

Figure 4: Difference between line and reference in X and Y axis

Smaller Dot with narrow stream width

Conventional jetted dots range in size 50 µm to 300 µm; dispensing into a sub-400µm opening requires significantly smaller dot weight. 50 µg dot weight with 1.6 specific gravity translates to approximately 400-µm diameter sphere in air. Thus a smaller dot was required, down to 16 µg, which translates approximately to a 270-µm diameter sphere, accounting for both the scribe line width and dispenser wet placement accuracy (±40µm) (Fig. 2). Figure 5 shows typical jetted dot in air.

A newly developed jetting applicator achieved the small dot size and in-air width with a new jet-cartridge design, PZT actuator, actuation velocity and stroke control.

Figure 5: Underfill dot shape

Higher Jetting Frequency

Jetting frequency had been 200 Hz for underfill dispensing in most field practices for flip chip assembly. Its actuation technology was pneumatic to drive the jetting. With the configuration above and 200 Hz frequency, it takes 4,700 sec ~ (300 x 50,000)/(16 x 200) to complete underfill for a whole wafer: 80 min. cycle time per wafer or 0.76 wafer per hour (WPH). This low WPH limited adoption of the COW process by commercial, high-volume manufacturers. Faster jetting frequency thus was required to significantly save production time.

The new jetting applicator achieved 1,000 Hz frequency at peak to solve the challenge. It included a PZT actuator with a new mounting design for higher frequency as well as long lifetime reliability. Although it has higher frequency capability, 600 Hz frequency for underfill dispensing was applied in the actual production configuration. The higher jetting frequency decreased the cycle time nearly 50% to 2,500 sec or 42 min per wafer: more than 1.4 WPH.

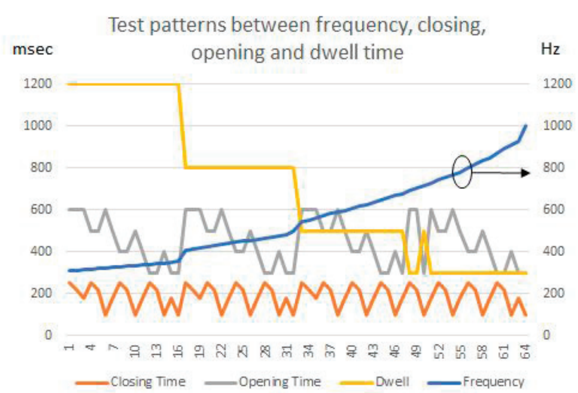

Figure 6: 64 Test patterns

Dispensing weight and shape was controlled by adjusting the opening, closing and dwell times of applicators. And the three duration combinations determined the frequency. The dot consistency was an important parameter for sustaining long-term production yield. Many various test patterns were investigated in terms of dot size: see Figure 6 for 64 test patterns. One of the investigation results showed dot weight variation over different opening times, see Figure 7.

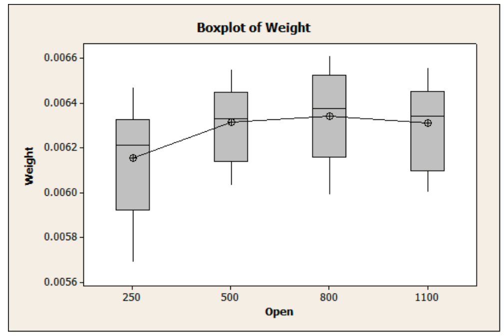

Figure 7: Dot weight variation over different opening time

Longer Lifetime of Jetting Applicator

The tighter interconnect gap proportionally increases capillary underfill fluid flow-out time. This limits underfill volume dispensed per pass to prevent excess fluid pile-up next to the chips. In turn, multiple passes of smaller dispensed volumes with more jetting cycles is required to achieve the total underfill volume. With the need to jet as many as 1 million cycles on a wafer, maximizing the lifetime of a jetting applicator can contribute significantly to cost reductions for high-volume manufacturing. The new jetting applicator has automated calibration and monitoring features to measure critical parameters such as operating temperature, jetting and consumable cartridge wear compensation. This ensures the applicator is operating at optimized efficiency for a long period. .

The new jetting applicator has an extended life expectancy of 2 billion cycles, reducing the failure rate to 0.05%. This improvement has a significantly positive impact on the cost to produce each wafer. The new jet demonstrated a much longer lifetime compared to other available PZT jet applicators in the market, which have 500 million cycle lifetimes.

All of the test applicators have passed more than 2 billion cycle lifetime in lab, and continue to operate beyond target criteria. Moreover, COW high-volume manufacturing has performed over 2 billion cycles in the field.

CONCLUSION

The newly developed dispenser platform, jetting applicator and operating software successfully solved the challenges that the chip-on-wafer (COW) process is facing now. Using these technologies and products, high-volume manufacturing was demonstrated in the field for emerging packaging technologies such as 3D package, FOWLP POP, and chip-last process for WLP.

The platform achieved ±40µm @ 3σ in X and Y axis accuracy; the applicator demonstrated small dot dispensing into 350 µm space. Higher jetting frequency (600 Hz) increased WPH by 84% and reduced production costs significantly with extended jet applicator lifetime; and the software contributed to effective operation of the applicator. All these product enhancements must be integrated as a total solution to accomplish the successful high-volume manufacturing in the field.

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