Fine Pitch Circuit Pattern Inspection Capability Study for Fan-out Wafer/Panel Level Packaging

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Abstract—Test Vehicles (TVs) were developed to examine the high-volume manufacturing (HVM) readiness of AOI (Automated Optical Inspection) systems supporting the inspection of fine pitch advanced substrates designed for high bandwidth applications. This study demonstrated the capability of defect detections with current inspection systems. The wide variability of the data suggests that some improvements are desired in feature edge detections. Additionally, some of the AOI systems are capable of HVM inspection down to 4 μm trace width/spaces with 1μm level defects.

Keywords—AOI, Defect Detection, Fine Pitch Patterns, Nick(Mouse-bite) and Protrusion, Advanced Packages

I. INTRODUCTION

Inspection limitations are likely to impact yield assessment and quality validation on printed circuit boards, substrates and interposers designed for heterogeneous System-in-Packages. Fine line wiring and close-space geometries provide the high density interconnect capabilities which supports the advanced package technologies used for multiple components integration. Advanced substrates and interposers with fine line and space designs below 10 μm can have defects that impact both yield and package performance.

iNEMI initiated a phased project of AOI studies from 2016 as to evaluate the limitation of AOI equipment and to access the readiness for HVM capability. Phase one was the conduction of an industry-wide survey to assess the readiness of measurement and inspection capability for fine circuit pattern substrates.[1]. Phase two and three studied the capability of AOI inspection. [2][3].

The TVs were designed with circuit patterns and trace widths from 10 μm nominal down to 1 μm nominal with associated defect designs such as protrusions and mouse-bites. The design features incorporated sharp angles, curvatures, and rotations with proximity to other features. This paper discusses the capabilities of the defect detection by the AOI systems, the types of substrate materials, unique trace design implementation, circuit pattern features and defect sizes of protrusion and mouse-bite defects.

II. MATERIAL AND METHODS

A. Test Vehicles Design and Layout

Figure 1 shows the TV design with trace width nominalss designed from 10 μm down to 1 μm with incorporated known defect modes of protrusions and mouse-bites.

B. AOI Measurement Parameters

The optics of the system is essential to detectability of AOIs. Higher resolution optics improves the resolution which reduces false errors in defect detection. Defect validation requires the ability to have selectable magnification, which might be done by verification stations. AOI systems vary according to alignment method, illumination, scan method and the optical magnification. This study allowed the participants to choose their own AOI inspection parameters to optimize their results in detecting the fine line widths and spaces.

C. Test Vehicles Verification

Glass, Silicon and Organic TVs were created to establish a non-destructive method of line width and defect detection by AOI. Line widths and line spacing were measured using an Optical Coordinate Measurement Machine with magnification of 31.42 and 0.25 μm pixel size. Additional validation was done with a Scanning Electron Microscope.

Figure 2 highlights the various level of designed defect sizes by the nominal trace widths. They were used to evaluate detectability of excess metal and missing metal.
D. Glass and Silicon TV Defect Inspection

The Phase Two study incorporated Glass and Silicon TVs. Due to the transparent nature of the glass material, some AOI companies could not measure properly thus only the Silicon TV was used for data collection. The silicon TV created a reference artifact for the AOI companies to measure and validate their capability to support fine line widths and spacing. It was shown that the AOI equipment could support HVM measurement greater than 3 um line/space design. Run rate is currently a challenge for both production and research and development (R&D) tools, but indications are the optical tools could support future HVM. defects, which can be associated with detection algorithm as mouse-bites have tighter requirements than protrusion in general by substrate manufacturers. Same mouse-bite were not detectable when they are near the end of the traces.

<table>
<thead>
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<th>Substrate Material</th>
<th>Company A</th>
<th>Company B</th>
<th>Company C</th>
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<tbody>
<tr>
<td>Glass</td>
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<td>Silicon</td>
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<tr>
<td>3 μm</td>
<td>Production</td>
<td>R&amp;D</td>
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<td>More than 3σ</td>
<td>More than 3σ</td>
<td>More than 3σ</td>
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<td>4 μm</td>
<td>Production</td>
<td>R&amp;D</td>
<td>R&amp;D</td>
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<td>More than 3σ</td>
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Fig. 3. Silicon TVs defect inspection results from 3 measurement sites on 10 μm, 6 μm and 4 μm design circuit patterns

E. Organic TV Defect Inspection Results

The results demonstrate that current AOI systems are capable for the defects detection (mouse bite and protrusion) down to 4 μm line width with defects affecting 30% of the trace width. With the use of fluorescent lighting good contrast of imaging and detection capabilities are achieved.

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<tbody>
<tr>
<td>Silicon</td>
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<tr>
<td>3 μm</td>
<td>Production</td>
<td>R&amp;D</td>
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<td>4 μm</td>
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</table>

Fig. 4. Silicon TVs defect inspection results from 3 measurement sites on 10 μm, 6 μm and 4 μm design circuit patterns

F. Defects Detection Repeatability

AOI systems from the participants performed well on the 6 μm to 10 μm patterns. However, from 4 μm down to 3 μm systems start having some difficulty detecting the design defects. The 80% to 40% defects were detected with no issues, but unstable detection was observed below 30%.

III. SUMMARY

Detection Limitation:

It was shown that AOI systems could detect mouse-bite defects close to one pixel size with a high detection rate (>90%). All AOI systems are capable to support 8/8 um and above line width / line space. Minimum detection of features are 3/3 um line width / line space with 10% defect (0.3 um defect is detectable on a 3 um trace i.e. 10% mouse-bite). Mouse-bite defects has higher detection rate than protrusion

IV. CONCLUSION AND NEXT STEPS

This study confirms the needs for developing better AOI equipment capability to meet the needs of high-volume manufacturing of 3/3 and 1.5/1.5 um line space design on advanced substrates. The project team will conduct another survey to grasp what new functions are now available on AOI equipment. Organic substrate samples were unable to be fabricated below 3 um line space patterns. The project team will work with the substrate manufacturer(s) to build the test vehicle with organic substrate for the measurement study.

ACKNOWLEDGMENT

The project team would like to acknowledge the contribution of the inspection and measurement by several measurement sites, especially AOI equipment manufacturers.

REFERENCES