Reveal previously invisible defects and contaminants in advanced packaging applications

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A new illumination technology compares favorably to conventional bright field illumination.

A new optical technique can reveal defects and contaminants that escape conventional inspection technologies in many advanced packaging applications. As wafer level packaging (WLP), and especially fan-out wafer and panel level packaging (FOWLP/FOPLP), gains broader acceptance, certain classes of defects that are characteristic of these processes present significant challenges to standard optical inspection tools. A new optical technology demonstrates increased sensitivity to transparent defects, such as residual dielectric films and photoresist, which are only marginally visible with conventional tools. At the same time, it is less sensitive to nuisance defects, such as those caused by the varying contrast and texture of grains in metal films, that should correctly be ignored.

Challenges in advanced packaging applications

Advanced packaging processes often involve the use of front-end-like technologies in back-end applications. Fan-out packaging is no exception, and, not surprisingly, it is following a similar development path, with increasing circuit complexity accompanied by shrinking circuit geometries. Redistribution layer (RDL) line widths, which were around 20µm in early implementations, will soon reach 2µm and are unlikely to stop there. Just as front-end processes placed increasing emphasis on enhanced process monitoring and control, advanced packaging processes will be forced to include more and better inspection and metrology capability at critical steps to maintain control and improve yields.

Advanced packaging processes, such as fan-out, face unique challenges that, for inspection systems, result in overcounting nuisance defects and undercounting yield-robbing critical defects. These advanced packaging techniques make extensive use of metal and organic polymers. Layers of metal are used to define conductive paths and organic polymer dielectric

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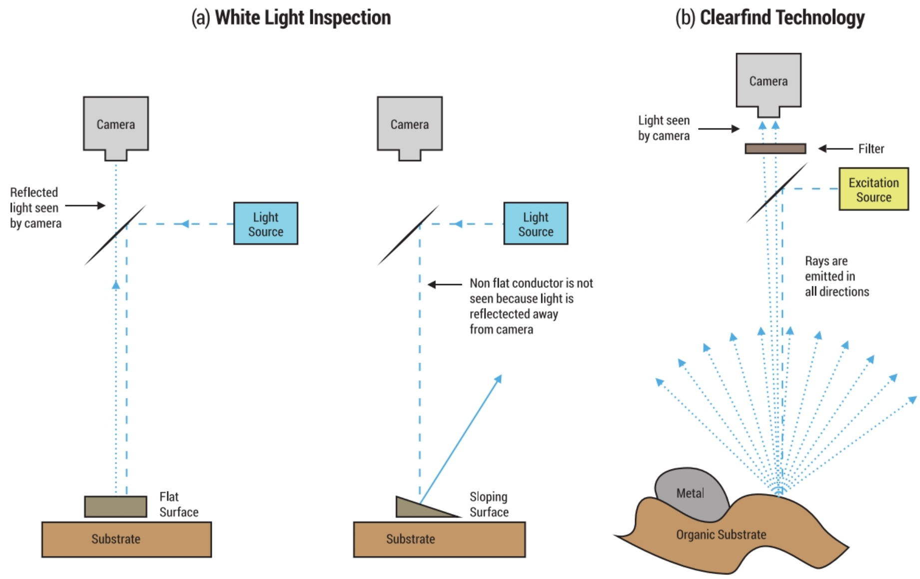

FIGURE 1. Simplified illustrations of the differences between traditional white light inspection systems (a) and CF technology (b).

materials are used to provide insulation between conductors and planar surfaces between the layers. Dark field and bright field inspection results often include tens of thousands of nuisance defects. These occur because the inspection algorithms are designed to find random aberrations in highly repeatable patterns and the variable grain patterns of metal conductors appear as defects when are not. If not excluded, their large numbers can quickly overwhelm the real defects. Metal grain features can be as large as 50µm, much larger than RDL lines, which are currently as small as 2µm, and likely to reach 1µm in the near future.

Another class of defects that has proven difficult for conventional optical inspection techniques is caused by the presence of organic residues left after etching and descumming operations. They are hard to find because these materials tend to be transparent at visible wavelengths, yielding little signal in bright field and dark field inspection. They can be especially troublesome when they occur on contacts such as bumps and pillars. The new illumination method effectively eliminates nuisance noise from metal surface textures and enhances signal strength from organic defects.

Clearfind™ technology

The results presented here were all acquired using a Firefly™ inspection system (Rudolph Technologies) that incorporates the new Clearfind (CF) illumination technology[1]. The new method takes advantage of the fact that many organic polymers exhibit distinctive optical properties that are not present in metals, silicon or other common inorganic materials used in semiconductor manufacturing. These properties tend to be unique to organic molecules displaying a high degree of conjugation, such as polycyclic aromatic hydrocarbons, and in linear or branched chain organic polymers with multiple regularly interspersed pi-bonds. This phenomenon results in the generation of a readily detectable, high color-contrast signal when the feature is appropriately illuminated against a metallic or other inorganic surface. The emission tends to be anisotropic and therefore less sensitive to surface topography that could potentially direct most ordinary bright field or dark field reflected light away from the detector. This results in increased sensitivity to organic residues and reduced sensitivity to interference from surrounding features. The method has the additional advantage of being relatively insensitive to signal variations caused by metal grains. **FIGURE 1** presents a simplified illustration comparing the new technology to traditional white light inspection.

The light source for the new technology is laser based, rather than the broadband source typically used in white light inspection systems. Thus, the light output is more stable in terms of both spectral range and output power. Autofocusing of the samples is accomplished using a patented high speed, near infrared-based laser triangulation system that maintains a constant distance between the imaging optics and the area being scanned. Images are acquired at high speed with a high-resolution camera. The result images compared in this article using bright

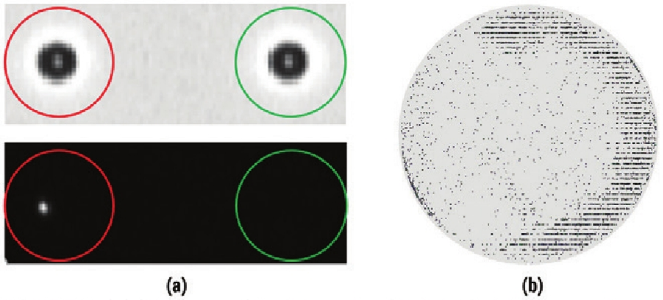

FIGURE 2. (a) (Upper set) in this pair of bright field images the TSV nails look the same. (Lower set) In this pair of CF technology images the residue is clearly visible in the left nail. (b) A full wafer map showing the concentration of defects toward the right edge of the wafer.

field, dark field and CF technology were all acquired on the same inspection platform using different illumination techniques.

Through Silicon Via (TSV)

The sample is a 300mm silicon wafer with revealed TSV pillars[2]. TSV nail diameter is about 8μm and the distance between TSVs is about 56μm. The TSVs are on the backside of the wafer and the front side of the wafer is attached to a carrier.

In **FIGURE 2a**, the top shows a bright field image of two TSVs. The TSV on the left, circled in red, is covered with unetched organic residue and the TSV on the right, circled in green, is completely exposed. In the bright field image both TSVs look good and the residue is not visible. The images at the bottom left of figure 2 were acquired with CF technology and show the same TSVs. The TSV on the left, circled in red, has a bright blob while the one on the right, circled in green, is completely dark. The organic residue remaining on the left TSV now emits a readily detectable signal.

FIGURE 2b shows the inspection result from the full TSV wafer. The dots on the wafer map represent defect locations. There is a heavy concentration of organic residue on TSVs on the right side of the wafer. Metal pads approximately 35μm in diameter will be placed on top of the TSVs. Any organic residue between the TSV and the pad can cause deplanarization, which may result in connectivity issues when the die is stacked together. In addition, organic residue can increase the resistance of the contact when the die is stacked. If the defects are found before the next process step the wafer can be reworked.

Under Bump Metal (UBM)

The sample is a 300mm wafer with RDL and under bump metallization (UBM). The UBM pads are about 50μm wide. In **FIGURE 3a**, the bright field image of two UBM pads shows the left pad is completely exposed and the right pad is covered with unetched organic film. However, the film is transparent and both pads look good in this image. Note the random metal texture visible in the bright field image, which adds noise and makes sensitive inspection for small defects more difficult. The image at lower left, acquired with CF technology, shows the same pads. The left pad, with no residue, appears black. The right pad, covered by residue, is significantly brighter. Also note that the metal texture seen in the bright field image with absent in CF illumination, permitting sensitive inspection for defects down to the pixel level.

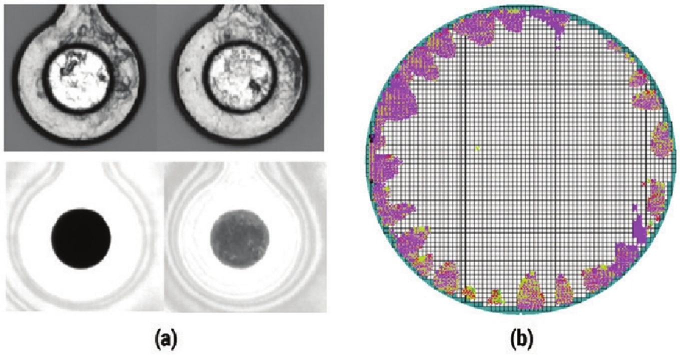

FIGURE 3. (a) UBM pads – In each pair the left pad is clear and the right pad is covered by an organic residue. In the bright field images (upper set) the two pads look the same and the graininess of the metal is clearly visible. In the CF images (lower set) the clear pad on the left is dark while the covered pad to the right is brighter. (b) The wafer map shows the distribution of defects concentrated near the wafer edges.

FIGURE 3b shows a map of the full wafer where there is a heavy concentration of defects on UBM pads near the edge of the wafer. As in the TSV example, residue remaining on the UBM pads can cause increased resistance or loss of connectivity to a bump deposited on the pad. Bumps deposited on the residue are higher than normal bumps,

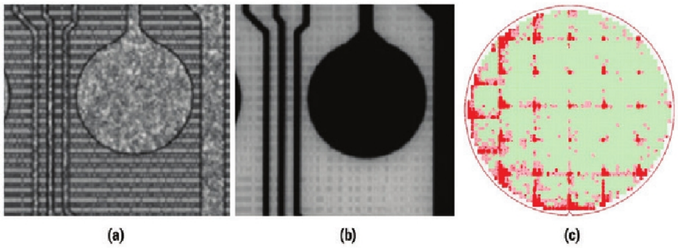

Figure 4. (a) bright field image shows considerable metal graininess, making it difficult to distinguish top layer metal from underlying metal visible through an interposed transparent layer. The metal graininess interferes with the detection of small defects. (b) CF technology suppressed the graininess in both the top layer metal and underlying metal layers, and there is good contrast between the top metal features and the transparent organic layer. (c) The full wafer map reveals a rectangular pattern that corresponds to the photolithography reticle.

leading to loss of coplanarity and connectivity issues. If the problem is found before starting the bump process, the wafer can be reworked and the residues removed.

Redistribution Layer (RDL)

The sample is a 300mm molding compound wafer for fan-out packaging. **FIGURE 4a** shows a bright field image that includes a UBM pad and several RDL lines. The middle image shows the same area viewed with the new illumination technology. In the bright field image, the metal of the UBM pad and the RDL lines is very similar to the underlying metal visible through an interposed transparent film. The texture and graininess of the metals add noise to the image, increasing the difficulty of detecting small defects. Inspection with bright field illumination resulted in high nuisance defect counts without finding real process issues on the wafer. In **FIGURE 4b**, the top surface metal features, RDL and UBM, stand out against the background of the transparent film, while the underlying metal features are barely visible. **FIGURE 4c** shows a full wafer map acquired using CF technology and reveals a rectangular pattern that corresponds to the reticle of the lithography tool. The rectangular pattern was not visible in the bright field wafer map.

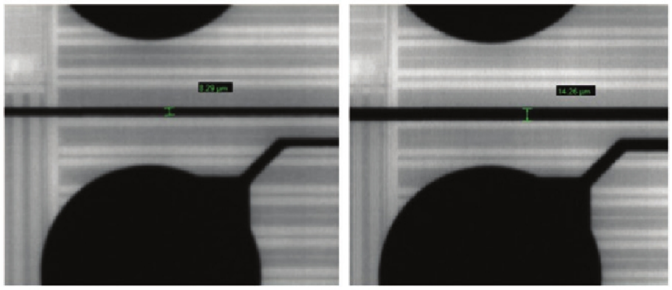

FIGURE 5. Further inspection with the new technology revealed thinned RDL lines (left) near the lower left corner of the reticle. The thinning was not detectable with bright field inspection.

FIGURE 5 shows additional RDL inspection results on the same wafer. CF technology revealed thinner lines toward the lower left corner of the reticle pattern. Ultimately, it was determined that these thinner lines were caused by a defect in the condenser lens of the lithography tool. The improved contrast between the first layer metal features in the underlying organic film, and the reduced noise, permitted more accurate and sensitive measurements using the new illumination technology. A bright field inspection of 20 wafers containing the same defect did not detect any thinner lines.

Photoresist

The sample is a 300mm patterned silicon wafer from a large memory manufacturer[3]. It contains die approxi-

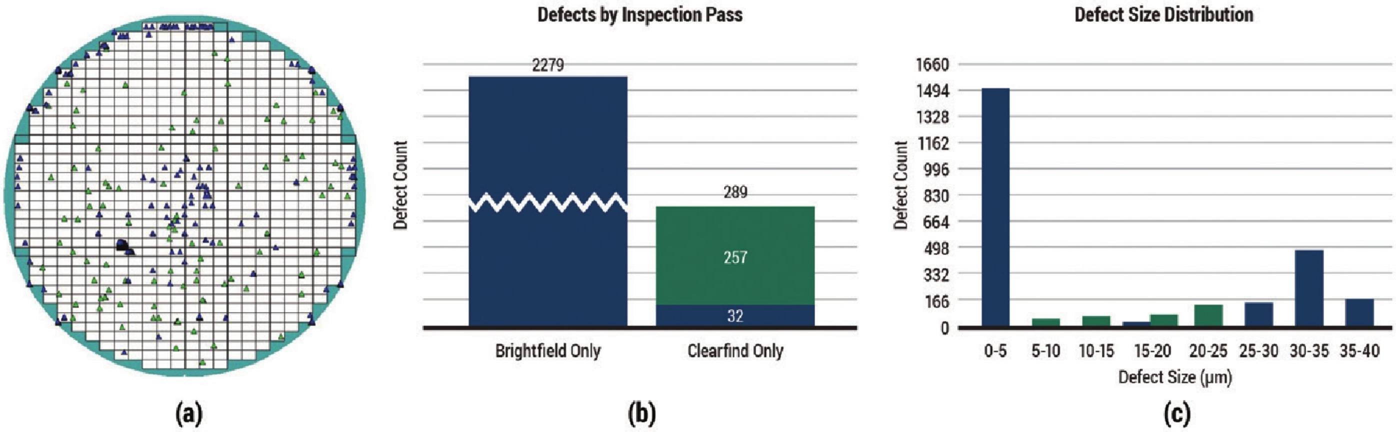

FIGURE 6. (a) A full wafer map shows defects detected by bright field (blue triangles) and CF technology (green triangles). (b) The bar graph shows the overlap between bright field defects and CF defects. (c) The bar graph shows the size distribution of the defects detected by each type of illumination.

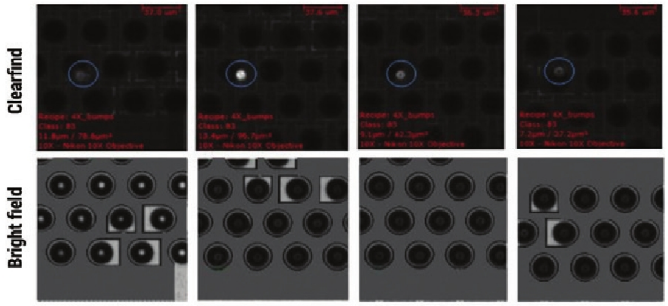

FIGURE 7. Comparing CFCF technology results (upper) and bright field results of the same defects.

mately 11.7mm x 7.6mm in size, and containing arrays of about 9,000 metal pillars, each pillar approximately 22µm in diameter. The customer was interested to know if the new illumination technology would find defects not found by bright field inspection. **FIGURE 6a** shows a wafer map overlaying bright field defects (blue triangles) and CF defects (green triangles). In both cases the defects appear to be randomly distributed and not clustered. As depicted by the bar chart in **FIGURE 6b**, bright field illumination found 2,279 defects compared to 289 defects found by CF technology. Most interestingly, only 32 of the defects found by CF technology were also found with bright field inspection. 257 defects would have been missed by bright field inspection. The bar chart (**FIGURE 6c**) shows the size distribution of defects discovered by both techniques. Bright field inspection found a very large number of small defects (less than 5µm) and more defects larger than 25µm. Defects found by the CF technology were between 5-25µm in size.

FIGURE 7 compares CF technology results (top) and bright field results (bottom). Each vertical pair shows a defect missed by bright field inspection and detected by CF technology. The enhanced brightness and circular shape of the defects detected by the new method strongly imply that they are associated with polymer residues. The enhanced brightness of the defects against the very black background is a unique and valuable feature of CF technology. Overall, these results demonstrate the value of supplementing bright field inspection with CF technology. All of the defects found by CF technology were of sufficient size to impact yield.

Conclusion

Results shown here demonstrate the benefits of imaging with the new CF illumination technology when compared to conventional bright field illumination. The new technology allows detection of transparent organic residues that are not visible with bright field illumination. It was also shown to detect types and sizes of defects that were not detected by bright field inspection. Equally important, its ability to reduce noise caused by metal texture and graininess significantly improves its sensitivity to small defects on metal features and dramatically reduces the detection of nuisance defects.

References

1. Gurvinder Singh, et al, "Advanced packaging lithography and inspection solution for next generation FOWLP-FOPLP processing", IEEE Xplore, October 2016.
2. Woo Young Han, et al, "Inspection challenges in wafer level packaging", International Wafer Level Packaging Conference, October 2017
3. Jonathan Cohen, et al, "Photoresist residue detection in advanced packaging", International Wafer Level Packaging Conference, October 2017 ◆