Inspection Challenges of Leadless Packages

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Abstract

The recent rise in popularity of leadless devices such as Leadless Chip Carriers (LCC), Bumped Chip Carriers (BCC) and Quad Flat No Leads (QFN) has gained the attention of the suppliers of inspection equipment for back-end semiconductor package assembly. Although still in its infancy, the leadless package appears to be the clear successor to current surface mount technology (SMT) for small packages. With a small footprint and an extremely thin profile, the leadless package is based on traditional wire bonding and leadframe processes, enabling an extremely attractive cost structure and price parity with SOP. By eliminating external leads, the package footprint can be decreased by almost 50%. In addition, the exposed die-attach pad can be soldered directly to the circuit board for enhanced thermal performance. The leadless package type is very well suited for devices with less than 100 I/O count, particularly those used in cost-conscious consumer market applications.

The advantages of leadless devices are many, but along with the new technology come new inspection challenges. This paper explores the post-singulation inspection challenges related to the implementation of leadless packages from the perspective of a user implementing a new packaging technology, as well as that of a supplier of inspection tools working to address unique challenges inherent in the package design. Inspection challenges to be reviewed include coplanarity, pad integrity, board quality, package sides and mark inspection.

Although leadless packages will undoubtedly simplify the manufacturing process of small surface mount devices, standard inspection processes may become more complex. Investigations into the inspection requirements of new manufacturing defects found on all six surfaces of leadless packages are explored. It seems clear that leadless device technology will not eliminate traditional requirements for three-dimensional inspection. Problems requiring side view inspections, such as copper smear, add yet another consideration to the final inspection process. Furthermore, with leadless devices, data used for two-dimensional (2-D) gauging cannot be determined from leads, as is done with leaded devices, and the package's molded body demands complex inspection methods to discern singulation and test defects including microcracks. To successfully meet the inspection requirements of leadless devices, successful customer/supplier collaboration and solutions are required.

Background

Suppliers of leadless components see a need for back end inspection performed between electrical test and packaging. Their customers are typically assembly houses that are using increasing quantities of leadless devices. Cautious with new technology, assemblers are demanding even cosmetic defects be screened. Many suppliers have responded by providing 100% or sampling inspection performed by inspectors armed with microscopes. The large volumes of leadless components make it difficult to maintain consistency. Automated inspection is the next logical step for many. A properly designed machine vision system can provide reproducibility while eliminating Beta risk and minimizing Alpha risk.

To understand the defect categories linked to the leadless family, a brief discussion of the manufacturing process is in order.

Leadless devices use traditional die-attach, wirebond, leadframe manufacturing processes. Two techniques are used for singulating devices from the lead frame: punch (Fig. 1a) and saw (Fig. 1b). Punch singulated devices typically have beveled corners and a top-hat design. Sawn devices are rectangular with vertical walls. Each process has its own advantages from a manufacturing perspective.

Saw singulation optimizes strip density separating components with a thin vertical wafer saw. A two-pass cut approach can be used to first electrically isolate components while holding the group rigid for economic gang electrical testing. A second, deeper cut mechanically isolates the components for packaging. The process is low impact. Disadvantages appear to be the high cost and maintenance due to excessive wear to the saw blade.

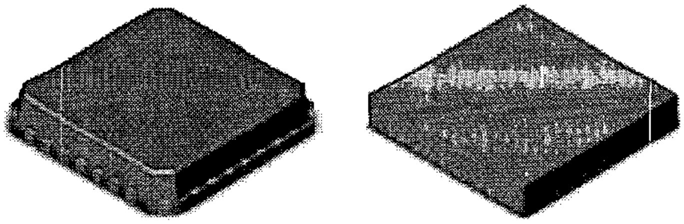
1a *1b*

Figure1. Punch and Saw Singulated QFN Devices

Punch singulation is lower cost and employed universally in leaded semiconductor manufacturing. A disadvantage of punch singulation is that electrical test must be performed on discrete components, as mechanical and electrical isolation are performed in a single step. Also, in the absence of a protruding lead, the impact point is closer to the die than formed lead components.

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Leadless Device Defects

With less packaging surrounding the die, mold defects are considered more seriously on leadless devices. Particular attention is paid to defects that may cause shorting between the electrical contacts known as lands. Several defect modes apply specifically to the singulation technique used in manufacturing.

Components that have been saw singulated are exposed to the second pass cut immediately following electrical test. A concern is raised that slight misalignment can cause friction between the blade and the previously cut lands, on the device sides. The heat generation combined with the motion of the blade can introduce a blurring effect of the copper known as *copper smear* (Fig. 2). This exposes a very real risk of the manufacturing process introducing electrical shorts post-test.

Figure 2. Copper Smear

An additional concern raised by the singulation process is *burrs* generated from the tearing force of a saw cut or the shearing of a punch. Burrs may extend downward preventing the board from resting flat at board assembly. This is similar to a coplanarity defect found on components with formed leads. Since burrs are typically flakes of conductive copper or solder, they also pose a potential threat to shorts undetected at electrical test.

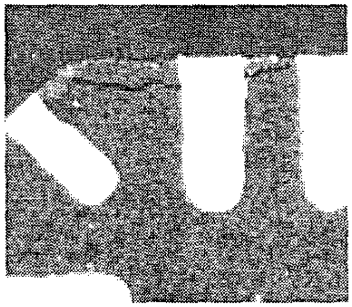

Figure 3. Microcrack

Punch singulated components exhibit a propensity to develop stress fractures that radiate from the device corners and along the edges. The top-hat design provides little support against the impact of punch singulation. After their formation, these cracks often close back into very thin fissures known as *microcracks* (Fig. 3). Since they reside near and occasionally directly over the die, microcracks may be an indication of internal damage. Their widths often reach 0.5 mils and below. Careful inspectors can detect defects of this size with microscope magnifications on the order of 200X.

An undetected microcrack is prone to catastrophic avalanching from small forces introduced in test and handling. Such a defect is known as a *chip out* (Fig. 4).

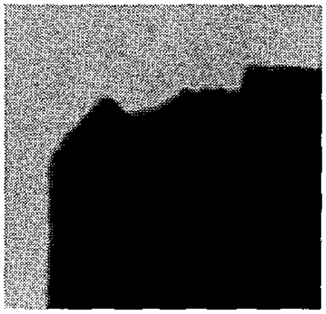

Figure 4. Chip Out

Defects associated with the lands, include *solder bridging* (Fig. 5) caused by excess solder bleeds or damaged solder plating. The lands are typically flush with the package mold. The solder tinning process now has the package acting as a palette for excess solder increasing the risk of shorts. *Missing solder* can be caused by insufficient dispense or subsequent flaking. *Damaged lands* may be a result of test probe contact. Verification of land *presence/absence*, *true position* with respect to the package outline, relative *pitch, width*, and *length* can all be monitored through automated gauging techniques.

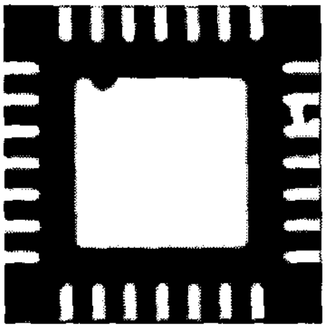

Figure 5. Solder Bridge

In addition to microcrack and chip out, the package body may have missing or damaged mold compound known as *incomplete mold, chips, pits, scratches* and *voids*. *Foreign material* is a generic category, but can cause shorting if conductive. Non-conductive foreign material protruding downward may cause coplanarity failures similar to those associated with burrs. Finally, although the packages are typically small, *package warpage* can cause coplanarity style errors.

The top surface of the device is typically laser or ink marked. Inspection requirements include verification of correct marking, mark legibility, quality, and contrast. Orientation indicators such as dimples and laser markings are used to identify the mechanical orientation independent of the brand markings. The top surface of leadless devices seems to be more robust and is subjected to a lesser degree to the forces of singulation and test.

Some Key Components of Machine Vision

In addition to understanding the defects, successful machine vision based defect detection requires attention to illumination, image resolution, and algorithm. For reliability, each feature of interest must be resolvable and in some way, have a signature that is significantly different from that of its surrounding area. The signal strength of a defect parameter must be greater than the background noise. The presence of a defect within an image is determined through conditional evaluation such as limiting the region of interest to the domain where the defect could possibly occur. One or more of many dimensions can then be used to characterize the defect: grayscale range, size, shape, color or contrast.

Illumination: Optimum illumination provides high contrast of the feature or defect under investigation while attenuating background noise. Rarely is a single lighting setup sufficient for a diverse set of inspections.

The direction of incoming light rays has a dramatic impact on the resulting image. It is useful to break down lighting into three zones: back lighting, bright field (on-axis), and dark field (off-axis). Back lighting originates behind the object along the line of sight of the observer. The result is a silhouette of the object created by its interruption of this light. Front lighting is used to generate images by reflecting light off of the object surface. Front lighting is divided into two zones, dark and bright field. In the bright field zone the actual light source is reflected back to the observer. With dark field illumination, the observer only sees light rays that have been scattered by the surface geometry (texture) in such a way as to bend the ray back to the camera. Defects and features of interest typically reveal themselves better under one or a combination of these illumination zones (Fig. 6).

Image Resolution: In order for a feature to be identified it must be resolvable. Contrast is provided by proper illumination, resolution is obtained through high quality optics and electronic sensors. Digital CCD cameras now offer large arrays, high frame rates, and high signal to noise ratios. Adequate resolution allows for highly repeatable and consistent defect size and shape to be measured and used for defect rejection criteria, something manual inspection lacks.

Algorithm: Once the imaging has been optimized for the defects and features of interest, software and/or hardware algorithms are used to further isolate, identify, quantify, and ultimately judge component quality. Image pre-processing may be appropriate to further increase defect contrast or filter unwanted background features. Convolutions of linear operators such as low-(smooth) and high-pass (sharpen) are common. Also non-linear enhancements such as median, min, max, and Sobel may be helpful. These tools are aimed at further accentuation of the defect from its surroundings or suppression of unwanted background noise.

To be effective, each region of interest (ROI) must be precisely identified such that the domain of the feature or defect is contained within boundaries. If those boundaries can change, such as scaling or displacement between components, real-time compensation is required. Algorithms such as correlation, geometric pattern matching, or edge detection are often used as search routines.

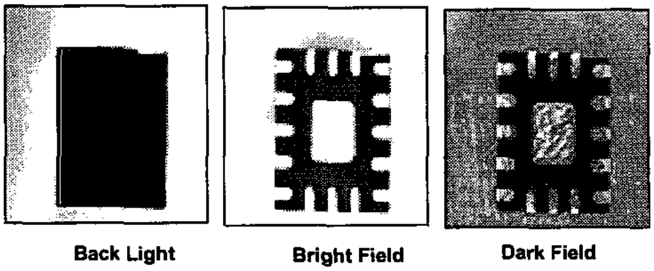

Figure 6. Examples of Lighting Zones

The defects are identified within each ROI with connectivity, correlation, or geometric pattern matching. It is critical that algorithms remain stable through real world changes such as light source decay, variations in ambient light, and part-to-part or lot-to-lot variation of the components under inspection. Edge detection tools as well as correlation and connectivity algorithms should employ normalization techniques to help maintain stability.

Leadless Inspection System

As a supplier of inspection equipment, the challenge was to first identify and interpret the defect information provided by the manufacturers and packaging houses. With this information, an automated inspection system was designed that specifically addressed the demands of leadless devices. This system would be integrated into back end packaging equipment, supplying 100% final outgoing inspection at production volumes. Key features include a comprehensive programmable lighting system, sufficient resolution for *microcrack* detection, and the ability to view all six sides of saw singulated components.

Since all six surfaces of the device may require inspection, two stations were used. Station 1 (Fig. 7) provides a top-view image while the component is supported from below. A low cost, standard resolution analog CCD camera was selected. Mark OCV inspection and orientation were considered sufficient for this surface. An image is shown in Figure 8.

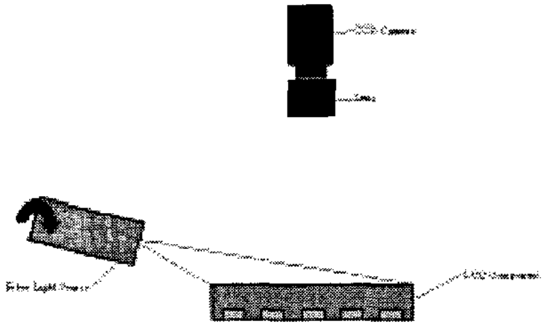

Figure 7 . Station 1 Top View

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Figure 8. Station 1

The 2nd station provides a view of the bottom surface along with optional side views. Held by a vacuum nozzle, each leadless component is plunged into the inspection module. An ideal inspection condition is achieved by immersing the component into a controlled lighting environment.

The leadless component is presented to the camera so that its body plane is normal to the optical axis. Notice the intensity of the background between back and front lit images (Fig. 9). A frame of side-view mirrors provides front and back lit imaging of the four sides in the same frame as the bottom view.

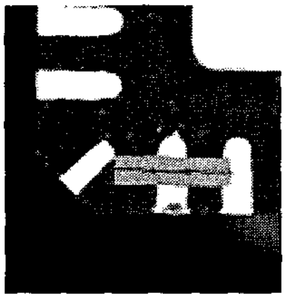

Figure 10 . Fine Location of Lands

In the case of leadless components, we found it useful to begin the image processing with a silhouette of the bottom view. Using a series of edge detection tools, the perimeter of the LCC device maintains sub-pixel accuracy through large amounts of component translation and rotation. This set of edge tools acts as a pattern location tool with the added benefit of performing board edge inspection. The edge tools intersect to form a polygon that represents the package outline. The polygon is scanned for localized peaks and valleys that often characterize burrs and chip outs. Given the shape and position, a datum is generated as a reference for ideal land positions.

The land areas are identified through a series of steps that lead to the ultimate gauging of size and position with respect to the previously established package outline. Fine location of the lands uses gradient based algorithms placed with respect to the rough land position (Fig. 10). Accurate land boundary and centroid positions are established and can be spatially related to the mathematical ideal component. Gauging of *land pitch, length, width, true position,* and *spacing* are now performed.

For defect detection on the lands and component surface, a sophisticated set of inspection algorithms and tools are combined into a high-order tool called the package tool. The package tool is multi-dimensional allowing the end user to address each defect type independently applying the proper filtering, ROI location, and defect detection algorithms. Each instance of the package inspection tool is assigned the appropriate image for the specific defect(s). Key image areas are then screened for abnormalities that fall outside of the normal product variation profile.

Microcracks are imaged as long, thin dark features that are almost exclusively found near the outer perimeter of punch singulated devices. Because they have the tendency to seal themselves into very narrow fissures, they require high resolution and strong contrast to resolve. This is a main reason that a more expensive high resolution CCD sensor was selected. Package inspection tools are used to isolate cracks and then detect their unique geometry (Fig. 11).

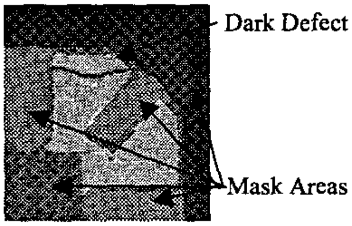

Figure 11 . Microcrack

Side view inspection is crucial to detecting the blurring effect of *copper smear* and *burrs* often invisible from the bottom view alone. When side views are required, the optics are changed to include surrounding mirrors. The front surface optical mirrors provide slightly oblique side perspectives simultaneously with the bottom view. *Copper smear* is detected by investigating the quality of each of the copper lands as well as the area between lands (Fig. 12).

Figure 12. Copper Smear Detection

Burrs are also best viewed through the side view mirrors via lighting that best outlines the abrupt protrusion from the otherwise flat edge of the component edge (Fig.13).

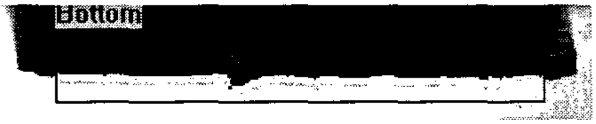

Figure 13. Burr Detection

Conclusions

As volumes of leadless devices climb and their defects become understood, manufacturers are beginning to replace manual inspection with automated post-test inspection. This is partially in response to the quality demands from board assemblers. With the scaling down of components, less material protects the die causing more attention to superficial surface damage. With leaded and bumped interconnects literally disappearing, other obstacles interfering with the flush mating of board-on-board must be considered. Saw singulated devices are at risk of electrical shorting cause by copper smear. Punch singulated devices are prone to stress fractures resulting in microcracks or the more severe (but more easily detected) chip out. All leadless devices can suffer from defective or improperly dimensioned lands, or excess solder resulting in electrical shorting.

Custom machine vision systems can provide a good solution to the inspection demands of leadless devices. The application requires flexible illumination, appropriate image resolution, and adaptable image processing algorithms as fundamental components to their design for the system to function.

The complex interaction of illumination, image resolution, and algorithm must be packaged with a user-friendly interface. Inspection applications should be customizable by the device manufacturers. The combination of cutting-edge inspection and ease of use provides the manufacturer with a solution to automated leadless device inspection.