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Guidelines for Visual Inspection and Control of Flip Chip Type Components (FCxGA)

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Guidelines for Visual Inspection and Control of Flip Chip Type Components (FCxGA)

Introduction

With the increased presence of flip chip type components - ball grid array (FCBGA), pin grid array (FCPGA), land grid array (FCLGA) - in electronic devices ranging from thin/light portable to massively parallel data centers, it is critical to offer clear guidelines for visual inspection and control that ensures quality and reliability of these components.

Guidelines for Visual Inspection and Control of Flip Chip Type Components (FCxGA)

(From JEDEC BoD Ballot JCB-12-50, formulated under the cognizance of the JC-14.1 Subcommittee on Reliability Test Methods for Packaged Devices.)

1 Scope

This publication provides description of defects observed in FCxGA components that can adversely impact end-user products and/or applications. It will also provide illustration on other defects that may be considered visual nonconformities since they should be less disruptive of quality or reliability to customer products. Finally, it will depict a method for visual inspection that can be utilized to identify these defects or visual nonconformities and guidance for disposition. Official criteria for product acceptance should be in actual product drawings and specifications.

2 Terms and Definitions

ball grid array (BGA) package: A package in which the external connections to the package are made via a rectangular array of ball-type connections, all on a common plane.

flip chip die: An unpackaged die whose electrical interconnections to a substrate are formed through solder joints. (Ref. JESD22-B109A).

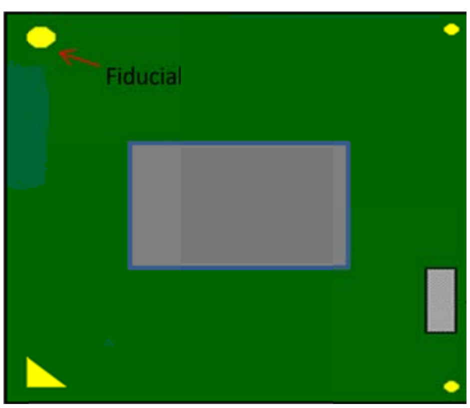
flip chip package (FCxGA): A package consisting of a facedown flip chip die on an organic substrate.

NOTE 1 The flip chip package may be configured to ball grid arrays (BGA), land grid arrays (LGA), or pin grid arrays (PGA) per customer requirements.

NOTE 2 The lowercase “x” in the abbreviation should be replaced by a capital letter representing the applicable construction, e.g., B for ball, L for land, P for pin.

NOTE 3 FCBGA packages typically have a filled epoxy that is dispensed between the die and the substrate.

fiducial marker; fiducial: An object, placed in the field of view of an imaging system, that appears in the image produced for use as a point of reference or a measure.



2 Terms and dDefinitions (cont'd)

field of view (in metrology): The area of the test sample under metrological examination.

land grid array (LGA) package: A package in which the external connections to the package are made via a rectangular array of land-type connections, all on a common plane.

organic substrate: A substrate with laminate materials constructed with glass fibers that are carbon-based epoxies.

pin grid array (PGA) package: A package in which the external connections to the package are made via a rectangular array of pin-type connections, all on a common plane.

3 Informative Reference Documents

JESD16-A, *Assessment of Average Outgoing Quality Levels in Parts Per Million (PPM)*

JESD47, *Stress-Test-Driven Qualification of Integrated Circuits*

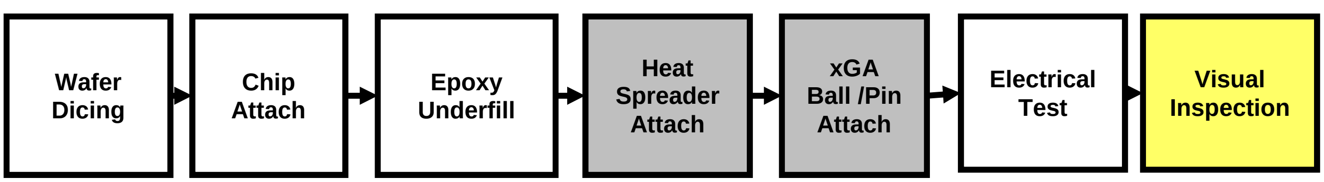
JESD22-B109A, *Flip Chip Tensile Pull*

JESD22-B101B, *External Visual Examination*

JESD22-B118, *Semiconductor Wafer and Die Backside External Visual Inspection*

4 Assembly Process Flow (illustration purpose)

A typical assembly flow for flip chip packaging for FCxGA (FCBGA, FCLGA, and FCPGA) is shown in Figure 4.1.



NOTE Steps in grey may/may not be part of the flow depending on package type. Yellow demarks focus of this document

Figure 4.1 — Assembly Process Flow

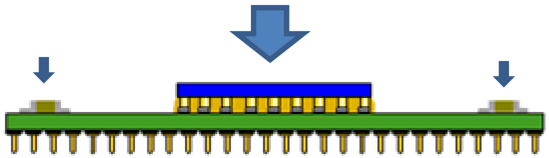
4.1 Wafer Dicing

To mechanically separate the functional Die (Wafer => Individual Dice)

4 Assembly Process Flow (illustration purpose) (cont'd)

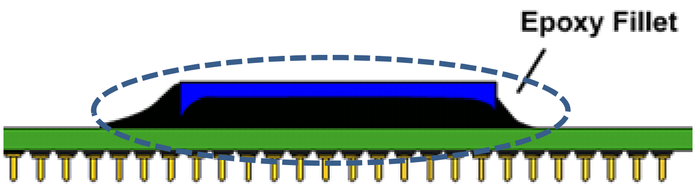
4.2 Chip/Component Attach

To place die on package and form the electrical and mechanical connections between the die/package by reflowing the solder at high temperature to form a high-quality solder joint. [Die Side Capacitors can also be placed and joints formed at this operation].



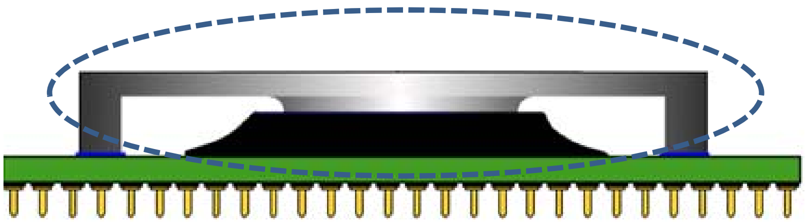
4.3 Epoxy Underfill

To fill the cavity under the die and around the die perimeter with epoxy. This seals the area and provides mechanical support for the die-to- package interconnects.



4.4 Heat Spreader Attach/Cure

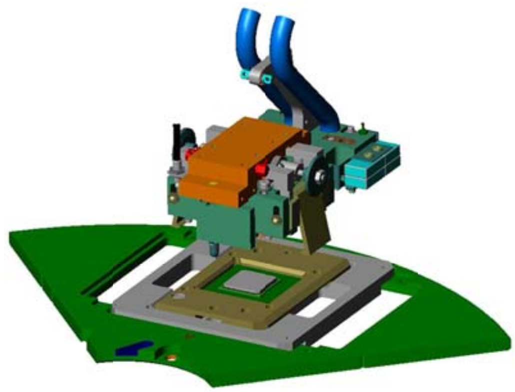
Thermal interface material is placed on top of the die and the Heat Spreader is attached with sealant (and cured). This is done to control thermal performance especially for products which have higher rates of heat generation or are very temperature sensitive.



4 Assembly Process Flow (illustration purpose) (cont'd)

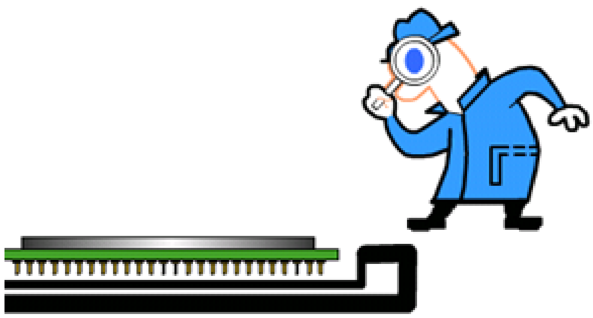
4.5 Electrical / Functional Testing

To perform electrical test in order to isolate manufacturing defects, ensure product meets performance specifications, and categorize components according to device performance.



4.6 Visual Inspections

To perform inspections against visual criteria, especially for items that may not represent electrical or functional failures. This can be done with automated inspections systems, manual inspections or some combination of both.

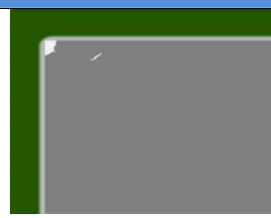
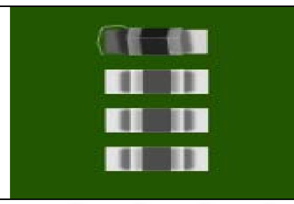
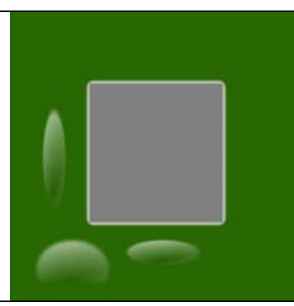
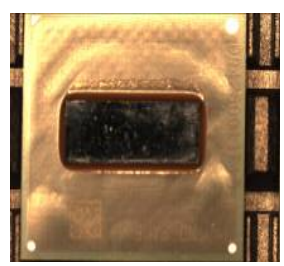
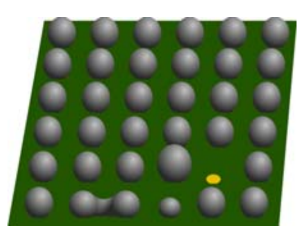
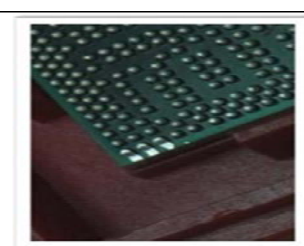


5 Types of Defects

Defects that can negatively impact end-user products are shown in Table 5.1, and designated as Tier 1. Conversely, Table 5.2 will list defects that may be treated as visual nonconformities since they are expected to less disruptive of quality or reliability of customer products.

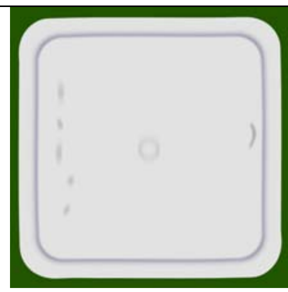
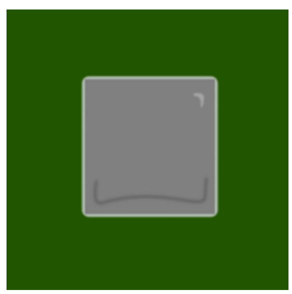
Note: in addition to actual images of these defects, generic illustrations have been included in Tables 5.1 and Table 5.2 for clarification purposes.

Table 5.1 — Tier 1 Defects

Defect:	Package Type	Description	Defect Illustration	Defect Images	Associated Risks
Die Damage / Die Crack	BGA LGA PGA	Mechanical damage to Silicon Die			Can cause electrical opens / Die Cracking (propagating from damage location)
Component Damage	BGA LGA PGA	Mechanical Damage to Die-Side or Land-Side Components.			Can cause electrical performance degradation.
Bent / Missing Pin	Only PGA	Pin Interconnect is tilted or missing			Can cause PGA socket insertion error (Bent Pin) or electrical signal disruption (missing pin)
Blister / Delamination	BGA LGA PGA	Substrate blistering is predominantly due to moisture			Can cause electrical opens or loss of margin in long term reliability.
Deformed / Merged Ball	Only BGA	Any severely deformed, missing or merged (to adjacent BGA) ball.			Can cause electrical open or short

5 Types of Defects (cont'd)

Table 5.2 — Tier 2 Defects

Defect:	Package Type	Description	Defect Illustration	Defect Images	Associated Risks
Laser Mark Defects or Missing / Unreadable Mark	BGA LGA PGA	Defects from Traceability Marking			While this is not considered a functional defect, many manufacturers use this mark for traceability. Inability to read the mark is a manufacturing disruption.
Stain / Discoloration on the Heat Spreader	BGA LGA PGA	Non-uniformity on the heat spreader surface.			Primarily considered visual nonconformity and should be minimized.
Stain / Discoloration on Die	BGA LGA PGA	Stain on Bare Die Component			Primarily considered visual nonconformity and should be minimized. Note: if there is physical height this could be material build-up that is possible to impact thermal performance.

NOTE The list of defects from this document is not all inclusive.

6 Visual inspection method

Note: The primary focus of this section is related to manual inspection. However, there are many options within the industry to enable automated visual inspections for a variety of product types. While automated inspections can provide significant value in consistency of detection and disposition vs. manual inspection (due to human to human variation and resulting ongoing training needs), there are also critical challenges of automated inspections systems. These include a requirement of high discriminatory power to distinguish signal from noise and inspection recipes, greater levels of calibration to the exact level of quality desired. It is highly recommended that if automated systems are pursued, a qualification plan be drafted and completed to instill confidence that the inspection successfully and repeatedly detects intended defect modes.

6 Visual inspection method (cont'd)

6.1 Basic equipment/apparatus

Table 6.1 lists some example of basic equipment for the work area setup and inspection. Each company should define its own requirements of necessary equipment.

Table 6.1 — Visual Inspection Equipment/Use

Equipment	Purpose/Comment
Ergo workstation and chair	For Inspector safety
Safety glasses with permanent side shield	
Wrist and/or heel ESD ground strap	For product protection such as ESD protection or any handling issues
Workstation table top ionizer	
Ionizing air-blow off gun	
Vacuum pick up or other suitable handling tool	
Clean room glove	To avoid unnecessary contamination
Face mask	
Overhead task light to provide 100-200 foot candle (~1000 to 2000 Lux) florescent	For consistent inspection environment
3 diopter 1.75 magnifier with ring light	To provide higher magnification for inspection or verification
Microscope or other magnifying aids	

6.2 Procedure

6.2.1 In tray inspection

- Make sure the appropriate personal protection equipment is being worn.
- Make sure all the proper, ESD-free handling procedures are being followed
- Leave the components to be inspected on the tray
- Hold the tray a distance of 12" to 21" (30.4mm to 533.4 mm) at about 45 degree angle during inspection. Inspection shall be performed perpendicular to the eye and the arm shall be at rest posture.
  - air gun may be used to blow off loose, dry foreign materials if appropriate
  - component should be inspected by naked eye/unaided vision or low power magnification specified by the company
- Upon completion of the inspection of one side of the component.
- Place an empty tray on top of the inspected tray to secure components
- Perform a tray stack flip and continue to inspect the other side of the component.
  - air gun may be used to blow off loose, dry foreign materials if appropriate
  - component should be inspected by naked eye/unaided vision or low power magnification specified by the company

6.2 Procedure (cont'd)

6.2.2 Out of tray inspection

- Make sure the appropriate personal protection equipment is being worn.
- Make sure all the proper, ESD-free handling procedures are being followed
- Pick up the components by designated appropriate materials handling equipment such as vacuum pick up tool
- Inspect all sides of the component based on proper materials handling procedure given by the company

6.3 Potential limitations

Considering the nature of visual inspection process where majority of tasks require manual intervention (tool setup, calibration, sample preparation, and inspection), there are limiting factors from the inherent subjectivity and variability from the operators to the potential effects of external environmental factors such as lighting, noise, and ambience. Finally, operator fatigue and inadequate ergonomic work area may cause gradual loss in inspection accuracy during the course of inspection hours.

6.4 Preventive or corrective measures for visual inspection

While it is difficult to completely remove human subjectivity from visual inspection process, there are steps that company can take to mitigate the concerns and improve consistence of the operation

- **Training**
  - Each of the inspector should complete training requirements and be certified.
  - Trainee should shadow the trainer for certain period of time and able to correctly classify each type of defect mode
  - Trainee should demonstrate understanding on all equipment that would be used for inspection. Example, ergo workstation, microscope, and other equipment.

- **Inspection criteria development**
  - Inspection criteria need to be design in mind for consistent human execution in high volume environment in addition to product protection.
  - Criteria should be designed with clear language to minimize open interpretation as much as possible. In today global nature business environment, criteria should also be designed to suit multi-lingual and cultural systems. This often requires engineer involvement from multiple countries to clarify criteria intent and purpose.

  - Case Study #1
    - Foreign material (FM) is determined to become detrimental to the product A when its size is bigger than 100 mils (2.54mm) and to product B when it is bigger than 120 mils (3.04 mm). If it is likely the same inspector will need to perform inspection on these two products, the company may consider unified the criteria to "reject when FM when its size is bigger than 100 mil (2.54mm) for both products to avoid unnecessary human confusion and increased risk of operational errors.

6.4 Preventive or corrective measures for visual inspection (cont'd)

- Case Study #2
  - Many devices have fiducial mark with known dimension that comes with each device. It is preferred to have inspection criteria reference the size of the fiducial mark or the multiple of it to increase the consistent of human operation.
  - Example, if crack or chipping is determined to become detrimental to product A when it is larger than 60 mils (1.524 mm). If there is a fiducial mark in size 45 mil (1.143 mm). Company may consider to reject any chip and crack greater than 45 mil (1.143 mm) instead of 60 mil (1.524 mm) if there is no other arrangement setup to aid inspector to reference know dimension

As stated before, inspectors should be fully trained and certified to conduct visual inspection, especially considering the sensitive nature of inspection and its inherent subjectivity. Table 6.1 provides a wide range of certification plans with varied degree of confidence level and permissible defect level corresponding to different levels of expectations. It employs a Zero Defect Sampling (ZDS) approach where an Inspector's skill is demonstrated after a number of consecutive inspections without any misclassification (correct identification and classification of defect as specified in this document). As expected, successful repetition of inspection will correspond to a greater inspection skill.

For instance, if a company chooses to follow the highlighted cell (grey) in the Table 6.1 for operator certification, then inspectors would only be certified after completion of n=300 successive inspections without any misclassification. By completing this task, then inspectors would be performing equivalently, and maintaining an outgoing process that achieves <1% defect rate at 95% confidence level.

Table 6.1 — Inspector Certification Requirements

	Defects Per Million (defect rate)							
Confidence Level (%)	200K (0.2)	100K (0.1)	50K (0.05)	40K (0.04)	30K (0.03)	20K (0.02)	10K (0.01)	5K (0.005)
70%	7	13	25	31	41	61	121	241
80%	9	17	33	41	54	81	161	322
90%	12	24	47	58	77	116	231	461
95%	15	30	60	75	100	150	300	600
99%	24	47	93	116	154	231	461	922

- Other techniques to minimize human subjectivity or variations include carefully design and written inspection criteria,
  - Dimensions provided should relate to a physical object on the package such as a circle or triangle fiducial.
  - If more than one concept in the inspection criteria, try put them in bullet for easy reading and understanding
  - Minimize or avoid criteria that based on color because inspector may be color blinded or the perception of the color may be influenced by the external lighting environment.

- Establish defect library (devices with known visual defects) for easy reference and perform peer review for "eye calibration."
- If more than one inspection station, all the inspection stations should setup the same with same lighting.
- External lighting should be monitored periodically to ensure inspection tasks are not negatively affected.

7 Sampling Plan

Table 7.1 provides a set of sampling guidelines for visual inspection of incoming component lots based on the traditional Acceptance Quality Limit (AQL) approach with alpha = 0.05. Corrective measures should be considered if the number of inspected units exhibited critical defects that surpassed the accepted number (c).

Please note that varying AQL targets and sampling strategies may be employed to reflect internal business needs or scope of the investigation. For instance, during initial run, a more comprehensive sampling plan may be suitable to demonstrate overall stability; conversely, a condensed plan might be more practical for scenarios where a stable baseline has been previously established.

Table 7.1 — Sample Sizes for Visual Inspection Using AQL approach for Acceptance Number

Acceptance Number	AQL		
	1%	2.5%	4%
C=0	5	*	*
C=1	35	14	9
C=2	82	33	21
C=3	137	55	34
C=4	198	79	50

**No Sampling Plan Available to Meet the Conditions*

NOTE Please refer to JESD-047 for other sampling alternatives and consult JESD16-A for outgoing quality rationale, potential inspection lot determination and statistical considerations.

8 Disposition Steps

In conjunction to clear documentation for defect classification (Tier 1 or Tier 2), it is suggested that an acceptable threshold is defined prior to the implementation of any sampling strategies shown in table 7-1. For Tier 1 defects, this will readily lead to quarantine of affected or suspected population when the number of critical defects surpasses that acceptable threshold. Appropriate remedy steps can be employed to determine disposition steps, and root cause pursuit to ensure defect levels are brought to permissible levels.

Addressing Tier 2 defects should be based on product drawings and specifications or other procurement terms.

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