Use and Handling of Semiconductor Packages with ENIG Pad Finishes

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ABSTRACT

Electroless Nickel/Immersion Gold plating, or ENIG, is a versatile process and enables fabrication of high-density flip chip BGA substrates needed for high-performance IC chips. ENIG is used extensively in advanced IC packaging of microprocessors, ASIC and DSP components. By its nature, ENIG plating forms brittle intermetallic compounds of nickel, tin, and other elements in the solder after solder balls are attached to the package substrate. Certain conditions of high strain and high-strain rate are known to cause ENIG solder joints to fail. Therefore, care must be used to avoid excessive shock and bending of the PC board during assembly, handling, and testing of FCBGAs with ENIG plating. This paper discusses the use and handling of semiconductor packages which contain electroless nickel/immersion gold BGA pad finishes.

Contents

List of Figures

1 Introduction

This application report describes the quality and reliability of flip chip ball grid array packages using electroless nickel/immersion gold pad finishes. Also included is information with which to make informed decisions regarding use and reliability of TI FCBGAs with ENIG finish.

1.1 Glossary of Terms/Acronyms

The following terms and acronyms are used throughout the document.

ASIC – application specific integrated circuit

BGA – ball grid array

DSP – digital signal processor

IC – integrated circuit

FCBGA – flip chip ball grid array

ENIG – electroless nickel/immersion gold

OSP – organic solderability preservative

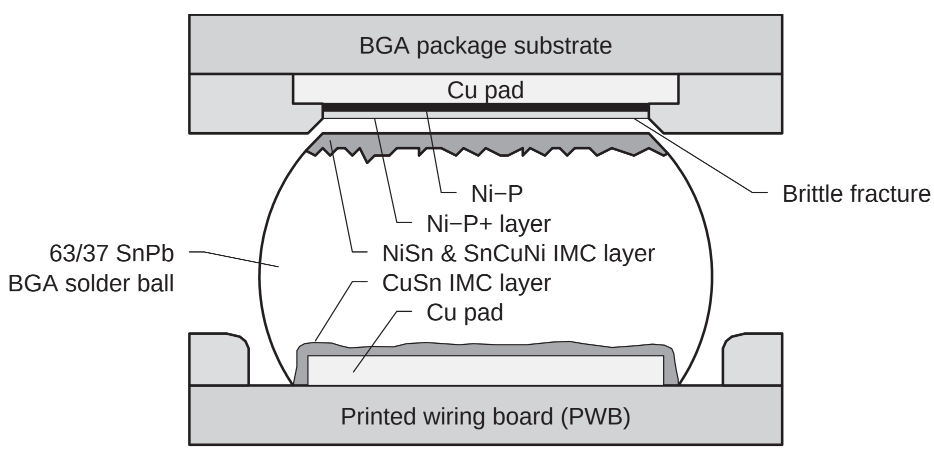
PC – printed circuit, as in printed circuit board, or PCB

1.2 Background

Flip Chip Ball Grid Array (BGA) packages produced with electroless nickel/immersion gold (ENIG) pad plating are at higher than normal risk for brittle solder-joint failure or the *package-off* defect. The brittle solder-joint failures are attributed to a quality problem with the nickel undermetal. This phenomenon is referred to in the industry as *black pad*.

The generally-accepted root cause for the poor quality of the ENIG finish, specifically black pad defect, is corrosion of the nickel undermetal during plating of the immersion gold layer. The Ni and Au plating layers are applied during the fabrication of the package substrate.

The most common solder-joint failure mode is a brittle solder-joint fracture. This fail mode is depicted in Figure 1.



Source: Goldstein, Julia, PhD., ed. Strain Gage Testing: Predicting and Preventing Brittle Fracture of BGAs, *SMT*, June, 2004.

Figure 1. Common Location for Brittle Solder Joint Fracture of a BGA with ENIG Pad Finish

1.3 Key Points Regarding Electroless Ni/Immersion Au Surfaces Finishes

The following points are important to understanding ENIG processes and finishes:

- ENIG is an electroless plating process. In this process, nickel and gold are plated on copper pads for IC components such as packages.
- ENIG plating is a versatile process and enables fabrication of high-density Flip Chip BGAs needed for high performance IC chips.
- ENIG is extensively used in the industry in advanced IC packaging in microprocessors, ASIC, and DSP.
- ENIG plating forms brittle intermetallic compounds of nickel, tin, and other elements in the plating after the solder ball is attached to the package. Brittle materials can break easily at high strain or under impact. Therefore, during assembly, testing, and handling, care must be used to avoid shock and excessive bending of PC board.
- Research is ongoing in the industry to develop alternative finishes, with improved toughness, to ENIG.
- Certain conditions of high strain and high-strain rate could cause ENIG joints to fail.
- Strain and strain rates on the PCB can be measured using strain gauges attached to the PCB, and special instrumentation.

1.4 Quality and Reliability of FCBGA Packages Using ENIG Pad Finishes

TI has evaluated the second-level solder joint reliability for IC packages with ENIG pad finishes, and has established minimum performance and reliability requirement for ENIG packages. These reliability requirements meet or exceed those of similar package technologies which use non-ENIG pad finishes such as electrolytic nickel/gold, and copper OSP.

Field reliability of ENIG packages is determined to be very good when the use and handling of the IC package is as described within this document. ENIG pad finishes have been used extensively by TI for FCBGA packaging since 1998.

To date, a high rate of customer returns after initial field deployment of the product into the customer's end application has not been observed. The occurrence of solder joint failure, as seen by package-off defects, has been observed primarily at SMT assembly, ICT and system integration, and not after extended field use by the customer.

1.5 Quality Control and Containment

Since the root cause for black pad defects is corrosion of the nickel undermetal, the phenomenon which causes black pad will most likely affect an entire substrate lot, as opposed to a single substrate or single BGA pad.

Identification of products affected with black pad is not possible by means of conventional, non-destructive techniques such as external inspection of the package and substrate. Destructive analysis techniques, such as microsection or ball pull test, are required to identify affected material. Thus, methods for detecting black pad in a high-volume assembly environment are very difficult to deploy.

Containment methods typically include quarantine of suspect material based upon observations of the SMT assembly process and designation of specific substrate lots as known bad material. Rework or repair of BGA pad metallization with black pad is not possible. Therefore, reballing or resoldering of BGA pads with black pad should be avoided.

1.6 SMT Board Design and Assembly Considerations

TI has determined PCB thickness to be an important element in the reliability of ENIG solder joints. To that point, TI has determined PCB thickness of 0.093” to be acceptable. Use of PCBs of lesser thickness should be fully evaluated using the assembly process, testing, and system integration procedures to be used by the customer or contract manufacturer. PCB thickness greater than 0.093” may have a deleterious effect on long-term cyclic temperature performance; thus, you should select a PCB thickness that is suitable to resist damage to the package during PCB assembly, and ensure long-term reliability for its intended field application.

In addition to properly designing the PCB, it is necessary to keep the following factors in mind:

- Understand the reflow process that best fits your PCB system mounting requirements. Follow the provided reflow profile and compare closely to the solder paste manufacturer’s recommended reflow profile,
- Conduct appropriate strain and strain rate characterization on PCB assembly process prior to component mounting on a new PCB design.
- Avoid excessive shock and bending of the PC board during assembly, handling, and testing of FCBGAs.
- Focus on material handling procedures that result in flexure, dropping or stressing of the PCB.

In order to extend the 2^{nd} level solder joint reliability of an ENIG package, the product/process engineer can consider the use of package−level underfill. Package−level underfill will distribute mechanical stresses imparted on the solder joint interface with the packages substrate, and will provide additional mechanical strength through adhesion to the package and PCB.

1.7 Characterization of the SMT Assembly, Test and System Integration Process

Certain conditions of high strain and high-strain rate are known to cause ENIG solder joints to fail. Therefore, you must use care to avoid excessive shock and bending of the PC board during assembly, handling, and testing of FCBGAs with ENIG plating. Examples of severe mechanical loading that produces high-strain and strain rates during PCB assembly are: In-Circuit Test (ICT), manual connector insertion, PCB edge-guide snap-off, two-sided assembly, and mechanical assembly. TI recommends appropriate strain and strain-rate characterization on the PCB assembly process be performed prior to beginning assembly of a new PCB design (see Figure 2). Additional care should be taken to avoid steps where severe mechanical loads could potentially impact the reliability of the ENIG solder joint.

PWB flexural loading depends upon system configuration, assembly location, etc. Consequently, some PCB assemblers characterize PCB strain for all operations associated with mechanical loading.

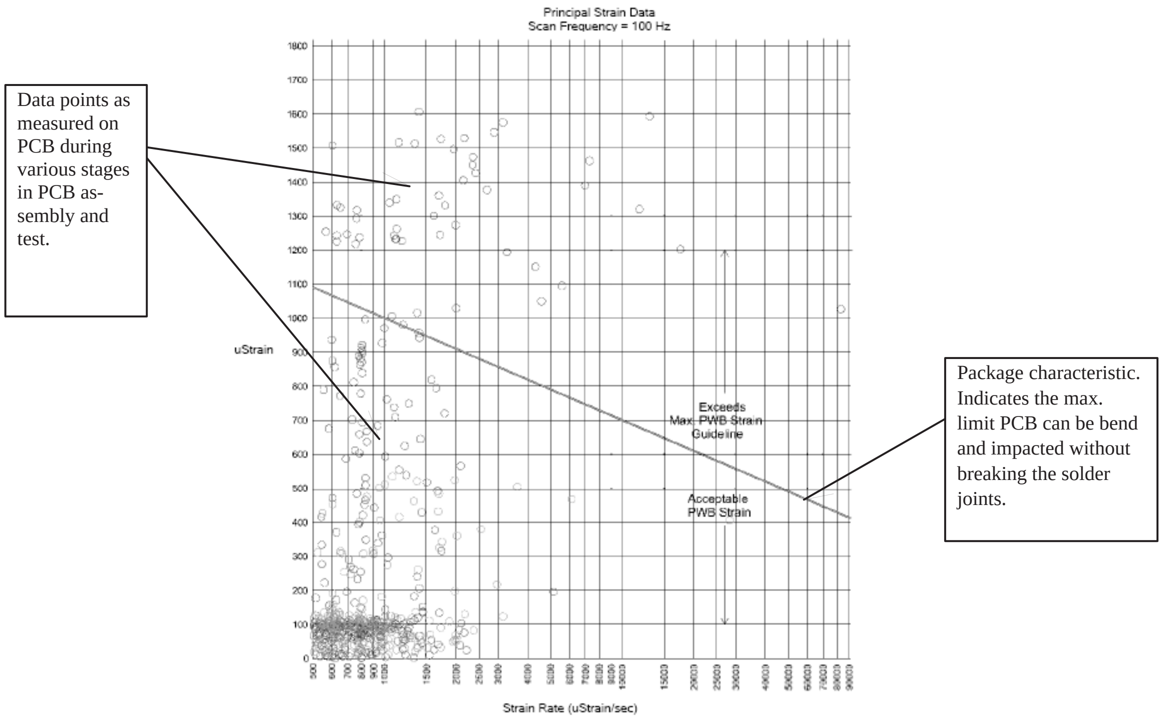


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Figure 2. Characterization of PCB Strain During Different Process Steps Superimposed with Package Characteristics

1.8 PCB Assembly Dynamics

The following strain vs. strain-rate points show the extent of stress placed on a PCB during assembly and test.

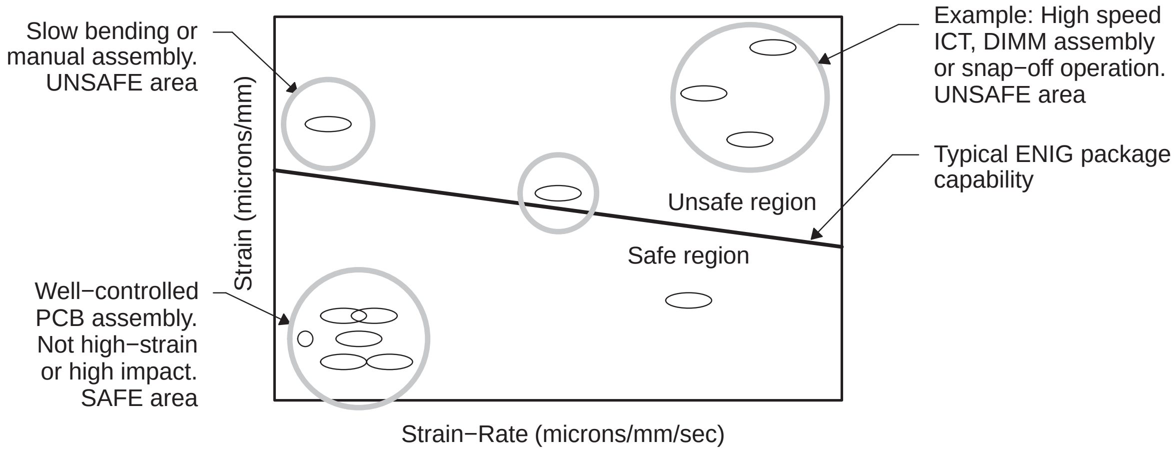

Figure 3. Strain vs. Strain−Rates on PCB During Assembly and Test

The following recommendations are important to prevent undue stress on PCB assembly.

Recommendation #1: Prevent bending, flexing and impact loads.

Check the following for potential problem areas and reduce flexion and impact:

- Second side assembly in a two-sided board
- All manual handling processes:
  - All rework and retouch processes
  - Connector installation
- Board test processes:
  - In-Circuit Test (ICT)
  - Board Functional Test (BFT), or equivalent functional test
- Mechanical assembly
  - Heatsink assembly
- System board integration
- PCI card installation
- DIMM installation
- Snap off of edge guides

NOTE: Assembly processes for different boards and manufacturers vary. Tests such as ICT and BFT are referred to generically in this document; nomenclature can vary at different manufacturing sites. In such cases, apply the same requirements to the equivalent test processes. However, the goal is to characterize all assembly steps involving mechanical loading. Do not constrain testing to the steps listed above or to perceived high risk areas. The data from these tests serve as a baseline for future reference.

Recommendation #2: Using special instrumentation, characterize PCB assembly process to identify high−stress operations.

Some assembly steps that require characterization include the following:

- Surface mount technology (SMT) assembly processes
- All manual handling processes:
  - All rework and retouch processes
  - Connector installation
- Board test processes:
  - In−Circuit Test (ICT)
  - Board Functional Test (BFT), or equivalent functional test
- Mechanical assembly:
  - Heatsink assembly
  - Manual component addition
  - Manual component soldering
  - Wiring harness attach/insertion
  - Packing
- System board integration
- PCI card installation
- DIMM installation

Additional information on predicting and preventing brittle solder joint failures through use of strain gage testing can be found in Julie Goldstein’s article, included in section 2, References.

Recommendation #3: Application of package−level underfill.

Upon completion of recommendations #1 and #2, additional precautions may be required to further reduce the chance of solder joint damage brought about by normal assembly and test operations. In this instance, package-level underfill can be applied to the as-mounted component to distribute stresses and reduce the effect of forces concentrated on the BGA solder joint.

Package-level underfill provides mechanical strength and stability for the package and PCB in the immediate region of the package. The underfill ensures that the PCB and package remains firmly affixed and protects the solder joints from high-impact forces which can otherwise damage the solder joint.

1.9 Conclusions

Electroless nickel/immersion gold (ENIG) plated packages are frequently used in high-performance flip chip packages. ENIG forms brittle intermetallics with solder. Care must be taken to prevent excessive strain and strain rate (bending and impact) during handling, assembly and test of ENIG packages. Strain and strain rate can be measured using special instrumentation. However, even if special instrumentation is not available, inspect and adjust each operation to avoid potential problems. Lastly, application of package-level underfill provides additional strength and protection to the solder joints to prevent damage.

TI continues to work with our suppliers and industry experts to identify positive process improvements with the electroless nickel/immersion gold plating process. This continuous improvement activity includes identification of superior process chemistries, optimized process parameters, and more sensitive quality control procedures.

New alternative BGA pad finishes are emerging. TI is currently involved in development and qualification of alternative finishes to ENIG, which will enable customers to realize greater robustness and reliability of the FCBGA package. Please contact your TI Field Service Engineer or Customer Quality Engineer for timing and availability of packages with non−ENIG pad finishes.

2 References

1. Goldstein, Julia, PhD., editor. Strain Gage Testing: Predicting and Preventing Brittle Fracture of BGAs, *SMT*, June, 2004.

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