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September 2005

JOINT INDUSTRY STANDARD

Selection and
Application
of Board Level
Underfill Materials



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IPC J-STD-030A

Selection and Application of Board Level Underfill Materials

Developed by the Underfill Materials Design, Selection and Process Task Group (5-24f) of the Assembly and Joining Committee (5-20) of IPC

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Users of this publication are encouraged to participate in the development of future revisions.

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Acknowledgment

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Selection and Application of Board Level Underfill Materials

1 SCOPE

This document provides users of underfill material with guidance in selecting and evaluating underfill material for assembly solder joints second level interconnects. Underfill material is used to increase reliability of electronic devices by two methods: alleviate coefficient of thermal expansion (CTE) mismatch (between the electronic package and the assembly substrate) and/or increase mechanical strength. Underfill materials are also used for environmental protection, mechanical shock or vibration, and anti-tampering uses. Materials used in underfill applications should not adversely affect device reliability nor degrade electrical performance (e.g., ionic impurities). When correctly selected and applied, underfill material should increase the life of the assembly solder joints.

Types of underfill materials currently available in the market include:

- Capillary Flow Underfill
 - Primary UFs (Package level not within the scope of this document)
 - Secondary (Board level)
- No-Flow/Fluxing Underfill
 - Thermal Compression Bonding (TCB) Epoxies (not within the scope of this document)
 - Non-Conductive Paste (NCP)
 - Non-Conductive Film (NCF)
- Removable/Re-Workable Underfill
- Corner Bonding/Glue Bonding
- Molded Underfill (not within scope of document)
- Wafer Applied Underfill (not within scope of document)
- Vacuum Underfill (not within scope of document)

1.1 Introduction This document covers polymer based underfill materials intended for use in printed circuit assemblies (PCA). (See Figure 1-1.)

1.2 Purpose The purpose of this document is to help in identifying underfill materials whose properties are compatible with component assembly joints to reduce thermo mechanical stress so that performance of the assembly is enhanced. The additional role of underfill is protecting the device from environmental factors and increasing strength. Evaluation methods are provided in the document that are intended to be used for assessing underfill material performance in specific applications as well as troubleshooting failures. This document represents the compiled knowledge and experience of the IPC Underfill Adhesives for Flip Chip Applications Task Group.

1.3 Definition of Requirements The word “shall” is used in the text of this document wherever there is a requirement for materials, preparation, process control, or acceptance of a soldered connection or a test method. The word “should” reflects “best processing techniques” and is used to reflect general industry practices and a suggestion for guidance only.

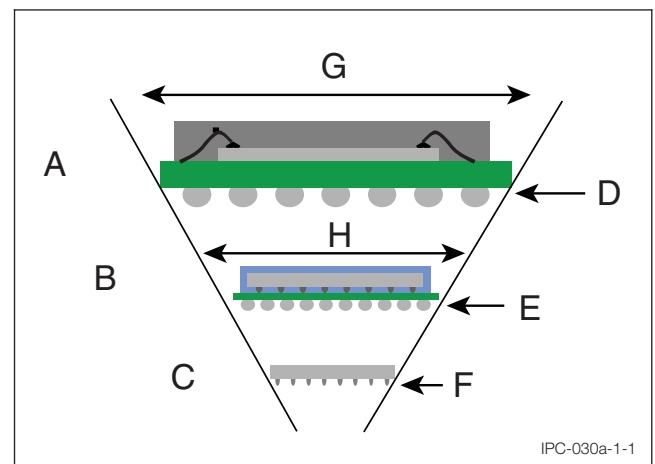


Figure 1-1 Comparison of Various Sized Array Packages

- | | |
|-----------------------------|---------------------|
| A. Ball Grid Array (BGA) | E. 300 micron balls |
| B. Chip Scale Package (CSP) | F. 75 micron balls |
| C. Flip Chip (FP) | G. 35 mm [1.38 in] |
| D. 760 micron balls | H. 12x chip size |

2 APPLICABLE DOCUMENTS

2.1 IPC¹

IPC-T-50 Terms and Definitions for Interconnecting and Packaging Electronic Circuits

IPC-TM-650 Test Methods Manual²

2.3.18 Gel Time, Prepreg Materials

2.4.28 Adhesion, Solder Mask (Non-Melting Metals)

2.6.1 Fungus Resistance of Printed Board Materials

2.6.3 Moisture and Insulation Resistance, Printed Boards

2.6.3.1 Moisture and Insulation Resistance - Solder Mask

2.6.3.2 Moisture and Insulation Resistance, Flexible Base Dielectric

2.6.14.1 Electrochemical Migration Resistance Test

IPC-9201 Surface Insulation Resistance Handbook

IPC-7711/7721 Rework, Modification, and Repair of Electronic Assemblies

2.2 American Society for Testing and Materials (ASTM)³

ASTM D150 Standard Test Methods for AC Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulation

ASTM D257 Standard Test Methods for DC Resistance or Conductance of Insulating Materials

ASTM D792 Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement.

ASTM D1002 Standard Test Method for Apparent Shear Strength of Single-Lap-Joint Adhesively Bonded Metal Specimens by Tension Loading (Metal-to-Metal)

ASTM D2471 Standard Test Method for Gel Time and Peak Exothermic Temperature of Reacting Thermosetting Resins

ASTM D2556 Standard Test Method for Apparent Viscosity of Adhesives Having Shear-Rate-Dependent Flow Properties

2.3 Telcordia Technologies, Inc.⁴

GR-78-CORE Generic Requirements for the Physical Design and Manufacture of Telecommunications Products and Equipment

3 TERMS AND DEFINITIONS

All terms and definitions used throughout this handbook are in compliance with IPC-T-50. Specific terms and definitions, essential for the discussion of the subject, are provided below.

Channeling – Filler settling due to the pitch of the bumps on the underfilled device being too small to allow the filler to flow through uniformly. The effect can be observed in a scanning acoustic image (for flip-chips) or cross-sectioned sample. The channeling may also occur due to the presence of flux residue that has reduced the effective gap size.

Board – In this document the term board is used to represent the following:

- a. Printed Circuit Assembly (PCA)
- b. Flex circuit
- c. Ceramic substrate

1. www.ipc.org

2. Current and revised IPC Test Methods are available on the IPC Web site (www.ipc.org/html/testmethods.htm)

3. www.astm.org

4. www.telcordia.com

4 BACKGROUND

4.1 Why Is Underfill Needed? Underfilling encapsulants were originally developed to improve reliability of early flip chip assemblies employing alumina (Al_2O_3) substrates. Solder fatigue of the outermost solder bump interconnections caused the failures in these assemblies. The relatively small thermal expansion mismatch between the silicon die ($\sim 3 \text{ ppm}/^\circ\text{C}$) and the substrate ($5 - 50 \text{ ppm}/^\circ\text{C}$) was responsible for the onset of fatigue during thermal cycling. The temperature range of the cycling and the size of the solder bump array (closely correlated with the die size) were the main factors determining the lifetime of the assembly. Inserting a curable liquid epoxy resin between the die and substrate as seen in Figure 4-1, was shown to dramatically improve assembly reliability by distributing stress due to CTE mismatch over the entire area of the die, instead of just the solder joints.

Underfill development accelerated with the introduction of epoxy-based laminates as substrates for flip chip assemblies (see Figure 4-1). A large CTE mismatch between the laminate and silicon (typically $12 \text{ ppm}/^\circ\text{C}$ or greater) made underfill a necessity to prevent very rapid solder fatigue. The underfill distributes the stresses caused by the CTE mismatch over the entire area of the die and forces much of the stress into the substrate. Interfacial delamination between the underfill and the die, not solder fatigue, is the dominant cause of failure in underfilled flip chip assemblies.

With the advent of handheld electronic products, use of board level underfills have become more prevalent. In addition to imparting thermal cycling reliability, underfills protect chips and interconnections from environmental factors and increase the mechanical strength of the package attachment. The latter is particularly important for chip scale packages (CSPs), which typically pass thermal cycling and environmental tests without underfill but fail when subjected to mechanical shock or impact (e.g., dropping a cell phone). These forces cause circuit board flexure that can lead to cracking at the substrate-to-ball interface or at the ball-to-package interface. Underfills protect CSP solder ball connections by locally stiffening the assembly, thus reducing the strain related to board flexure. In these cases the CTE is not as critical parameter as Modulus (see Section 12).

When determining the appropriate board level adhesive for product use, material coverage type as well as appropriate material properties should be considered. Material coverage will be dictated by necessary enhancement sought for product implementation and Figure 4-2 illustrates different coverage types.

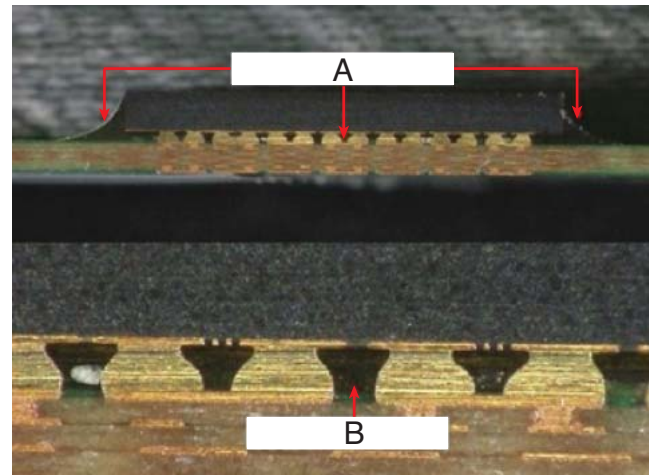


Figure 4-1 Both the Flip-Chip and CSP Underfill in a Flip-Chip CSP Soldered to a PCA
A. Component Level Underfill
B. Board Level Underfill

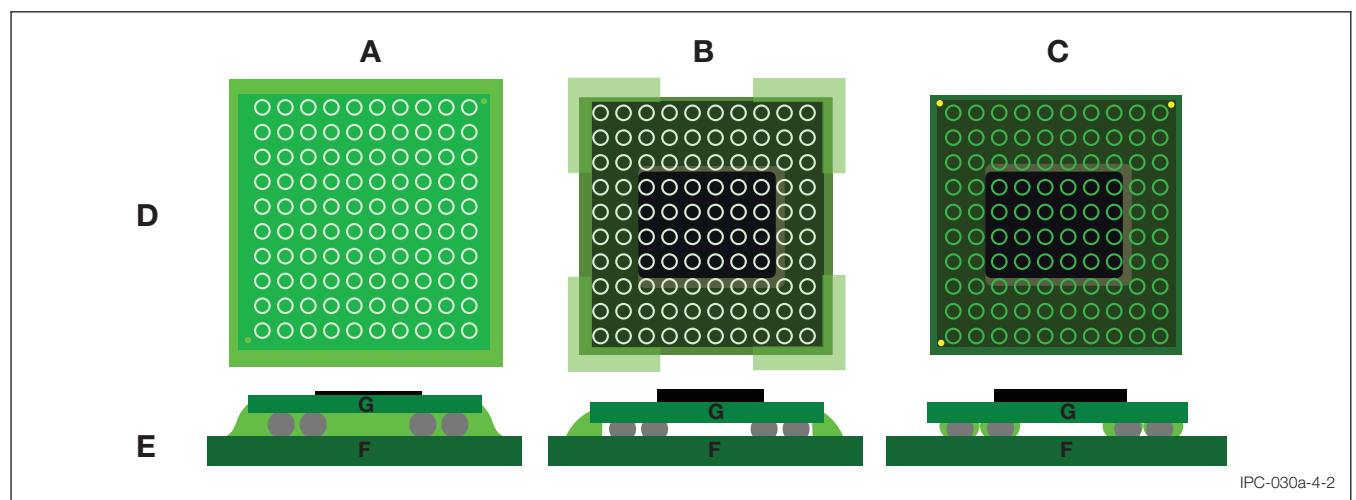


Figure 4-2 Different Material Coverage Types for Top and X-Sec View (Underfill, Corner Glue, Epoxy Flux)

A. Underfill **C. Epoxy Flux** **E. Cross-Section** **G. Package**
B. Corner Glue **D. Top View** **F. Board**



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Table 4-1 provides some guidelines for coverage selection as well as the appropriate material properties required for addressing the desired reliability need. In all cases a careful review of the physical properties and product testing with board level adhesives would need to be conducted to confirm the reliability enhancement has been achieved.

Table 4-1 Guidelines for Evaluation

Reliability Need	Full Underfill Coverage	Edge/Corner Bond or Glue Coverage	Epoxy Flux Coverage	Relevant Physical Properties of Adhesive to Address Reliability Need
Thermal Cycling	Yes	Not typical; only a localized benefit can be achieved	Not typical; limited benefit due to low material coverage	T _g , CTE, Modulus
Drop or Shock	Yes	Yes	Yes	Modulus, Adhesion
Bend or Twist	Yes	Yes	Yes	Modulus, Adhesion
Fluid/Gas Protection	Yes	No	No	Adhesion, Chemical Resistance
Vibration	Yes	Yes	No	Modulus, Adhesion

4.2 Types of Underfill Underfills are typically two-part pre-mixed and frozen epoxy systems (see Figure 4-3). These epoxy systems may contain inorganic particles to modify the physical properties of the system. These inorganic particles are called fillers. See 6.1 for more information on filler systems.

4.2.1 Capillary Underfill These low viscosity liquids are designed to flow under a component by capillary action, wetting to the component and substrate surfaces and encapsulating the solder joints. Underfills designed for assembly-level flip chips generally cure in five minutes or less to form a hard seal with high adhesion to both the component (flip chip or CSP) and the board - those types of underfills are typically called snap-cure underfills. Faulty or skewed components must be detected prior to underfill cure, since capillary flow underfills are typically permanent and even in the case of reworkable underfills reworking a part with adhesive has yield and time impacts.

Underfill is applied close to the edge of a flip chip or CSP to enable capillary forces to encapsulate the gap between the component and the board. Dispensing of capillary underfill materials requires specialized equipment to achieve the accuracy and precision required for high volume assembly (see Figure 4-4). At minimum, the dispenser must reproducibly position successive assemblies and apply a pre-determined volume or weight of underfill to the edge of the component. Heating the substrate is a common secondary requirement that accelerates capillary flow, and minimizes voiding. Cure is usually accomplished in belt-style reflow or batch curing ovens.

4.2.2 Fluxing (No-Flow) Encapsulant Fluxing encapsulant can be applied in different ways. Two common methods are dispensing directly onto the board prior to component placement or the component can be dipped into the fluxing material and then placed onto the board. A fluxing function incorporated into the underfill combines the component attachment, soldering, and underfill cure processes thus improving throughput and cost by decreasing the number of manufacturing steps and decreasing cost by a reduction in floor space.

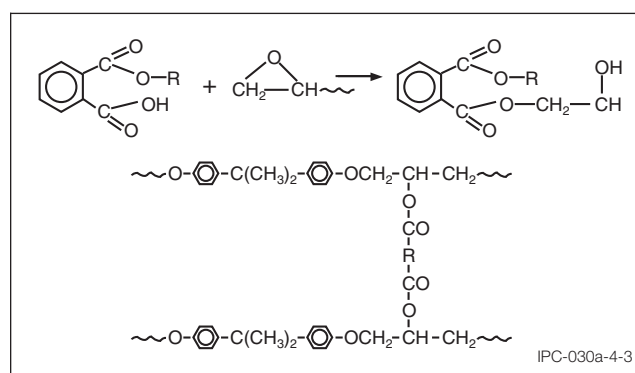


Figure 4-3 Example of Epoxy Chemical Reaction

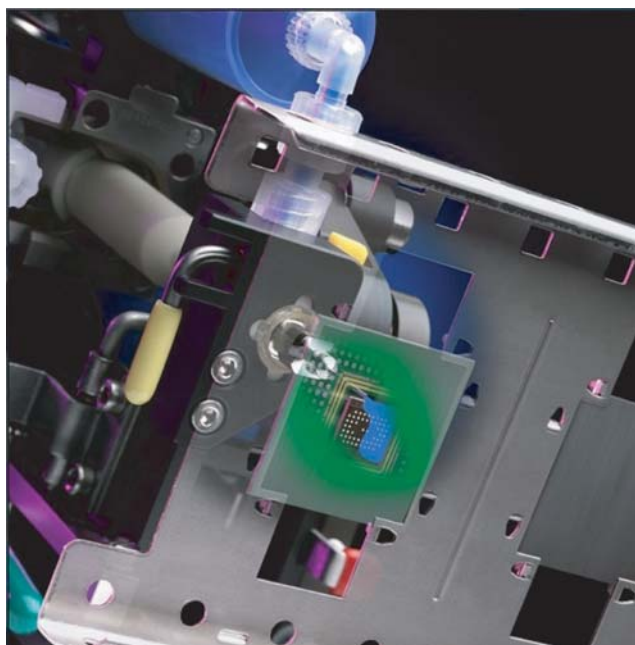


Figure 4-4 Image of Needle Dispensing of an Underfill (Bottom Side View)

Fluxing underfill is applied directly to the attachment site of the board prior to component placement. The flip chip BGA (FCBGA) or CSP is then placed into the underfill (see Figure 4-5). During reflow, the underfill acts as the flux, enabling interconnect formation and self-centering prior to curing of the underfill. Ideally, underfill cure is completed in the reflow oven. Otherwise, subsequent reflow or deliberate heat treatment is required to complete underfill cure.

Fluxing underfills are different from capillary flow materials in several ways. Viscosities are typically much higher than that of capillary underfills. The inorganic fillers used to modify the properties of capillary underfill systems cannot be used in no-flow systems since the inorganic filler would interfere with the electrical connection between the bumps and the pads. Therefore, no-flow systems typically have higher CTE than capillary underfill systems.

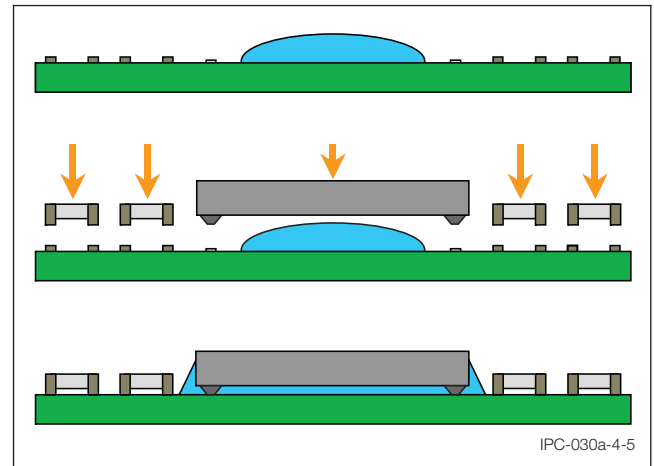


Figure 4-5 Fluxing Underfill Process

After the underfill and reflow processes, the additives that provide the fluxing function are inert and should not compromise electrical reliability with proper process conditions. If there is concern for a specific formulation and processing condition, testing can be performed using industry standard SIR/ECM methods, both IPC (IPC-TM-650, TM 2.6.3, Surface Insulation Resistance, Fluxes) and Telcordia (GR-78-CORE, Generic Requirements for the Physical Design and Manufacture of Telecommunications Products and Equipment).

4.2.3 Removable/Reworkable Underfill Occasionally, malfunctioning FCBGA or CSP components are discovered in the factory or in the field. Conventional underfills are not reworkable once cured without destroying the substrate and/or pads, requiring that a malfunctioning assembly be discarded, sometimes at considerable cost. The use of reworkable/removable underfill enables repair of the assembly after underfill dispense and cure.

Reworkable underfill is typically dispensed and processed similar to other underfills (capillary or fluxing). Different formulation characteristics enable them to soften or degrade when sufficiently heated. The assembly repair process is similar to that of other solder surface mount technology (SMT) components with the exception of extra steps or extra time required to remove residual underfill before and after component removal.

4.2.4 Cornerbond Adhesive (Dispensed or Placed Prior to Reflow Process) Another class of adhesives used for enhancing reliability is placed only along the edges of the component and can be cured during the reflow process. Due to the close proximity of the printed solder paste and the edge of the component, this process has limited use and is dependent on product layout design as well as placement accuracy for both the part and the adhesive. The implementation challenges for pre-reflow glue have led to other adhesives that are applied and cured after the SMT process.

Figure 4-6 is an example of the process used for reflow cured cornerbond underfills. The cornerbond material must not cure until the solder paste and solder ball wet and joint formation has completed.

4.2.5 Corner Glue/Corner Tack Underfills (Applied After SMT Reflow) Very similar to the corner bond materials, this class of adhesive is only applied along the perimeter of the component needing reliability enhancement. The material is applied after the SMT reflow process and can be cured via a thermal process in an oven or using UV light.

Figure 4-7 illustrates a thermally cured corner glue/corner tack on the left and on the right a UV-cured corner glue/corner tack material.