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YOUR QUARTERLY LOOK INSIDE SEMICONDUCTOR TECHNOLOGY

Transfer Molding

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In this month's Feature Article, we continue our series on Transfer Molding. Transfer Molding is one of the more common steps in semiconductor packaging, and provides protection for the sensitive semiconductor components and packaging interconnect. In this article, we will discuss mold compound properties.

Let's begin by listing the key epoxy resin mold compound properties. We group them into three categories: physical, electrical, and other. In the physical category, the key properties are thermal expansion, thermal conductivity, glass transition temperature, flexural modulus and flexural strength, and tensile strength. In the electrical category, the key properties are electrical resistance and resistivity, and dielectric constant (also known as permittivity) and dielectric strength. In the other category, the key properties are moisture resistance, fluidic properties, and optical properties. We will discuss several of these properties in more detail in this newsletter and following newsletters.

WHAT'S INSIDE?

Want to take control of your learning? See page 8

Upcoming Courses:

- Failure and Yield Analysis
- Semiconductor Reliability and Product Qualification
- Semiconductor Technology Overview
- IC Packaging Technology
- Wafer Fab Processing

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First, we will discuss one of the most important physical properties – thermal expansion. Thermal expansion is governed by a material's Coefficient of Thermal Expansion, or CTE. When materials have large mismatches in CTE values, such as between the die and the epoxy resin mold compound, mechanical stress occurs. This can result in the delamination of the epoxy resin mold compound from the chip or the leadframe; cracking of the epoxy resin mold compound, cracking of the passivation layer, or even cracking of the device itself. In other instances, package warpage and coplanarity problems can result. We show some example CTE values associated with the package materials in Figure 1.

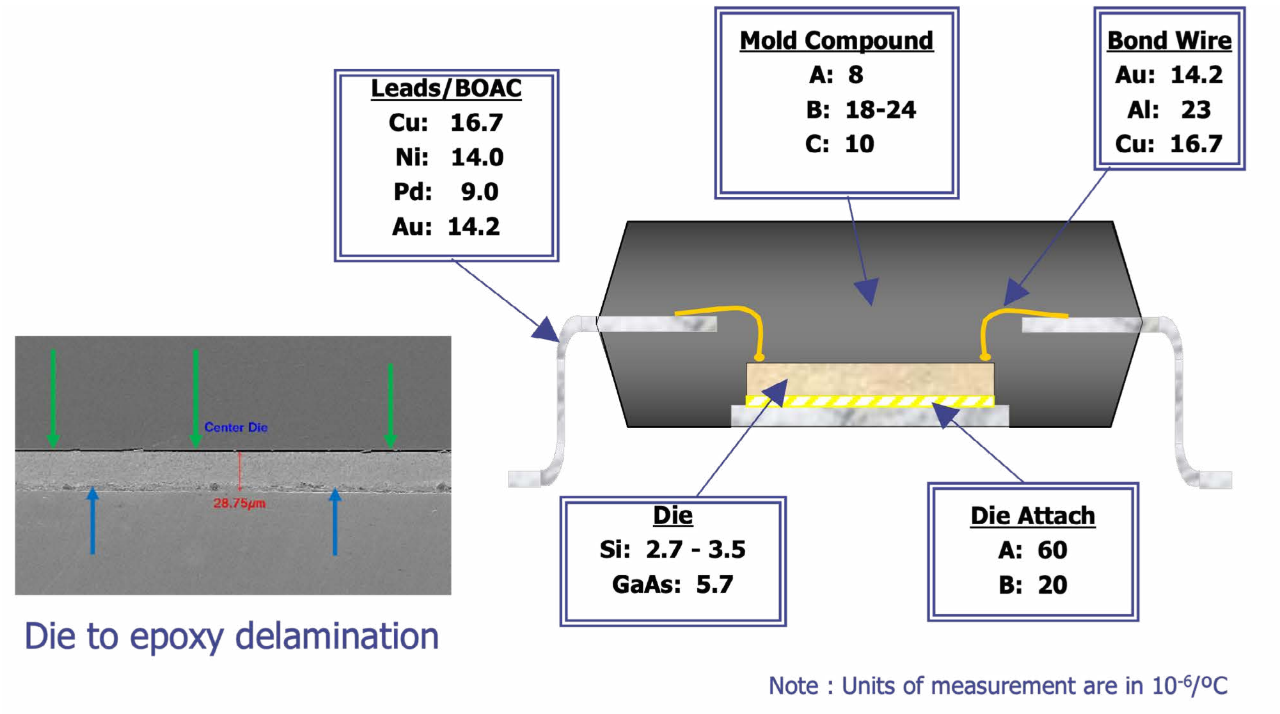

Figure 1- Example of CTEs in a Leaded Surface Mount Package.

The main factors that govern the thermal expansion properties are the epoxy resin mold compound and the filler material. Since filler material is typically silica, and since silica has a low CTE value, we can tailor the CTE of the epoxy resin mold compound by adjusting the amount of filler material in the epoxy resin mold compound. A higher weight percentage of filler particles will produce a lower CTE value for the epoxy resin mold compound. The CTE is further impacted by the shape of the filler particles. The more spherically shaped the filler particles are, the lower the CTE value will be. Filler particles also raise the thermal conductivity, which in most cases is a good thing.

Figure 2 shows both CTE and Young's Modulus, a measure of hardness, as a function of the percentage of filler particles. The CTE decreases almost linearly as one adds filler particles into the epoxy resin mold compound. However, Young's Modulus increases as one adds filler particles. If Young's Modulus is too high, then the cavities may not fill completely. Therefore, process engineers need to optimize the CTE properties.

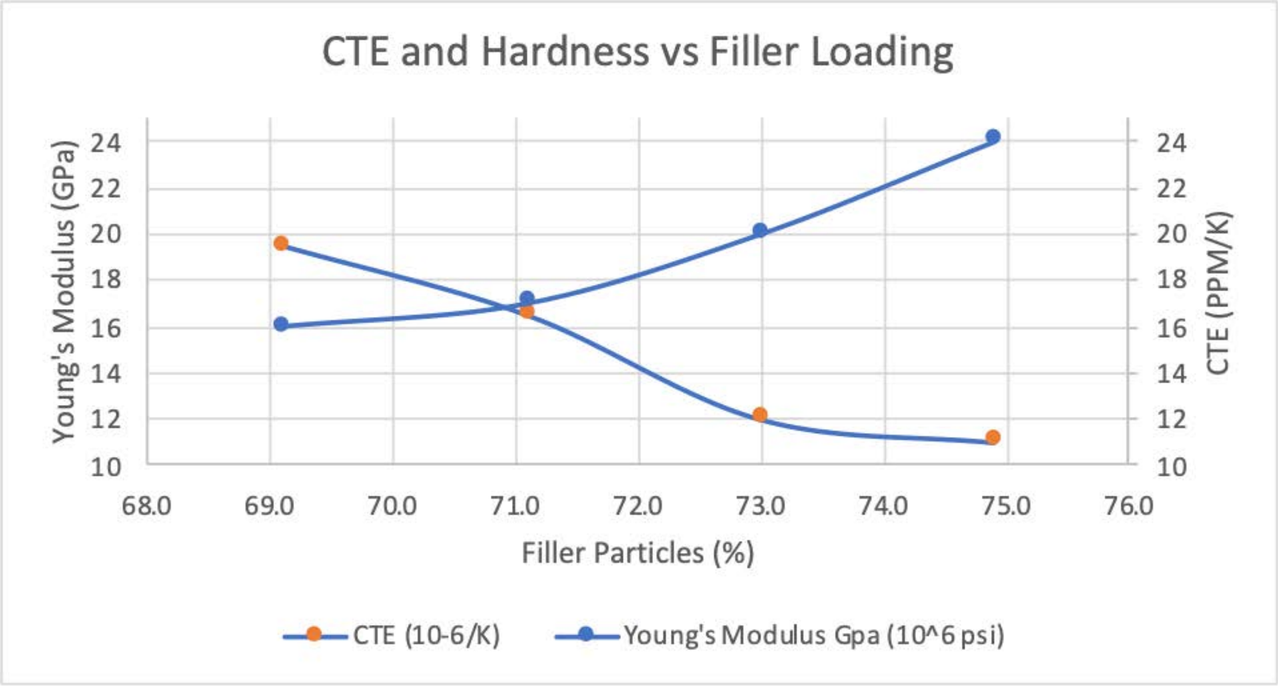

Figure 2- Coefficient of Thermal Expansion and Young's Modulus below the glass transition temperature at different levels of filler loading.

A second important physical property is thermal conductivity. The rate of heat transfer is a function of the area of the material, the thickness of the material, the temperature difference from one side of the material to the other, and the thermal diffusivity. Polymer materials like epoxy resin mold compounds have a lower thermal conductivity than metals or ceramics. Since epoxy resin mold compounds have a significant amount of polymeric material, their thermal conductivity is not very good.

A third important physical property of an epoxy resin mold compound is its glass transition temperature. At low temperatures, the material acts like a solid glass. At a higher temperature, it becomes less rigid. At still higher temperatures the material acts like it is in a liquid rubbery state. This change occurs at the glass transition temperature, or Tg. Also, the CTE goes through a dramatic change at the glass transition temperature. Due to these significant changes, the operating temperature of the packaged semiconductor chip should not approach the glass transition temperature. Epoxy resin mold compounds reach their glass transition temperature between about 160-175ºC, so most plastic packaged ICs are limited to a maximum operating temperature of about 125ºC and a maximum storage temperature of about 150ºC. The glass transition temperature of unprocessed epoxy resin mold compound is around 40-50ºC, and is, therefore, solid at room temperature. The epoxy resin mold compound becomes liquid as it heats during the transfer molding process. As the epoxy resin mold compound heats further, the polymerization process causes the glass transition temperature to increase. The post mold cure brings the glass transition temperature to a final value.

Figure 3 shows the glass transition temperature as a function of the post mold cure time. The glass transition temperature rises quickly within the first hour of the post mold cure, and then levels off at around 170ºC for most common epoxy resin mold compound formulations.

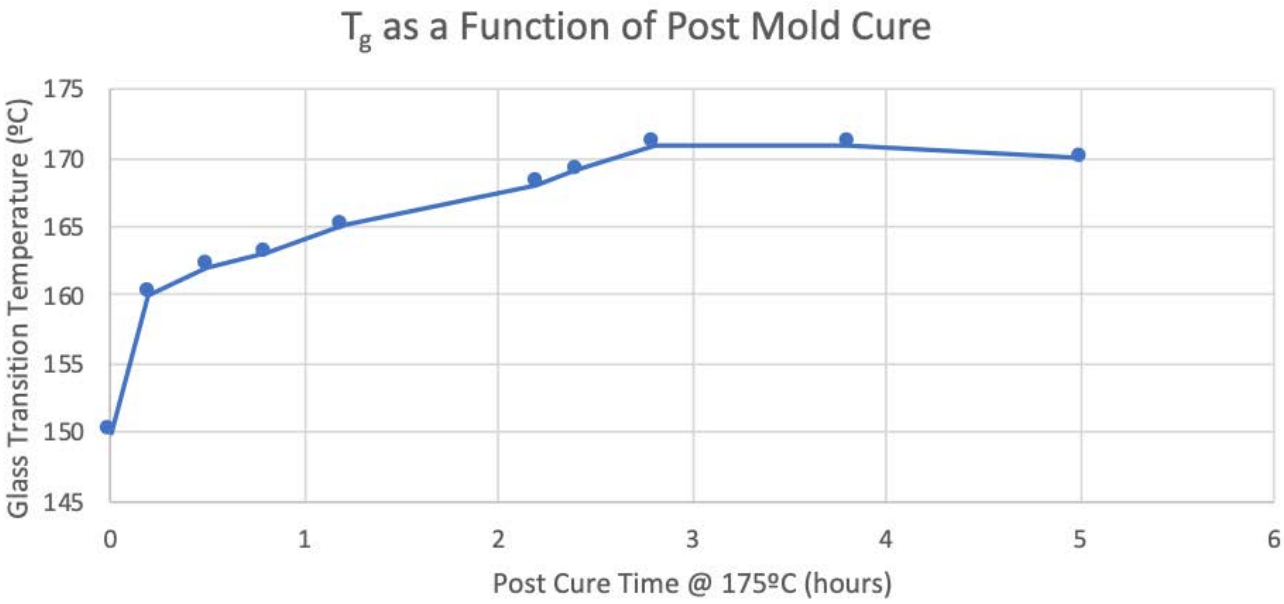

Figure 3- Glass transition temperature as a function of the post mold cure time for an example epoxy mold compound.

To summarize, the glass transition temperature is the temperature at which an epoxy resin mold compound moves from a rigid, brittle state to a "rubbery" state and the CTE starts to increase. The CTE is the measure, or rate, of dimensional change of a solid material for a given increase in temperature expressed as ppm/ºC. CTE is typically specified between two temperature ranges, usually below and above the Tg. The CTE below Tg is sometimes referred to as "Alpha 1" and the CTE above Tg as "Alpha 2". One can use Thermal Mechanical Analysis, or TMA, data to determine the glass transition temperature. The analyst generates a curve and then draws tangents to that curve, like we show in Figure 4. Where the tangents intersect indicates the glass transition temperature on the temperature axis. Another material property in addition to the Tg that is determined from TMA measurements is the CTE. The CTE is the slope of the curve and is higher above the Tg (glassy state) than below the Tg (rubbery state). A high value of CTE above the Tg can create excessive stress in finished packages. Higher Tg materials will experience lower CTE during the same environmental excursions to high temperatures.

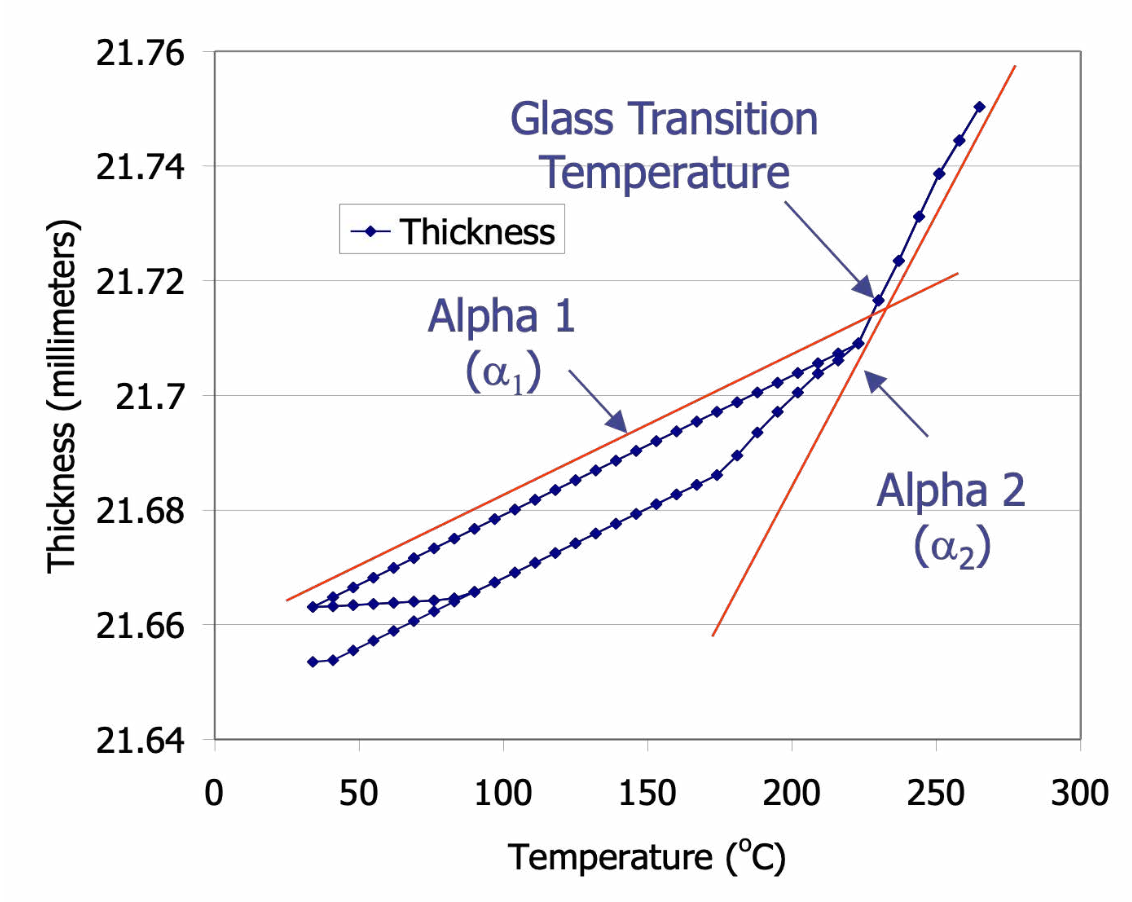

Figure 4- Epoxy mold compound thickness as a function of temperature, measured using TMA.

Another important physical property of epoxy resin mold compounds is flexural modulus. The flexural modulus is the ratio of stress (the force applied over a certain area) to strain (the change in length over the original length) experienced by a material during bending where tension and compression occur on opposite sides of the material. The strain is measured in terms of the deflection, or bending of a sample. The flexural modulus does not distinguish between plastic deformation or elastic deformation. Plastic deformation is a type of deformation where the object does not return to its original shape, whereas elastic deformation is a type of deformation where the object does return to its original shape. It is simply a measure of relative stiffness. Figure 5 shows a three-point bend test, which tends to better simulate conditions one might find during use conditions in the field.

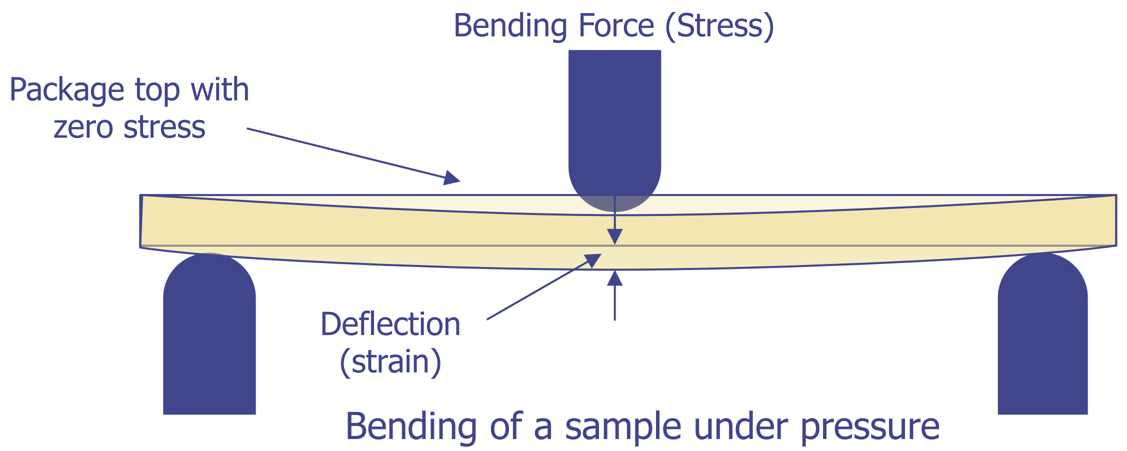

Figure 5- Diagram showing the three-point bend test.

Lastly, another important physical property is flexural strength. The flexural strength of a material is typically defined as the maximum bending force the material can survive before it fractures. For a packaged IC, this will depend on the package dimensions. Samples for flexural strength are measured according to ASTM Standard D790-71.

In next month's Feature Article, we will continue our discussion of transfer molding by focusing on the electrical properties of mold compound properties.

Technical Tidbit: Probe Tips for Reliability and Failure Analysis

This month's Technical Tidbit covers the probe tips used for reliability and failure analysis applications.

There are several types of probe materials used for reliability applications. The most common probes are tungsten-based. Tungsten is a hard material that withstands numerous contacts with bond pads. Today, manufacturers are moving toward tungsten alloys. The most popular is tungsten-rhenium. It is less brittle than pure tungsten, giving it better properties for overdrive. It still has the hardness necessary for breaking oxide barriers on a probe pad to make good contact. It also has better wear resistance than pure tungsten and works well for high frequency measurements. Another common probe material is beryllium-copper. Beryllium-copper has a lower contact resistance, making it better for high power measurements where resistance can cause heating. They are also useful for measurements that require resolving small changes in resistance, like electromigration testing. Since the tips are softer, they require higher overdrive to make good contact for a long period of time. Therefore, they do not work well for burn-in or life test applications. Another common probe material is a fiber probe tip. Sometimes called cat whisker probes, these are useful in applications where one must avoid damage to the circuit. The downside of fiber probes is their high resistance. Table 1 shows some basic probe tips and their uses.

Style	Tip diameter	Point radius (microns)	Point taper length	Material	Attributes
Fine tip	.005"	.35	.020"	Shank: nickel Tip: tungsten	Bendable, cat whisker, flexible tip and shaft
Heavy Duty Needle	.02"	0.5-200	0.06"-0.08"	Tungsten	Larger targets
Small Target with "C" bend	.005"	0.35	0.025"	Dumet (CuFe)	Bendable, cat whisker
High Temperature	.020"	5	.075"	Tungsten Carbide	For cutting
Small Targets	.001"	.5-10	.001"-.004"	Nickel	Bendable, cat whisker, super flexible
Low Contact Resistance	.020"	1.0	.135"	Beryllium Copper	For low contact resistance
High Compliance	.005"	.35	.020"	Shank: Nickel Tip: Tungsten	Fine tip, very flexible, prevents "fishhooking"
Very Small Targets	.003"	.1	.008"-.013"	Shank: Nickel Tip: Tungsten	Bendable cat whisker, sharpest probe

Table 1- Types of probe tips and their applications.

To purchase individual probes, there are several possibilities. The probe station manufacturers provide a number of different probe tips and configurations, as well as companies that specialize in probe needles, like: Pacific Instruments, MB Electronique, Nauganeedles, Advanced Probing Systems, and many others.

Ask The Experts

Q: I have a few questions regarding ABF. Is ABF always used for coreless substrates or can it be used with a core as well? Also, is ABF generally used as a low warpage substrate in the industry? And finally, does the core influence the warpage properties of the substrate by lowering warpage?

A: First, as a background comment, ABF stands for Ajinomoto Build-Up Film. ABF can be used either by itself, or as a series of layers on a core. ABF is definitely not a "low warpage" solution when it is used by itself. The thin-film metal and polymer layers in the ABF are not rigid, and do not have CTE values that match well. However, when ABF is used with a rigid substrate, the combination of the two can be used to create a low-warpage substrate. To answer the third question "does the core influence the warpage properties of the substrate by lowering warpage?", the short answer is most definitely. The type of core material, its thickness, and size all affect the warpage. Generally, harder materials like glass or silicon will lead to lower warpage values for the substrate, whereas softer core materials, like polyimide, benzocyclobutene, or standard printed circuit board material (FR-4), will lead to higher warpage values for the substrate.

Course Spotlight: SEMICONDUCTOR RELIABILITY AND PRODUCT QUALIFICATION

OVERVIEW

Product reliability and qualification continues to evolve with the electronics industry. New electronics applications require new approaches to reliability and qualification. In the past, reliability meant discovering, characterizing and modeling failure mechanisms, and determining their impact on the reliability of the circuit. Today, reliability can involve tradeoffs between performance and reliability; assessing the impact of new materials; dealing with limited margins, and other factors. This requires information on subjects like: statistics, testing, technology, processing, materials science, chemistry, and customer expectations. While customers expect high reliability levels, incorrect testing, calculations, and qualification procedures can severely impact reliability. ***Semiconductor Reliability and Product Qualification*** is a 4-day course that offers detailed instruction on a variety of subjects pertaining to semiconductor reliability and qualification. This course is designed for every manager, engineer, and technician concerned with reliability in the semiconductor field, qualifying semiconductor components, or supplying tools to the industry.

Participants will learn to develop the skills to determine what failure mechanisms might occur, and how to test for them, develop models for them, and eliminate them from the product. This skill building series is divided into four segments:

1. **Overview of Reliability and Statistics.** Participants will learn the fundamentals of statistics, sample sizes, distributions and their parameters.

2. **Failure Mechanisms.** Participants will learn the nature and manifestation of a variety of failure mechanisms that can occur both at the die and at the package level. These include: time-dependent dielectric breakdown, hot carrier degradation, electromigration, stress-induced voiding, moisture, corrosion, contamination, thermomechanical effects, interfacial fatigue, and others.

3. **Qualification Principles.** Participants will learn how test structures can be designed to help test for a particular failure mechanism.

4. **Test Strategies.** Participants will learn about the JEDEC test standards, how to design screening tests, and how to perform burn-in testing effectively.

COURSE OBJECTIVES

1. This course will provide participants with an in-depth understanding of the failure mechanisms, test structures, equipment, and testing methods used to achieve today's high reliability components.

2. Participants will be able to gather data, determine how best to plot the data and make inferences from that data.

3. This course will identify the major failure mechanisms, explain how they are observed, how they are modeled, and how they are eliminated.

4. This course will offer a variety of video demonstrations of analysis techniques, so the participants can get an understanding of the types of results they might expect to see with their equipment.

5. Participants will be able to identify the steps and create a basic qualification process for semiconductor devices.

6. Participants will be able to knowledgeably implement screens that are appropriate to assure the reliability of a component.

7. Participants will be able to identify appropriate tools to purchase when starting or expanding a laboratory.

COURSE OUTLINE

DAY 1

1. Introduction to Reliability
   a. Basic Concepts
   b. Definitions
   c. Historical Information

2. Statistics and Distributions
   a. Basic Statistics
   b. Distributions (Normal, Lognormal, Exponent, Weibull)
   c. Which Distribution Should I Use?
   d. Acceleration
   e. Number of Failures

DAY 2

3. Overview of Die-Level Failure Mechanisms
   a. Time Dependent Dielectric Breakdown
   b. Hot Carrier Damage
   c. Bias Temperature Instability
   d. Electromigration
   e. Stress Induced Voiding
   f. BEOL Dielectric Reliability

4. Package Level Mechanisms
   a. Moisture/Corrosion
      i. Failure Mechanisms
      ii. Models for Humidity
      iii. T_{ja} Considerations
      iv. Static and Periodic stresses
      v. Exercises
   b. Thermo-Mechanical Stress
      i. Models
      ii. Failure Mechanisms
   c. Chip-Package Interactions
      i. Low-K fracture
   d. Through Silicon Via Reliability
   e. Thermal Degradation/Oxidation

DAY 3

5. Board Level
   a. Package Attach (Solder) Reliability
      i. Creep/Sheer/Strain
      ii. Lead-Free Issues
      iii. Electromigration/Thermomigration
      iv. MSL Testing
   b. Board Level Reliability Mechanisms
      i. Interposer
      ii. Substrate

6. Use Condition Failure Mechanisms
   a. Electrical Overstress/ESD
   b. Radiation Effects

7. Test Structures and Test Equipment

8. Developing Screens, Stress Tests, and Life Tests
   a. Burn-In
   b. Life Testing
   c. HAST
   d. JEDEC-based Tests
   e. Exercises

DAY 4

9. Calculating Chip and System Level Reliability

10. Developing a Qualification Program
    a. Process
    b. Standards-Based Qualification
    c. Knowledge-Based Qualification
    d. MIL-STD Qualification
    e. JEDEC Documents (JESD47H, JESD94, JEP148)
    f. AEC-Q100 Qualification

11. JEDEC Tests

12. Exercises and Discussion

Upcoming Courses:

Public Course Schedule:

Failure and Yield Analysis - March 25-28, 2025 (Tues.-Fri.) | San Jose, CA - $2,195

Failure and Yield Analysis - May 12-15, 2025 (Mon.-Thurs.) | Munich, Germany - $2,095 until Mon. Apr. 21

Semiconductor Reliability and Product Qualification - May 19-22, 2025 (Mon.-Thurs.) | Munich, Germany - $2,095 until Mon. Apr. 28

Semiconductor Technology Overview - June 16-17, 2025 (Mon.-Tues.) | Dubai, UAE - $1,195 until Mon. May 26

IC Packaging Technology - June 18-19, 2025 (Wed.-Thurs.) | Dubai, UAE - $1,195 until Wed. May 28

Wafer Fab Processing - June 23-26, 2025 (Mon.-Thurs.) | Dubai, UAE - $2,095 until Mon. Jun. 2

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To submit questions to the Q&A section, inquire about an article, or suggest a topic you would like to see covered, please contact Jeremy Henderson at jeremy.henderson@semitracks.com

We are always looking for ways to enhance our courses and educational materials and look forward to hearing from you!