empfasis

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The EMPF is a U.S. Navy-sponsored National Center of Excellence focused on the development, application and transfer of new electronics manufacturing technology by partnering with industry, academia and government centers and laboratories in the U.S.

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Power Distribution: Characterizing an ETO for High Power Applications

A technical challenge exists within the Naval fleet for managing and operating an electrical shipboard load in conjunction with the requirements of the propulsion/motor drive combination. An effective solution for this effort is the development of advanced power semiconductor systems that can operate to maintain the specific stability and power quality required by the load bus. Consequently, with the advancement of these devices has evolved the need for higher power testing facilities to accommodate the high-energy potentials and improved switching performance of the semiconductor packages. This is a challenge that the Naval Surface Warfare Center (NSWC), American Competitiveness Institute (ACI) and Virginia Polytechnic Institute (VPI) have teamed together to satisfy through power semiconductor characterization and a program called The Regional Electric Power Technology Integration and Leveraging Enterprise (REPTILE). The team has chosen to characterize the turn-off capabilities of the Emitter Turn-Off thyristor (ETO), from VPI, at a maximum power level of 4 megawatts (MW) and frequency of 2 kilohertz (kHz). Achieving successful characterization will demonstrate new electric power technologies and testing capabilities to the Navy and power utility applications.

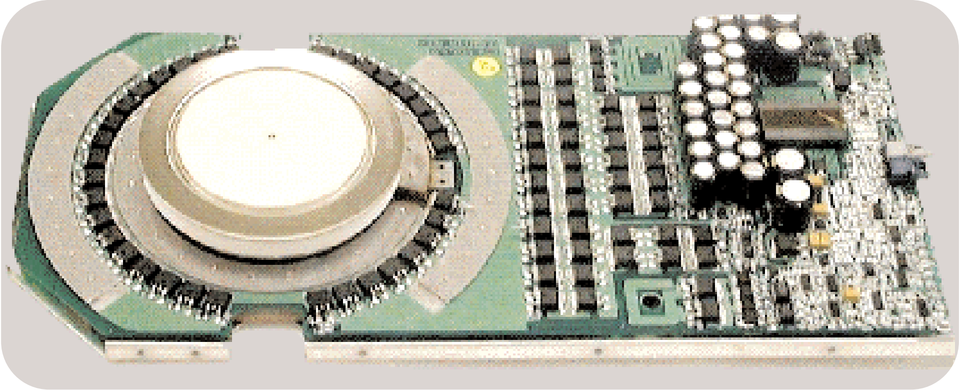

Figure 1. ETO

Power Testing

The design and development of the test system to characterize the turn-off properties of the ETO (Figure 1) is being derived through a boost converter circuit, feedback controller and appropriate heat sinks. The current ETO (see Figure 2) is stack designed with thermally and electrically conductive heat sinks for rapid cooling of the GTO and diodes during the power switching operation. This type of stacking design enables multiple ETO's and power diodes to be stacked together for various configurations and applications (i.e. phase

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Power Distribution (continued from page 1)

legs of a multi-phase inverter). Through the use of a 10-ton low temperature chiller and manifold system, a process flow loop will be established for parallel circulation of a fluid through the multi heat sink stack. Due to the sub-freezing temperature (<20^{O}F) of the process fluid, the chiller will be filled with a 35% solution of deionized water and ethylene glycol, with a resistivity above 1MV (for conductivity purposes). The large chilling capacity is required because ACI thermal calculations predict a total loss of the system to exceed 22.4KW.

Figure 2. Current power stack configuration for single ETO device

Connecting the boost circuit to the ETO stack will create the increased current/voltage needed to evaluate the switch during high power turn-off. With the use of the equipment below, discontinuous operation over a continuing time cycle will be achieved for frequency ranges between 500Hz to 2kHz.

- DC Power Supply: 900V, 300A
- DC isolated supply: 24V, 100W, isolation voltage >1kV
- AC power supply: 120VAC, 1kW
- Oscilloscope, Bandwidth = 1GHz with voltage (5kV) and current (5kA) probes
- Air cooled inductors
- High power film capacitors
- Power diodes
- Resistance load bank 112KW @900V

Device Life Testing

Discontinuous mode testing will be performed up to preferred power levels for the ETO device, but won't exceed practical levels for both the facility and future ETO based converters. Power cycling and sustained power operation will be the subtasks within the REPTILE project that derive the switching characteristics for device assessment.

ACI will employ the equipment in the EMPF Reliability and Failure Analysis Laboratory to test devices designed and produced by the ETO development team for long term reliability. The first step in any reliability-testing plan is to define the end use environment of the product once delivered to the field. ETO devices tested in Task 2 will be designed for high-power switching applications required by shipboard (IPS), motor drive and storage (ESS) systems.

Common Modes of Failure

Electronic devices can fail due to a number of causes, but ACI will inspect the environmental affects of moisture and temperature on the ETO PCB and components. The most common failure mode is due to thermomechanical fatigue, which is caused primarily by varying rates of contraction and expansion of different materials during a temperature change. Temperature cycling will be performed to accelerate this potential thermomechanical fatigue on the ETO device, and will comprise a cycle of 0^{O}C to 100^{O}C with a 20^{O}C per minute ramp rate and fifteen minutes of dwell time. This cycling process will continue for 192 hours or until 50% failure is achieved. These conditions are considered rigorous for typical utility requirements and will allow the most data to be collected in the shortest possible time frame. Thermal effects will also be determined by performing high temperature operating life (HOLT) testing to monitor the device under low operation in an oven set to a predetermined temperature. Ideally, all tests would be performed

Figure 3 - Half Bridge Converter

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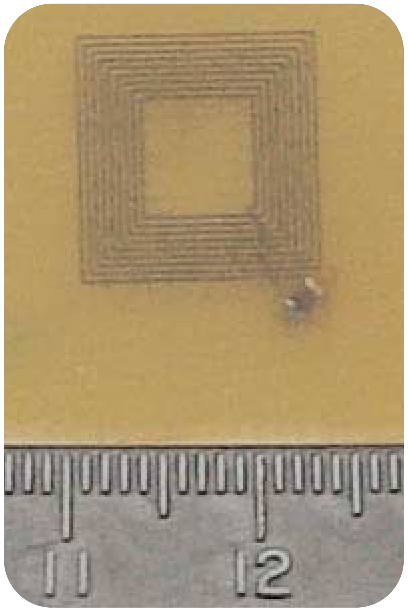
Embedded Sensors for Structural Health Monitoring

The increased use of advanced composites, in both retrofit applications and new construction, necessitates on-line process monitoring and evaluation to ensure the performance and serviceability of the composites. There are numerous non-destructive evaluation (NDE) and sensing techniques that address these needs.

NDE surface sensors, such as acoustic emission detectors, can provide much information regarding the health of a structure. However, many issues involving thick wall composites (both graphite- and glass-based), ranging from internal curing and residual stresses to the progressive evolution of internal damage (blistering, delamination, cracking), are better sensed from within the structure. An internal (embedded) sensor can determine the cure state and following mechanical behavior in situ and at points remote from the surface without affecting the integrity of the finished component.



Embedded sensors must be chemically, physically, mechanically, and structurally compatible with the host polymer matrix. When a sensor's mechanical properties differ from those of their surroundings, inclusion-matrix problems can occur. The primary mechanical issue is the Coefficient of Thermal Expansion (CTE) mismatch between the sensor and the matrix. It is desired that the CTE of the sensor be as close as possible to that of the composite to avoid cracking. CTE mismatch can also yield spurious strains and subsequent readings due to temperature rather than mechanical stresses.

Fiber optics are the predominant structural health sensor type. Optical fibers can accurately measure strain with little impact to the composite. Yet, for structural health monitoring each sensor must be "wired" to a central processing computer. Therefore, a discrete sensor network has a significant advantage over the fiber optic network. In addition, for the optical fiber network, damage or malfunctions that occur at one location will effect the entire network. This may contribute to a negative effect on laminate mechanical strength associated with a large network of fiber optic sensors. Other drawbacks are fragility of the optical fiber, cost of equipment and sensors, and the need to provide egress and ingress.

Strain gauges are another form of embedded sensors capable of measuring the strain behavior of a composite. A properly designed and installed strain gauge can be benign to the composite. A drawback is the relatively large sensor area as compared to other sensor types. Finally, like the fiber optic sensors, the strain gauges must be wired to a central processor.

From the above, a highly desirable feature is remote monitoring, without a requirement for a physical connection to the outside world. Some Micro Electro Mechanical Systems, (MEMS) exhibit this quality. A MEMS consists of a miniaturized power source, signal-processing electronics, and telemetry needed to transmit the strain data, all on a substrate. The substrate is typically silicon. A significant disadvantage is the stress mismatch between the hard silicon and a typical polymer composite matrix. In operation, this results in an unfavorable stress distribution. Additionally, since a MEMS device is an active component rather than a passive component, it requires power. If the source is a battery, then the lifetime of the MEMS is limited to the battery life. Additional issues with batteries include limited space and toxic risks.

If, as part of a MEMS, an attached antenna receives power, the properties of the antenna may not be compatible with the host composite and will require two radio systems to transmit and receive, further complicating the system and increasing costs.

Magneto-elastic based sensors are used to measure many properties including strain. Their advantages include low material costs and strain information is transmitted without direct electrical connections to the sensor. The detection system requires two coils in addition to the sensor itself.

Example

A customer had a need for a strain detection system that provides a new tool to monitor defects in advanced composites. The American Competitiveness Institute (ACI) proposed a solution to develop and demonstrate a remotely addressed strain detection system for composite materials. The system consists of a passive embedded sensor and a handheld detector that may be stationary or portable, operating on the principle of an LC tank circuit. This system applied well known principles of an

continued on page 4

Embedded Sensors (continued from page 3)

electronic circuit with carefully balanced forces of inductance and capacitance, applied in a novel manner, to provide the following advantages:

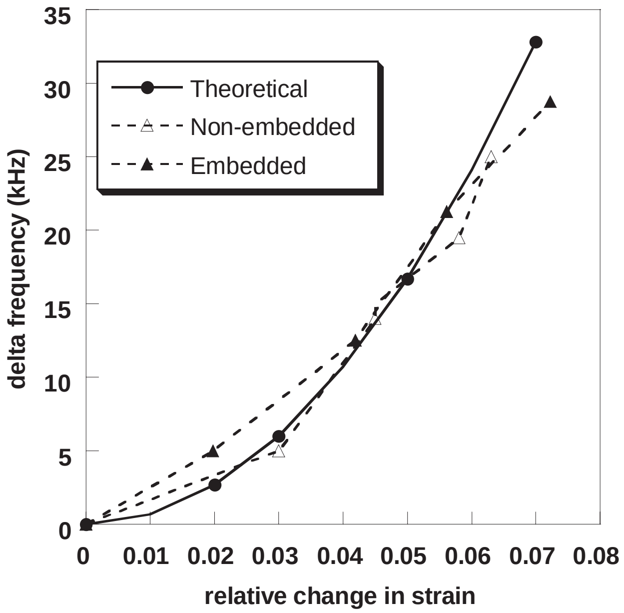
- As envisioned, the passive embedded sensor is affordable.
- The response of the embedded sensor is highly reproducible, based on the inherent properties of its fabrication process.
- The sensor can be tuned for excellent sensitivity in a variety of configurations and applications.
- The embedding process does not impact the mechanical properties of the host.
- Used in composite applications, internal composite strain may be assessed remotely at any stage of cure, fabrication and application.

Borrowing from the operating principle of the anti-theft tag, ACI, working with the Army, has pursued a smart sensor technology that combines all the above desired characteristics with low fabrication and maintenance costs. The anti-theft system sensor electro-magnetically resonates at a predetermined frequency that identifies the active tag. The ACI sensor is an inductor-capacitor (LC) tank circuit in planar form. When the composite is mechanically strained the implanted tank circuit is also strained, changing the dimensions of either the capacitor or inductor, causing the resonant frequency of an unstrained tank circuit to be shifted. This shift is proportional to the imposed strain. The frequency shift can be maximized through careful selection of sensor dimensions, material, geometry, and shape.

The likely inductor geometry is spiral. The change in inductance takes place because strain shifts the distance between adjacent turns and the flux captured, all of which affect the inductance. Capacitors can exist in two preferred embodiments. The first is the parallel plate capacitor. Under strain, the changing separation between top and bottom plates alters the capacitance. The other is the interdigitated capacitor. Under strain, the spacing between sets of fingers changes which alters the capacitance.

ACI sensors can potentially be generated using any of several repeatable, inexpensive methods. One potential method uses photolithography to form sensors. Another uses the screen-printing process, and yet another uses wire wound forms.

Detection is carried out using a gate dip meter. This device allows for the measurement of the resonant frequency and impedance of tuned circuits, in ACI's case, the LC tank circuit. Detection takes place with a highly maneuverable sensing coil placed close to, but not necessarily touching, the composite surface. At the resonant frequency of the embedded tank circuit, energy is absorbed by the tank circuit; thus reducing the energy present within the dip meter. By sweeping across a frequency band and measuring the frequency of maximum energy loss, the shifted resonant frequency is obtained and the strain derived.



Detection is also carried out with a detector coil attached to a frequency variable impedance analyzer. The sensor, in close proximity to the detector coil, acts as the second arm of a transformer and changes the impedance relative to the case of a single detector coil. In the presence of strain either the inductance or capacitance changes shape and value. This change also alters the total impedance due to the presence of the unstrained sensor and this relative change can be correlated to strain.

Conclusion

A number of embedded sensor technologies and their application to strain detection have been explored. The optimum technique is a novel remote query, passive, resonant circuit, inductively coupled strain sensor. The operating principle is that strain in the host is coupled to the embedded LC sensor distorting either the capacitor or inductor. As both properties vary with dimension, their capacitance and inductance are also varied. This changes the resonant frequency from a different strained or relaxed state. This is then repeatably and accurately detected using one of two detection techniques.

Automated Test Equipment - Electrical Inspections

Because of the increasing demand to cut costs without sacrificing quality, process control is essential on any manufacturing line. There are several process control tools available to the electronics manufacturing industry, which include automated inspections that happen during the assembly process.

The primary use of Automated Test Equipment (ATE) is to detect defects that occur in the assembly process of PCBs. The inspections range from visual (e.g. x-ray), material (e.g. paste) and electrical. The following electrical inspections will be briefly examined: In-Circuit Test (ICT), Functional Test (FT), and Flying Probe Test (FPT).

In-Circuit Test

ICT's typically place a PCB onto a fixture with crown tip probes that are positioned at the test points. A functional test of the board is usually performed revealing any anomalies. This process generally occurs at the end of the manufacturing line but prior to placement in an assembled unit. ICT detects failures, but does not specifically reveal the source.

Functional Test

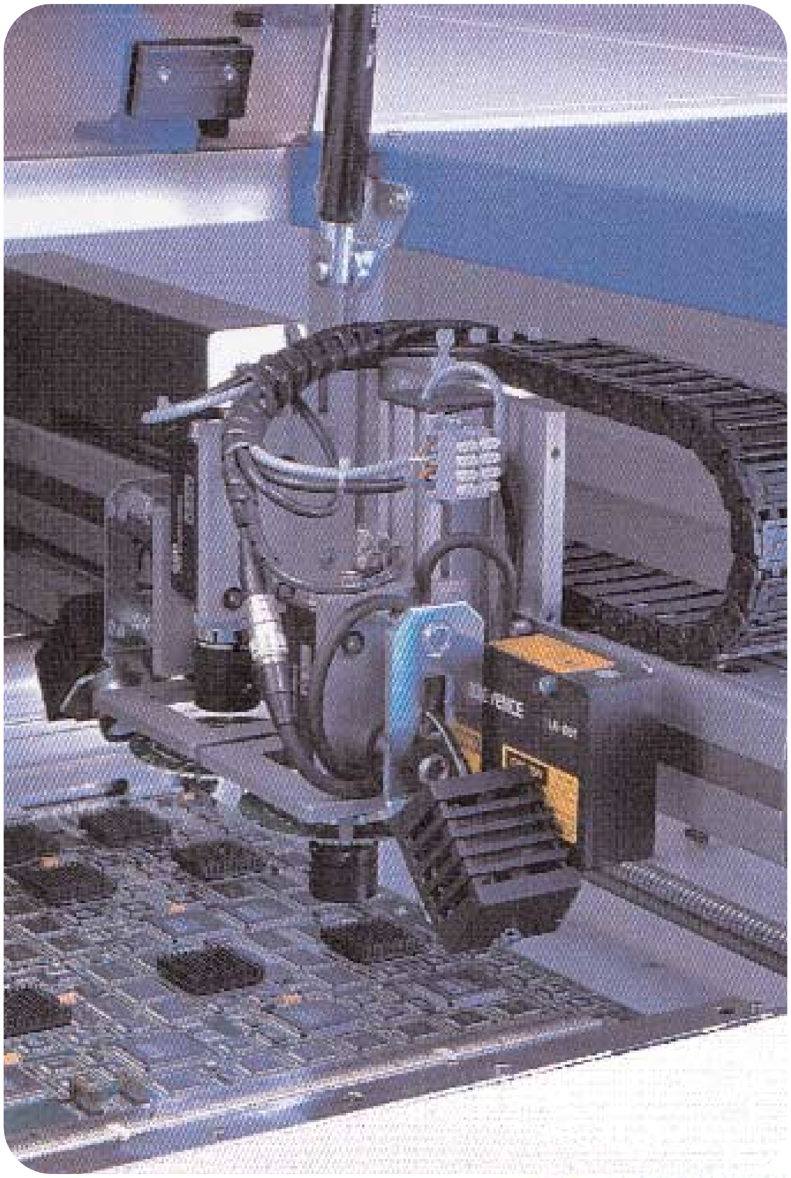
Like ICTs, FTs test a completely assembled PCB and identify functioning vs. non-functioning areas. The only difference is the method. Each PCB is plugged into an FT unit to check for functioning. This process also requires an additional step to detect any defects with the actual assembly of the PCB.

Though these processes are a part of manufacturing, they may not necessarily pinpoint problems in the assembly process. One of the effective ways to improve control is the inspection of the PCB during or at the end of the assembly line. During the assembly, line inspections are visual rather than electrical. Electrical tests occur at the end of the assembly line after the PCB has gone through the soldering processes.

Flying Probe Test

Inspection at end stage will determine the quality of the assembly. The machines used to implement the test are called Flying Probe Testers (FPTs). As it may suggest these machines have a probe that moves about the PCB and makes contact to a lead and/or pad. The probing is generally done on one side at a time. FPTs are non-functional testers which means that the PCB is not powered up to measure any values or signals at test points. FPT's can check for resistance, capacitance, opens and shorts. Additionally, as with any inspections, a golden board is programmed into the machine for comparison purposes. Resistor and capacitor values are checked against the golden board to insure properly placed parts. Opens and shorts indicate any soldering issues on the PCBs, while resistance can indicate the integrity of the solder joint to a lead.

These electrical inspections done by ATEs help the process control of the assembly and may indicate necessary adjustments to paste printing, component placement and reflow processes. It also is a step in the assembly which improves the overall functional testing of the PCB. Using ATEs for electrical inspections combined with visual inspections and standard process control, improves the overall quality of the unit and reduces the cost of assembling PCBs.



Power Distribution (continued from page 2)

until 50% of the devices under test have failed. This will allow models and Weibel plots to be constructed that can aid in lifetime predictions (such as MTBF) and the design for reliability cycle.

If a device fails, a full physics of failure analysis will be performed to determine how and why the device failed. Expectations are for most of the failures (if exist) to be a result of thermomechanical stress induced during the thermal cycling process. Knowledge gained through reliability analysis will be applied towards improving the manufacturability of future ETO devices (Gen. 4).

Future ETO-Based REPTILE Applications

With new device technologies, the field of high power electronics can realize dramatic improvements in the performance of systems for utility applications, motor drives and shipboard operations. The performance of high-power converters can be improved dramatically in terms of dynamics, efficiency, size, and protection, due to the improved switching speed and modifications to the typical topology. DC/DC converters and three-phase inverters are typical applications on the horizon for newly developed ETO devices, and hold great promise as standard building blocks for almost all-high power topologies. Figure 3 is a prototype example of a half bridge converter based on ETO technology. With the successful development and test of the single ETO devices at NSWC, a similar converter will be built for integration into a potential NAVY/DoD or power utility application.

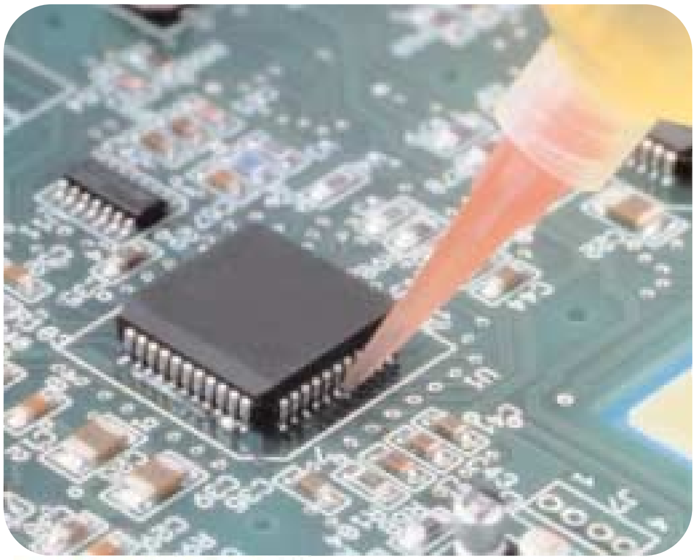
The overall goal of the REPTILE- Task 2 project is to establish the verification of high power electronic components for modular sub-assemblies and high power electronic processing applications. The first step is proving the operation of the ETO at the specified power levels and then progressing into converter development based on next generation ETO topology.

Electronics Manufacturing BOOT CAMP

BOOT CAMP at the EMPF's Learning Center is designed to provide electronics manufacturing personnel with two weeks of comprehensive *hands-on* training in every aspect of the electronics manufacturing process, in our state-of-the-art teaching factory.

Who Should Attend?

Boot Camp is geared towards manufacturing, process and quality engineers or supervisors responsible for one or many of the steps in the entire electronics manufacturing process. Trainers, college and trade school instructors as well as technical sales representatives will benefit from successful completion of this course.



Sample of Topics Covered

Component Insertion & Placement
Solder Paste Application
Reflow/Thermal Profiling
Statistical Process Control & Experimental Design
Dispensing
Cleanliness Testing
Wave Soldering
Inspection/Specifications & Standards
Design for Manufacturability
Bare Board Fabrication
Component Identification
Hand Soldering/Rework
Conformal Coating

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BOOT CAMP A - Week 1	*BOOT CAMP B - Week 2*
January 27-31, 2003	February 3-7, 2003
May 5-9	May 12-16
August 4-8	August 11-15
October 13-17	October 20-24

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Electronics Manufacturing Productivity Facility

TECH TIPS...

MOISTURE SENSITIVE COMPONENTS

In August 2002, the IPC and JEDEC released new versions of two important standards. The J-STD-020B and J-STD-033A communicate an extensive collaboration between users and suppliers to address moisture sensitivity and reflow for Surface Mount Devices.

- J-STD-020B classification of components includes testing at reflow temperatures required for Pb free soldering. Large components designed for Pb free soldering will be tested at 250°C +0/-5°C. So, while the Standard Moisture Sensitive Caution Label has not changed you may see higher peak package body temperatures if components have been classified to the new standard.

- J-STD-033A Table 4-1 now has standard times for user bake at 90°C. This cycle is significantly faster than the 40°C time and can be performed, in most cases, without special condensing ovens.

- J-STD-033A Table 4-1 now makes a distinction between components that are saturated and components that have recently exceeded a floor life limit. This can reduce the amount of time required to reset the package.

- Bake times at high temperature may reduce solderability. Do not exceed 125°C and limit time above 90° to 48 hours. Remove rubber bands, bubble wrap, paper and cardboard before baking at these temperatures. These cycle temperatures also require the use of high temperature carriers.

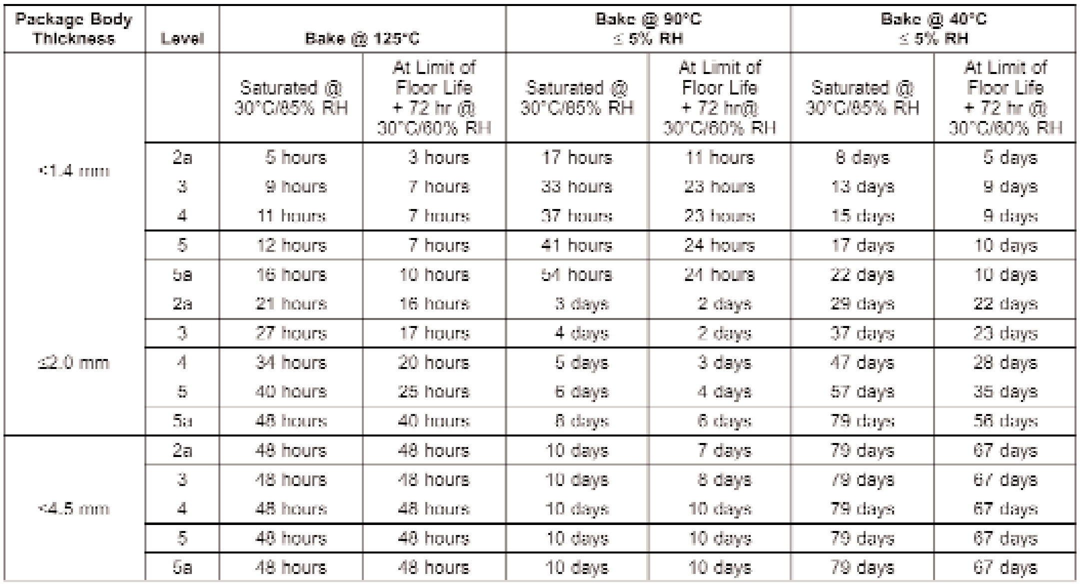
- Bake times at 40°C require RH <5%. In a normal shop environment with ambient 23°C and RH 50% exchanging shop air without conditioning RH in the oven will be significantly higher than 5%. Most low temperature carriers cannot withstand temperatures higher than 40°C. Unless your oven can dehumidify, the 40°C bake is probably not useful.

- You may not need to bake if you have a dry cabinet that maintains RH = 5%. Depending on the components MSL (moisture sensitivity level), a dry cabinet can be used both to store and reset SMD packages.

- The floor life clock is not reset by reflow or rework processes. If more than one reflow cycle is required, do not exceed the floor life of components before the final temperature excursion. Remember, batteries, electrolytic capacitors, some LEDs and FR-4 materials cannot withstand a 24hr bake at 125°C. Choose an appropriate temperature for your assembly.

- Be aware that the floor life standards are based on conditions=30°C/60%RH. J-STD-033A provides, in Table 7-1, equivalent total floor life. If your shop has a very well controlled environment, 23°C ±2° and RH controlled 45% ±5%. You may get an extra day or two of floor life, for a Level 3 BGA with body thickness < 1mm you get an extra week of floor life.

Table 4-1 Reference Conditions for Drying Mounted or Unmounted SMD Packages
(User Bake: Floor life begins counting at time = 0 after bake)



Package Body Thickness	Level	Bake @ 125°C		Bake @ 90°C ≤ 5% RH		Bake @ 40°C ≤ 5% RH	
		Saturated @ 30°C/85% RH	At Limit of Floor Life + 72 hr @ 30°C/60% RH	Saturated @ 30°C/85% RH	At Limit of Floor Life + 72 hr@ 30°C/60% RH	Saturated @ 30°C/85% RH	At Limit of Floor Life + 72 hr @ 30°C/60% RH
<1.4 mm	2a	5 hours	3 hours	17 hours	11 hours	8 days	5 days
	3	9 hours	7 hours	33 hours	23 hours	13 days	9 days
	4	11 hours	7 hours	37 hours	23 hours	15 days	9 days
	5	12 hours	7 hours	41 hours	24 hours	17 days	10 days
	5a	16 hours	10 hours	54 hours	24 hours	22 days	10 days
≤2.0 mm	2a	21 hours	16 hours	3 days	2 days	29 days	22 days
	3	27 hours	17 hours	4 days	2 days	37 days	23 days
	4	34 hours	20 hours	5 days	3 days	47 days	28 days
	5	40 hours	25 hours	6 days	4 days	57 days	35 days
	5a	48 hours	40 hours	8 days	6 days	79 days	56 days
<4.5 mm	2a	48 hours	48 hours	10 days	7 days	79 days	67 days
	3	48 hours	48 hours	10 days	8 days	79 days	67 days
	4	48 hours	48 hours	10 days	10 days	79 days	67 days
	5	48 hours	48 hours	10 days	10 days	79 days	67 days
	5a	48 hours	48 hours	10 days	10 days	79 days	67 days

Note: Table 4-1 is based on worst-case molded lead frame SMD packages. Users may reduce the actual bake time if technically justified (e.g., absorption/desorption data, etc.). In most cases it is applicable to other non hermetic surface mount SMD packages.

Moisture Sensitive Components (continued)

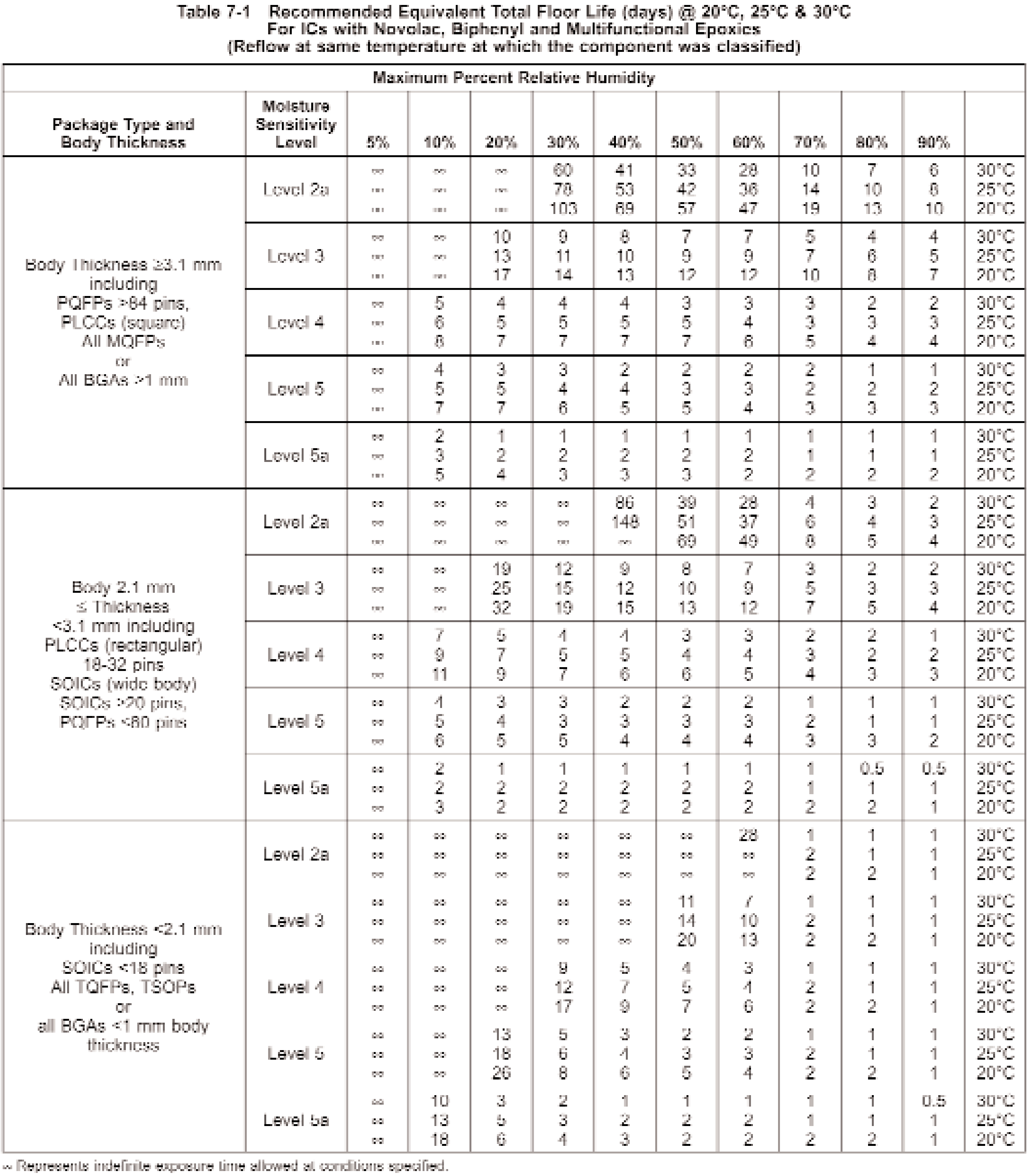


Table 7-1 Recommended Equivalent Total Floor Life (days) @ 20°C, 25°C & 30°C
For ICs with Novolac, Biphenyl and Multifunctional Epoxics
(Reflow at same temperature at which the component was classified)

		Maximum Percent Relative Humidity										
Package Type and Body Thickness	Moisture Sensitivity Level	5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	
Body Thickness ≥3.1 mm including PQFPs >84 pins, PLCCs (square) All MQFPs or All BGAs ≥1 mm	Level 2a	∞	∞	∞	60	41	33	28	10	7	6	30°C
		∞	∞	∞	78	53	42	36	14	10	8	25°C
		∞	∞	∞	103	69	57	47	19	13	10	20°C
	Level 3	∞	∞	10	9	8	7	7	5	4	4	30°C
		∞	∞	13	11	10	9	9	7	6	5	25°C
		∞	∞	17	14	13	12	12	10	8	7	20°C
	Level 4	∞	5	4	4	4	3	3	3	2	2	30°C
		∞	6	5	5	5	5	4	3	3	3	25°C
		∞	8	7	7	7	7	6	5	4	4	20°C
	Level 5	∞	4	3	3	2	2	2	2	1	1	30°C
		∞	5	5	4	4	3	3	2	2	2	25°C
		∞	7	7	6	5	5	4	3	3	3	20°C
	Level 5a	∞	2	1	1	1	1	1	1	1	1	30°C
		∞	3	2	2	2	2	2	1	1	1	25°C
		∞	5	4	3	3	3	2	2	2	2	20°C
Body 2.1 mm ≤ Thickness <3.1 mm including PLCCs (rectangular) 18-32 pins SOICs (wide body) SOICs ≥20 pins, PQFPs ≤80 pins	Level 2a	∞	∞	∞	∞	86	39	28	4	3	2	30°C
		∞	∞	∞	∞	148	51	37	6	4	3	25°C
		∞	∞	∞	∞	∞	69	49	8	5	4	20°C
	Level 3	∞	∞	19	12	9	8	7	3	2	2	30°C
		∞	∞	25	15	12	10	9	5	3	3	25°C
		∞	∞	32	19	15	13	12	7	5	4	20°C
	Level 4	∞	7	5	4	4	3	3	2	2	1	30°C
		∞	9	7	5	5	4	4	3	2	2	25°C
		∞	11	9	7	6	6	5	4	3	3	20°C
	Level 5	∞	4	3	3	2	2	2	1	1	1	30°C
		∞	5	4	3	3	3	3	2	1	1	25°C
		∞	6	5	5	4	4	4	3	3	2	20°C
	Level 5a	∞	2	1	1	1	1	1	1	0.5	0.5	30°C
		∞	2	2	2	2	2	2	1	1	1	25°C
		∞	3	2	2	2	2	2	2	2	1	20°C
Body Thickness <2.1 mm including SOICs <18 pins All TQFPs, TSOPs or all BGAs <1 mm body thickness	Level 2a	∞	∞	∞	∞	∞	∞	28	1	1	1	30°C
		∞	∞	∞	∞	∞	∞	∞	2	1	1	25°C
		∞	∞	∞	∞	∞	∞	∞	2	2	1	20°C
	Level 3	∞	∞	∞	∞	∞	11	7	1	1	1	30°C
		∞	∞	∞	∞	∞	14	10	2	1	1	25°C
		∞	∞	∞	∞	∞	20	13	2	2	1	20°C
	Level 4	∞	∞	∞	9	5	4	3	1	1	1	30°C
		∞	∞	∞	12	7	5	4	2	1	1	25°C
		∞	∞	∞	17	9	7	6	2	2	1	20°C
	Level 5	∞	∞	13	5	3	2	2	1	1	1	30°C
		∞	∞	18	6	4	3	3	2	1	1	25°C
		∞	∞	26	8	6	5	4	2	2	1	20°C
	Level 5a	∞	10	3	2	1	1	1	1	1	0.5	30°C
		∞	13	5	3	2	2	2	1	1	1	25°C
		∞	18	6	4	3	2	2	2	2	1	20°C

∞ Represents indefinite exposure time allowed at conditions specified.

Tables 4.1 and 7.1 of the JSTD033a reprinted with permission.

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Manufacturer's Corner

BeamWorks Spark 400

The EMPF has a new partnership agreement with BeamWorks. The BeamWorks Spark 400 is an all-in-one assembly system that performs automated selective assembly and rework by dispensing paste, placing components, laser soldering and inspection (concurrently) without impacting already assembled components. The EMPF will utilize this system in the Chip Scale Manufacturing, SMT Manufacturing, SMT Soldering & Rework, Power Electronics and Boot Camp training classes. This system provides the EMPF with the following capabilities:

- New assembly technology.
- Capabilities to rework high-density PCB assemblies with BGA, Micro BGA, flip chip and Chip scale packaging parts in an automatic environment.
- Advanced training tool with de-soldering, dispensing, pick and placement of components and laser reflow technology.
- SMT process within one system frame.

Commonly, PWB assemblies must be reworked due to design changes, component failures, manufacturing errors, etc. Even with conventional through hole assemblies, which have been around since the 1950s, every company performs some level of rework. Surface mount is no exception, and there is no reason to believe the need for rework will ever go away completely.

However, rework is not always a negative thing in the manufacturing process. For instance, consider a situation in which 90% of your materials are delivered and ready for assembly, yet the remaining 10% are delayed. Rather than accepting a costly production delay, manufacturing may begin, using the available components, then completed at a later date. In addition to the traditional rework initiatives, the BeamWorks Spark 400 may also be utilized to place the remaining materials in a planned multi-step production schedule.

Common Issues

When reworking a PCB assembly, an issue of concern is to know, in real-time, the rate of temperature change as well as the maximum temperature reached. Intense local heating for a relatively long time may result in the board warping, among other problems.

Although design for manufacture (DFM) guidelines regarding package spacing may exist, they are not always followed. Furthermore, component spacing is continuously decreasing. Therefore, the use of ministencils to selectively print solder paste during rework is becoming increasingly difficult. Also, because a ministencil is needed for each size and type of part, it not only slows the process but also adds to the cost of rework. In addition to ministencil issues as they pertain to decreasing package space, the use of different hot air nozzles for each size and type of part being removed also adds to the cost and complexity of rework. Additionally, the potential for melting solder joints of neighboring components is a serious concern.

The EMPF uses the BeamWorks Spark 400

Throughput in rework is very important. Unfortunately, the typical time to remove and replace a simple component like a 32-pin plastic leaded chip carrier (PLCC) can take more than 12 minutes in the conventional process. Ball grid arrays (BGA) and some of the larger components can take at least 20 minutes per component.

Rework Processes

For surface mount rework, three processes are used today: conductive, hot air and laser. Conductive rework tools are the least expensive. Hot air is the most common,

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while the up-and-coming rework process for surface mount rework is laser.

Conductive Tools

Conductive tools such as soldering iron tip attachments are used to desolder components from the substrate. The tip attachment is shaped such that all the solder joints on a particular device are heated simultaneously, and the part is lifted by the tool itself or by other aids such as tweezers.

Attachment size and shape will vary with the size and shape of the part to be removed. Thus, chips and small-outline integrated circuits have a heating attachment on two sides of the package, but PLCCs need an attachment on all four sides. Using the appropriate tip, heat is applied to the surface mount component to be desoldered until all solder melts. The component then is removed with a twisting motion. There is no preheating mechanism unless an external system is used to preheat the boards.

Conductive tools will increase the potential for lifting pads and board damage. This method does not address the ministencil issue but does not melt solder joints of neighboring components.

Hot Air

Hot air systems are either manual or semiautomated. Essentially, they are sophisticated air heaters, which blow hot air on the part to be reworked. The part is pulled away from the board when the solder on all joints is molten. The hot air usually is directed on the leads by a nozzle specifically designed for that component. The package body is heated by the hot air and conduction. Initially, the package is preheated with the nozzle some distance away (typically 1" or more) from the body. Then the nozzle is lowered to a point just above the body and lead temperature increases sharply. During this process of blowing hot air, the solder joints of neighboring components, even half an inch away, may reflow, an unwanted and undesirable result.

After the component is removed, paste application for reattachment is a most difficult and time-consuming process. Typically, a ministencil is used to apply the paste. Both hot air nozzles and ministencils are needed for each type and size of part being reworked. Both these items require sufficient interpackage spacing for rework.

Lasers

Up-and-coming rework systems use from one to four lasers. Some of the laser systems are limited to reworking only peripheral components, in which the leads are in the laser's line of sight. However, the higher end systems that use multiple diode lasers can rework both peripheral and array type packages such as BGAs, chip scale packages (CSP) and flip chips by rapidly scanning surfaces. This causes BGA/CSP/flip chip ball reflow underneath by conduction, as is the case in hot air rework. Some of these high-end systems also have a built-in automated thermal management capability to monitor and control package temperatures within the specified limits to prevent overheating. Unlike hot air systems, with their built-in temperature monitoring systems, the higher end laser rework systems can remove components, dispense paste, place and solder components automatically without nozzles or mini-stencils.

In a fully automated rework system, such as the BeamWorks Spark 400, all rework process steps - defective part removal, solder paste or flux application, vision-assisted precision placement of small and large components from tape-and-reel feeders or trays, and reflow without overheating the part being removed or reflowing neighboring components - must be accomplished automatically. Such a systems makes rework manageable and yield consistent quality. Because reflow time will be in milliseconds as opposed to minutes as in conventional systems, the intermetallic thickness would be less than a micron (compared to 5 micron in conventional processes). Thin intermetallic and complete independence from human variables improve the overall quality of the solder joint - one key rework concern.

The EMPF will utilize this system in the Chip Scale Manufacturing, SMT Manufacturing, SMT Soldering & Rework, Power Electronics and Boot Camp training classes.
If you would like more information or a demonstration, please call Jeff Stong at (610) 362-1200 x224 or e-mail jstong@aciusa.org

Ask the EMPF Helpline!

CUSTOMER ISSUE: The EMPF Helpline received a call from a board manufacturer involving intermittent opens on their flex-rigid boards during thermal cycling. The problem was isolated to the BGAs and their interconnections. The EMPF was tasked with determining if the opens can be attributed to cracking of the vias in the board material, defective BGA components or assembly issues.

The EMPF Helpline Response

The EMPF investigated the cause of the failure using the following methods:

- Scanning acoustic microscopy (SAM)
- X-ray analysis
- Cross-sectioning
- Optical microscope analysis
- Scanning electron microscopy (SEM)

An Ultra High Resolution scanning acoustic microscopy (SAM) system was used with a 15 MHz 0.5" focus transducer to perform a nondestructive evaluation of the BGAs. Using this system the BGAs were inspected for possible delamination areas. X-ray analysis was also conducted on the BGAs in order to detect any abnormalities that might be inside such as voids and/or shorts.

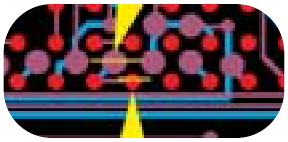

Figure 1. Gerber file with locations of cross-section through a micro-via (red) and full via (purple).

The BGA assembly was separated from the rest of the board using a diamond saw and mounted. The mounted BGA assembly was cross sectioned at the first row of micro-vias and balls. The vias in the BGA assembly were causing continuity problems (see Figure 1). Optical and scanning electron microscopy (SEM) analyses were performed on the cross-sectioned area. A second plane, containing a full via that was connected to the micro-via, was also examined using optical and SEM analyses.

The SAM image of the BGA. indicated nothing unusual. The change in darkness across the board is a byproduct of the system, not a delamination or defect. The X-ray images produced by the BGA also showed no abnormalities.

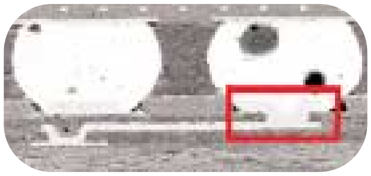

Figure 2. SEM cross-section image through the first row of micro-vias showing the balls and via area of interest.

The initial cross section revealed not only the micro-via in the top layer but also the micro-via it is connected to in the second layer of the board. The via was examined for abnormalities, but did not have any apparent defects (see Figure 2). *Many of the back walls showed cracks at the Kapton layer in the via during cross-sectioning (see Figure 3).*

The PWB (Printed Wiring Board) used in the product was a flex-rigid board, meaning a flexible polyimide-based board has been laminated to FR-4 and, in this case, Thermount stiffeners. This combination of materials is known to have a tendency to cause reliability issues with plated through holes in the flex-rigid structure. The acrylic adhesive used to bond the flex to the rigid and within the flex layers has a particularly high CTE. This tends to concentrate stress generated in the thermal cycling test in the region of the stack up occupied by the adhesive and flex layers. In the case of the customer circuit board, this is the center of the stack up.

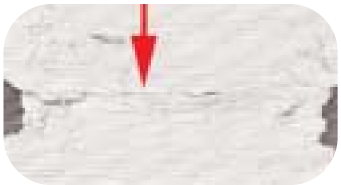

Figure 3. SEM image: cross-section of the back wall of the full size via revealed a crack.

One of the materials used in the external layers of the flex-rigid sandwich is Thermount Epoxy-Aramid, having non-woven, Aramid (Kevlar) fiber as the reinforcement. This material is known to be hydroscopic (absorbs water readily) and is also known to dull conventional drills because of its tough, abrasive nature. During cross-sectioning, cracks were seen in the barrels of holes plated through the Thermount/FR-4/Polyimide flex sandwich.

Conclusions

The two micro-vias showed nothing unusual. SAM and X-ray analysis did not reveal any defects in the area of interest. The problem appeared within the full size via. The cross-sections show problems with either cracking or pullouts near the Kapton layer.

Open recommendations suggest precautions to help the plated through holes survive the temperature cycling. First, laser-ablate away the facing Thermount before mechanically drilling the sandwich, so that the Thermount material could not dull the mechanical drills. Another suggestion is to use adhesive-less polyimide material for the flex member of the PWB, eliminating the low CTE material (the adhesive) that concentrates stresses in the flex and flex-to-rigid bonding layer making it more likely to crack during thermal cycling.

If you have an electronics manufacturing problem, call the EMPF Helpline at (610) 362-1320

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