Screening for Counterfeit Electronic Parts

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Abstract

Counterfeit electronic parts have become a significant cause of worry in the electronics part supply chain. Most of the counterfeit parts detected in the electronics industry are either new or surplus parts or salvaged scrap parts. The packaging of these parts is altered to modify their identity or to disguise the effects of salvaging. The modification can be as simple as the removal of old marking and then adding new marking, or as complicated as recovery of a die and repackaging.

In this chapter, we discuss the type of parts used to create counterfeits and the defects/degradations inherent in these parts due to the nature of the sources they come from, proposed inspection standards, and limitations of these standards. The processes used to modify the packaging of these parts to create counterfeits are then discussed along with the traces left behind from each of the processes. We then present a systematic methodology for detecting signs of possible part modifications to determine the risk of a part or part lot being counterfeit.

Keywords: counterfeit electronics, inspection techniques

1 Introduction

A counterfeit electronic part is one whose identity (e.g., manufacturer, date code, lot code) has been deliberately misrepresented. Several factors contribute to the targeting of the electronic parts market by counterfeiters, including obsolescence; lead time (manufacturer or an authorized distributor unable to supply parts within the lead time requirement of customer); price issues (parts available at lower prices from independent distributors and brokers); absence of pedigree verification tools in the electronics part supply chain; availability of cheap tools and parts to create counterfeits; and costly inspection/testing procedures.

Easy availability of unauthorized parts is one of the prominent reasons for the growing problem of counterfeit electronic parts. There are relatively few incidents of illegal manufacturing in the electronics industry due to the high costs involved in manufacturing electronic parts such as integrated circuits. Counterfeit parts are generally relabeled part (e.g., marked as higher grade or with a recent date code or as RoHS[1] compliant), refurbished parts (i.e., used part reworked to appear as new), or repackaged part (e.g., recovery of die and repackaging). Counterfeiters have access to reclaimed, scrapped, and excess parts, which are easily available from unauthorized sources.

Excess inventories comprise of electronic parts that are no longer required by product manufacturers or contract manufacturers for normal production needs [1]. Excess inventories result due to a variety of reasons, such as differences between forecasts and actual production schedules, delay in discontinuations of slow moving product lines, and economic recessions [2][3]. Disposal options for excess inventories include alternate use within the company; returning the parts to original suppliers (manufacturers, distributors); disposing of the parts into the gray markets (unauthorized markets); and scrapping the parts. Out of the four disposal options, selling the parts in the gray market creates a source of parts for counterfeiters. Improper scrapping procedures used to scrap the excess parts (in the absence of other disposal options) can also result in counterfeiters salvaging the parts [4].

The pedigree of excess parts is often unknown due to the anonymous nature of transactions taking place in gray markets. The quality of excess parts depends on prior storage conditions, the duration of storage, and handling procedures. Depending on the construction, handling, and storage, excess parts can become unsolderable, contaminated, damaged, or otherwise degraded.

Part manufacturers and testing companies often scrap parts, which fail quality checks and other screening tests (e.g., functional tests, burn-in). Often companies do not destroy the parts in-house but rely on third parties. However, some parts escape destruction and are salvaged by counterfeiters.

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[1] The RoHS Directive stands for the restriction of the use of certain hazardous substances in electrical and electronic equipment.

Examples of attributes of scrapped parts include manufacturing defects such as absence of die, lifted wire bonds, missing or no bond wires, and damaged terminations (e.g., broken leads, balls, or chip-out in the terminations of passive parts).

Reclaimed parts are parts that have been recovered from assembled printed circuit boards of discarded electronic assemblies and failed boards which are scrapped by contract manufacturers. The pedigree of these discarded assemblies is often unknown. Parts that are reclaimed from such products may have undetected defects or degradations. Reclaimed parts may also have defects induced during the reclamation procedures, such as damaged terminations, popcorn damage in the molding compound, and delamination of the molding compound from the die attach [5].

Apart from excess inventories, scrapped parts, and reclaimed parts, counterfeiters may also buy new parts and relabel or repackage them to make them appear to be a different part. Such parts may have handling or packaging related damages such as ESD[2] damage or poor workmanship issues.

Unlike material characterization (e.g., XRF[3]) and destructive tests (e.g., decapsulation) that require expensive tools and equipment, visual inspection can be carried out with a light optical microscope, Visual inspection can be a first step in the detection process, but should not be the only method. The visual inspection process also requires access to data sheets and support from manufacturers to obtain the actual attributes of parts, e.g., date code validity.

An electronic part that has been re-marked with good quality ink and without errors is hard to detect through the visual inspection method. Marking permanency tests will not work in the case of laser-marked parts. Even in case of ink-marked parts, marking permanency tests may erase the marking of an authentic part, thus giving the impression of the part being counterfeit. With the growing sophistication of technology, counterfeiters use better quality inks and laser equipment to create counterfeit parts. A salvaged scrap part, which has been scrapped because of internal quality problems, such as missing bond wires, may not be detected through the visual inspection method or marking permanency tests. A part that has been repackaged (from the die) may have discrepancies (e.g., different manufacturers) in the die and package markings. Such discrepancies can only be detected through destructive techniques such as delidding. Refurbishing techniques such as reballing and solder dipping may initiate failure mechanisms such as interfacial delamination or bond pad corrosion, which can only be detected through scanning acoustic microscopy. Visual inspection also cannot detect discrepancies in termination plating materials. Such discrepancies can only be detected through material characterization techniques such as XRF spectroscopy.

Table 1: Types of Parts Used to Create Counterfeits

Types of parts	Sources and attributes
Excess inventories	**Sources:** OEMs[4], Contract manufacturers **Attributes:** handling, packaging, and storage related damage; defects due to aging; no traceability; unknown pedigree
Scrapped parts	**Source:** part manufacturers, testing companies, contract manufacturers **Attributes:** internal quality problems such as missing die or bond wires; die contamination; part termination damage
Reclaimed parts	**Source:** recyclers **Attributes:** damaged terminations and body; inherent defects induced during reclamation; unknown pedigree

[2] Electrostatic discharge.
[3] X-ray fluorescence spectroscopy.
[4] Original equipment manufacturers.

The Independent Distributors of Electronics Association (IDEA) has developed a document for acceptability of electronic parts that are distributed in the open market [6]. The document, IDEA-STD-1010A, provides visual inspection techniques (including marking permanency tests) and acceptance criteria for open market parts. Electrical and destructive or invasive inspection techniques (e.g., delidding) are out of the scope of this document and it only covers visual inspection of the markings, surface texture, mold pin, external packaging (tray or tube), and body of a part. This document or any other methods that use only external visual inspection are not sufficient for detecting counterfeit parts.

Some test laboratories depend on electrical tests for detecting sub-standard and counterfeit parts. Electrical tests include parametric testing, board-level testing, and hardware and software functionality testing. In most cases, electrical tests are used to detect non-functional or failed parts. Some counterfeit parts may function properly during the electrical tests, but they may have inherent defects (e.g., contamination) induced during refurbishing or re-marking. Inherent defects induced during the counterfeiting process can only be detected through a systematic packaging evaluation. In this paper, we present a counterfeit detection process that incorporates packaging evaluation using tools and methods to detect signs of possible part modifications.

Table 2: Limitations of Using Visual Inspection Alone for Detecting Counterfeits

Types of counterfeit parts	Examples of limitations of visual inspection
Repackaged	○ Cannot detect internal discrepancies such as bond wire misalignment or missing bond wires, missing or damaged die ○ Cannot detect die and package marking mismatches
Remarked	○ Fails if markings on counterfeit parts are good quality ○ Need access to datasheets or support from original manufacturer
Refurbished	○ Cannot verify RoHS compliance claims ○ Cannot detect termination plating discrepancies with original parts ○ Cannot detect internal failure mechanisms induced during the refurbishing processes such as interfacial delamination
Salvaged scrap parts	○ Markings may be original manufacturer's, thus difficult to detect any discrepancies ○ Internal problems such as missing die or bond wires cannot be detected

2 Creation of Counterfeit Parts

With easy availability of parts to create counterfeits, counterfeiters have developed inexpensive methods of counterfeiting that rely on modifying the packaging of the parts by processes such as relabeling or refurbishing. In this section, we discuss the three most commonly used methods used by counterfeiters to create counterfeits.

2.1 Relabeling

Relabeling is the process of altering the markings on a part to make it appear as a different part. A typical part marking includes part number, lot number, and the manufacturer's logo. In some cases, part marking also includes the country of origin mark. The relabeling process includes erasing the original marking by methods such as black topping, or sand blasting and applying a new marking to create a counterfeit part. Sandblasting is the process of smoothing, shaping, or cleaning a hard surface by forcing solid particles across that surface at high speeds. Blacktopping is a process in which a layer of material is applied to the top surface of a part to cover over old marking. Blacktopping may also be carried out after the part has been subjected to sandblasting.

Relabeling may be carried out according to the needs of the customer to have higher grade parts (e.g., changing processor speed), different parts with the same pin count and packaging type, different vintage parts (e.g., changing date code), or different military specifications. Some cases of relabeling also include dual part marking, i.e., the presence of part marking at two different places on the part.

GIDEP[5] issued an alert about operational amplifiers, LT1057AMJ8/883 with date code 0122 in 2006. Linear Technology Corporation (LTC) received the parts from a customer when the parts failed functional tests at the customer's facility. Destructive and physical analysis (DPA) of the parts revealed the die to be an original LTC die manufactured in October 1995 as a military lot. The parts were found to have been relabeled to make them appear to be new parts [7].

[5] GIDEP: Government industry data exchange program.

Relabeling leaves behind traces that can be detected through visual inspection or marking permanency tests. Some of the traces left behind are part marking irregularities such as spelling mistakes, different marking techniques used (e.g., laser marking instead of ink marking); dual part markings; part markings with invalid date codes or part numbers; parts (ink-marked) failing marking permanency tests; a filled-in or unclean pin-1cavity; die markings (date code, manufacturer) not matching with the package marking; and absence of country of origin marking.

2.2 Refurbishing

Refurbishing is a process in which parts are renovated in an effort to restore them to a like new condition in appearance. The terminations of refurbished parts are realigned and re-finished (in the case of leads) or undergo reballing (in the case of ball grid array (BGA) type interconnects) to provide a new finish. Refurbishing is often carried out in conjunction with relabeling to sell used parts as new parts. Refurbishing is also carried out to hide defects that arise during reclamation of parts from circuit boards and improper handling. Refurbishing induces defects/degradations in parts such as bridged balls, missing balls, broken leads, popcorning, warpage, or localized delamination.

Realignment of leads (such as straightening) is often carried out on reclaimed or scrapped parts that have bent or non-aligned leads caused during reclamation of the parts from printed circuit boards or poor handling. Realignment of leads may cause damage to terminations such as broken leads or improperly aligned leads. The realignment process may also cause internal defects such as interfacial delamination and cracked passivation layer.

Solder dipping is frequently used to change the lead finish, e.g., from lead free (Pb-free) finish to a lead finish or vice-versa. Solder dipping is also used to improve or restore the solderability of the parts. But poor finish and thermal shock experienced during the solder dipping process can lead to defects in the terminations such as bridging across leads, internal delamination leading to package cracking, a cracked passivation layer, and deformation in die metallization [8].

Reballing is a process carried out on BGA parts to replace damaged balls or to change the termination finish from Pb-free to lead or vice-versa. Counterfeiters often use the reballing process to refurbish the part terminations (BGA) of reclaimed or used parts (with damaged balls) to make them appear to be new parts. Inconsistencies during reballing can cause defects such as missing solder balls, damaged pads, and bridged balls. Other defects caused by improper reballing are warpage, popcorning, and local delamination.

2.3 Repackaging

Repackaging is the process of altering the packaging of a part in order to disguise it as a different part with a different pin count and package type (e.g., dual-in-line (DIP) or plastic leaded chip carrier (PLCC)). The process involves recovery of die (by removing the original packaging) and molding the die into the desired package type. Counterfeiters generally do not use proper handling procedures, tools, and materials for repackaging the die, which may lead to defects or degradation in the repackaged parts such as die contamination, moisture-induced interfacial delamination, and cracks in the passivation layer. There may also be workmanship issues with the repackaged parts such as missing bond wires, missing die, bond wire misalignment, or poor die paddle construction. The marking on repackaged parts also may not match with the die markings. There may also be marking irregularities such as spelling errors, discrepancies in part number, or an incorrect logo. Counterfeiters may also use inferior quality materials to package the die, such as cheap filler materials and flame retardants.

Table 3: Processes Used to Create Counterfeits and Associated Defects

Process of counterfeiting	**Associated defects**
Relabeling	Marking irregularities, poor quality marking, filled-in or unclean mold cavities, discrepancies in package marking with the die marking, ESD damage
Repackaging	Discrepancies in package marking with the die marking; workmanship issues such as missing bond wires or poor die paddle construction; internal defects such as moisture induced interfacial delamination; poor materials used
Refurbishing	Bridged or improperly aligned terminations; internal defects such as interfacial delamination and cracked passivation layer induced during processes such as solder dipping, reballing, and realignment of terminations; differences in termination plating material with original part

3 Detection of Counterfeit Parts

Most of the counterfeit parts detected in the electronics industry are either new or surplus parts or salvaged scrap parts that are modified. The modification can be as simple as removal of marking and re-marking or as sophisticated as recovery of the die and repackaging. Most of these modifications leave behind clues that can be uncovered in order to establish the authenticity of the part. In this section we present a sequence of detection techniques that can be applied for detecting signs of possible part modifications. Detection is an important step to determine the risk of a part or part lot being counterfeit. The evaluation methodology begins with steps that can be implemented at the receiving department. The steps can include a thorough evaluation of shipping packages, inspection of humidity indicator cards, ESD bags, tube and tray materials and shipping labels. Inspection procedures of higher sophistication levels can be then be applied. These steps include external visual inspection, marking permanency tests for external compliance and X-ray inspection for internal compliance. These inspection processes are followed by material evaluation in destructive and non-destructive manners such as XRF and material characterization of the mold compound using thermo-mechanical techniques. These processes are typically followed by evaluation of the packages to identify defects, degradations and failure mechanisms that are caused by the processes (e.g., cleaning, solder dipping of leads, reballing) used in creating counterfeit parts. This method of assessment is necessary since the electrical functionality and parametric requirements may be initially met by the counterfeit parts, but authenticity can only be evaluated after complete evaluation of the package. The latent damages caused by the counterfeiting process can only be detected by a thorough packaging evaluation.

Table 4: Inspection Methods, Severity and Tools or Equipment Needed

Inspection method	**Severity and tools or equipment required**
Incoming Inspection	**Severity:** non-destructive, may induce handling related damage such as ESD if precautions are not taken **Tools/Equipment**: Low power stereo macroscope, bare eyes, ruler, weighing balance. Information on original part material may be needed.
External visual inspection	**Severity:** non-destructive, may induce handling related damage such as ESD if precautions are not taken **Tools/Equipment:** low power optical macroscope, optical microscope, solvent for marking permanency tests, part datasheet information
X-ray inspection	**Severity:** non-destructive, may induce handling related damage such as ESD if precautions are not taken. Instances of part damage due to X-ray radiation exposure are also reported. **Tools/Equipment**: X-ray machine, X-ray images of an authentic part
Material evaluation and characterization	**Severity:** may be destructive or non-destructive depending on the type of equipment used **Tools/Equipment:** XRF, environmental scanning electron microscope (E-SEM), energy dispersive spectroscopy (EDS), differential scanning calorimetry (DSC), thermo-mechanical analyzer (TMA), thermomechanical analyzer (TMA), dynamic mechanical analyzer (DMA), hardness testers, Fourier transform infrared spectroscope (FTIR). Information on original part material may be needed
Packaging evaluation	**Severity:** non-destructive **Tools/Equipment**: scanning acoustic microscope (SAM), ion chromatography.
Die inspection	**Severity:** destructive **Tools/Equipment:** automatic chemical decapsulator, can also

	be carried out through manual etching; information on original die markings and attributes needed. wire pull, ball bond and solder ball shear testing, environmental testing and micro-sectioning.

3.1 Incoming Inspection

Incoming inspection is the process of verifying the conditions of materials used for shipping the suspect packages. Attributes to inspect for include the status of humidity indicator cards (HIC), moisture barrier bags or ESD bags. Not only should the as-received state of the above materials be checked, but their authenticity should also be verified. Instances of counterfeit or fake HIC cards are on the increase..

Incoming inspection should start with verification of the receiving documents and external labels on shipping boxes and matching the details in the purchase order with the shipping list enclosed with the shipment. Manufacturers' logs and shipping origin should also be checked and verified. Any certificate of conformance (CoC) should also be inspected for authenticity and cross-checked with existing CoCs from same distributor or part manufacturer. The next step is an inspection of the ESD and moisture barrier bags to check for any damage or sealing issues. The HIC should also be checked to verify that it is genuine and based on the color indicator, that the shipment has not been exposed to elevated levels of humidity that may prove detrimental to the functioning and reliability of the electronic part. Brand of tray, tube and reels used in the shipment should also be inspected. Single shipments of counterfeit parts have been known to be shipped in trays of different brands.

3.2 External Visual Inspection

External visual inspection is a process of verifying the attributes of parts such as package and part markings (part number, date code, country of origin marking), part termination quality, and surface quality. Visual inspection is performed on a sample of parts from a given lot. Resources required for carrying out visual inspection are standard tools for handling electrostatic sensitive parts [9], part datasheet information (part number format, dimensions, number of pins and package type), a microscope with at least 30X magnification (magnification of the microscope can be adjusted to inspect certain features of the part), a camera built into the microscope (some of the processes of determining a counterfeit require sending copies of photos to different resources for their evaluation), and a solvent to check for part marking permanence.

The visual inspection starts with the inspection of the label on the packaging in which the parts are shipped. Features to inspect include spelling errors on the manufacturer labels, validity of manufacturer codes on the labels (such as codes that contain information on manufacturing location), verification whether the date codes on the external packaging match date codes on the parts, and validity of date codes. The packaging inspection also includes any part specific requirements such as the requirement of a dry pack and a humidity indicator card for moisture-sensitive parts.

The next step in the inspection process is the verification of whether the part markings, such as logo, part number, lot code, date code, and Pb-free marking (if any), conform to the shipping and purchase order information. This is followed by verification of the validity of the part number, date/lot codes, and Pb-free marking (if any) with the original part manufacturer requirements. In some cases counterfeiters may not place Pb-free marking on the parts (when they relabel the parts with newer date codes), though the original manufacturer may have shifted to Pb-free manufacturing. The part should also be inspected for any dual part marking, such as marking on the top as well as on the side of a part with different and often conflicting information. The markings should also be inspected for any irregularities such as spelling mistakes, font size differences compared with the original part, and the marking technique used on the part. For example, an authentic part may have ink marking, whereas the counterfeit part may have laser marking. Figure 1 provides examples of items to look for during visual inspection of a part.

Marking with inferior quality inks or laser equipment can be detected by conducting marking permanency tests on the parts or looking for any laser-induced defects on the parts, such as holes on the surface. Acetone is a common solvent used to determine if a part has been remarked, but a less harsh solvent is a combination of 3 parts mineral spirits and one part alcohol. This is the mixture that MIL-STD-883 (Method 2015.13) [10] requires part markings to withstand. Certain harsher solvents such as DynaSolv 711 are also frequently used for checking for marking permanency. If the result of the marking permanency test is a change in the surface texture or wiped-off marking, this is a possible sign of the part's being counterfeit.

The pin-1 cavity and other mold cavities (part of the plastic mold process) present on a part should be inspected for uncleanness or unevenness, because sandblasting or blacktopping leaves the mold cavities unclean or filled in. Verification of the pin-1 or other mold cavities on a part is a critical way to determine signs of relabeling on a part. In some cases, counterfeiters also etch a new pin-1 cavity in place of the filled-in cavity. Also, the presence of marking over the pin-1 cavity is a sign of the part's being counterfeit.

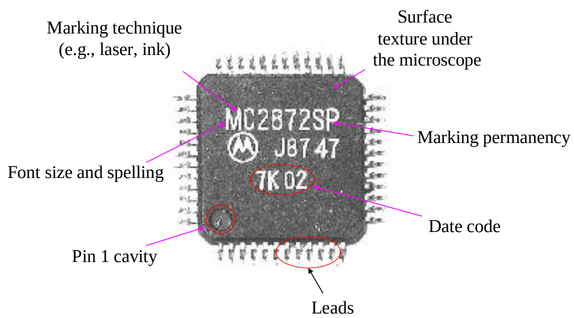

Figure 1: Examples of attributes to look for during visual inspection

The surface texture of a relabeled part is different from an authentic part. The surface of an authentic part when looked at with a microscope is usually sharp and rough (due to molding process residues and filler particles), whereas surface of a relabeled part is smooth because of relabeling methods such as sandblasting or blacktopping. Sandblasting also leaves marks that have a directional pattern on the surface of a part. Sandblasting also leads to rounded corners and edges.

Visual inspection also includes inspection of the part termination (leads or balls) quality to detect possible signs of counterfeiting. Part terminations should be inspected for any signs of refurbishing (solder dipping or reballing) or damage (broken or bent leads, bridged balls) due to reclamation. If the termination type is leads, things to look for are straightness, coplanarity, scratches, or other defects caused by reclamation or prior use. Termination refurbishing techniques such as solder dipping and reballing leaves behind traces that can be detected through visual inspection, such as bridged terminations and missing solder balls.

3.3 X-ray Inspection

X-ray inspection is carried out to conduct internal inspection on parts to verify the attributes of parts such as die size and bond wire alignment. X-ray inspection is also used to detect anomalies such as missing bond wires, missing die, or the presence of contamination (Figure 2). Counterfeit parts are sometimes packaged without a die or with a different die. A die from a different manufacturer than the one listed on the package does not necessarily indicate a counterfeit since manufacturers sometimes institute a process change on a particular product (but production protocol requires a change in lot/date code). X-ray imaging is not the tool to resolve manufacturer logos and markings on the die surfaces to authenticate the device.

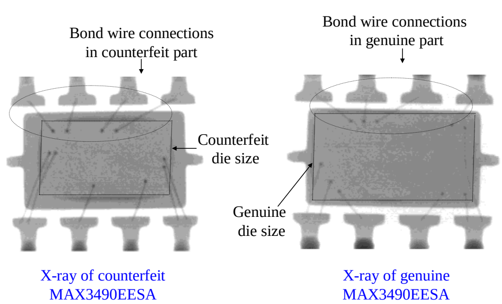

Figure 2: Example of X-ray inspection[6]

3.4 Material Characterization

Counterfeit parts often have discrepancies in termination material or molding compound material when compared with an authentic part. A part that has been relabeled with a newer date code may have tin-lead (SnPb) solder as the termination material, whereas the authentic newer version of the part has no lead in the termination.

Similarly, the same counterfeit part may contain a halogenated flame retardant in the mold compound, whereas the authentic newer version of the part may be halogen-free to comply with RoHS directives. Similarly, a counterfeit part may also claim to comply with RoHS directives but may actually have Pb or halogens in the termination finish or mold compound.

X-ray fluorescence spectroscopy (XRF) can be carried out on the parts to evaluate the material composition of the terminations and the molding compound in order to detect the presence or absence of Pb and any other discrepancies with an authentic part. XRF can also be a useful tool to detect counterfeit passives. CALCE conducted authentication services on customer-returned multi layer ceramic (MLCC) capacitors using X-ray fluorescence spectroscopy. The capacitors were found to be similar to an authentic part except for low concentration of a critical rare-earth element, Yttrium. Figure 3 shows a plot of the variation in the amount of Yttrium among the various parts that were analyzed with XRF.

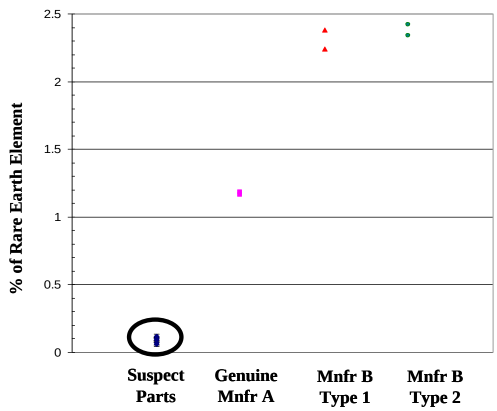

Figure 3 Plot showing the variation in the amount of Yttrium among the various parts

Another method of evaluating the material composition is through environmental scanning electron microscopy (E-SEM) and electron dispersive spectroscopy (EDS). E-SEM is conducted on parts after removing the encapsulants (decapsulation) or after delidding. For example, E-SEM microscopy can be used to verify the elemental composition of the metallization layers. E-SEM microscopy can also be used to verify the solder plating composition on the part termination. In certain cases E-SEM can also be used for inspecting the external part packaging for signs of sandblasting and for detecting topographical changes resulting from the black-topping process.

If a non-authentic raw material is used in a part, polymeric materials such as the component molding compounds, attach materials and coatings need to be evaluated in comparison with the authentic parts in order to detect counterfeit parts. Tools and equipment that aid in material characterization includes differential scanning calorimeter (DSC), thermo-mechanical analyzer (TMA), dynamic mechanical analyzer (DMA), hardness testers, and Fourier transform infrared spectroscope (FTIR). In the dynamic (temperature scanning) approach, a DSC can be used to study the cure reaction and glass transition temperature of the epoxy molding compounds which can be compared with the cure reaction of epoxy molding compound from a known authentic part. The TMA can be used to measure the coefficient of thermal expansion (CTE) of molding compounds of suspect parts which can then be compared with CTE of an authentic part. A DMA can be used to determine the visco-elastic material properties of an epoxy molding compound which can be compared to similar properties of expected molding compound. FTIR spectroscopy, by means of an infrared spectrum of absorption and emission characteristics of the different organic functional groups within molding compound, can help in distinguishing between counterfeit and authentic parts.

It should be clarified that typical processing steps such as solder reflow, rework and burn-in testing can introduce changes to the thermo-mechanical and cure properties of epoxy molding compounds due to the significant high temperature exposure. While using tools such as DSC, TMA, DMA and FTIR, results can vary among genuine parts if they are sourced from assemblies that have been exposed to any of these processing steps and some variations in material properties is expected.

3.5 Packaging Evaluation to Identify Hidden Defects/Degradations

Processes used to create counterfeits such as relabeling, refurbishing, and repackaging often induce internal defects/degradations in parts due to a lack of proper equipment/tools used and improper handling procedures. In this section we provide techniques and procedures for packaging evaluation to identify hidden defects/degradations.

Delamination, voids, and cracks in plastic-encapsulated microcircuits lead to failure mechanisms such as stress-induced passivation damage over the die surface, wire bond degradation due to shear displacement, accelerated metal corrosion, reduction in die attach adhesion, intermittent outputs at high temperature, popcorn cracking, die cracking, and device latch up (hot spot formation). Defects such as delamination, voids, and cracks can be caused due to thermal and mechanical shocks during reballing, solder dipping, realignment of leads, and repackaging.

Moisture-induced interface delamination can occur during each of the processes of relabeling, refurbishing, and repackaging. Moisture-induced interface delamination begins with the package absorbing moisture from the environment, which condenses in micropores in polymer materials such as the substrate, die-attach, molding compound, and various adhesives along the interfaces. During the PCB assembly process, when the part is exposed to high temperatures associated with the soldering process, popcorning may occur.

Scanning acoustic microscopy (SAM) is a non-destructive method which can be used to detect delamination of the molding compound from the lead frame, die, or paddle (top side and bottom side separately); voids and cracks in molding compound; and unbonded regions and voids in the die-attach material. SAM can detect hidden defects such as delamination growing along the die, isolated voids (bubbles or from outgassing), lack of die attach material between die and substrate, and delamination growing along substrate. Procedures for acoustic microscopy for non-hermetic encapsulated electronic parts are provided in JEDEC Standard J-STD-035 [11] and NASA Standard PEM-INST-001 [12]. Examination of the package for voids, cracks, and delamination should be performed at multiple locations including the interface between the die surface and molding compound (top view), and interface between the lead frame and molding compound (top and back view).

3.6 Die Inspection

For die inspection, a preparatory method to expose the die is necessary. Once the die is exposed, the attributes of the die, such as die markings (e.g., manufacturer logo, date code), passivation layer quality, and interconnection quality, can be verified using a high power microscope (Figure 4). A part that is counterfeited using relabeling and repackaging will usually have discrepancies in the die and package marking.

Defects induced during the refurbishing process due to thermal and mechanical shock such as metallization layer damage (due to ESD, corrosion), contamination, bond wire defects, and cracks in the passivation layer can be detected by inspecting the die features. Repackaging-induced defects, such as chip-to-substrate attachment failure leading to voids and thermal stress problems, deformation of bond wires due to improper bonding, and cracks at the bond pad–bond wire junction, can also be detected by inspection of the die area.

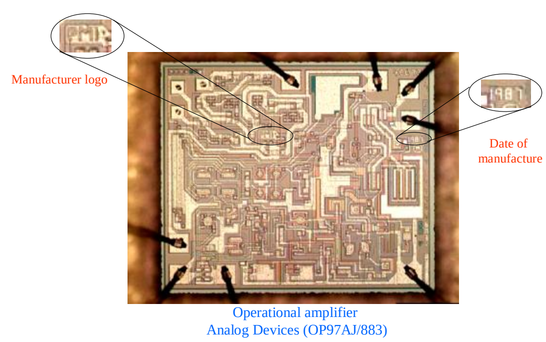

Figure 4: Example of die inspection[7]

4 Summary and Recommendations

Often there is damage inherent in parts that are used to create counterfeits. The damage may result from improper handling, storage, or packing procedures, as in the case of new or excess inventories or overruns. Damage may also occur when parts are reclaimed from assembled printed circuit boards. Parts may also have failed even before they were counterfeited, as in the case of parts that are scrapped by the part manufacturer during quality control (QC) checks. Parts may be counterfeited using processes such as relabeling, refurbishing, and repackaging, each of which leaves behind traces in some form or other.

A systematic methodology for detecting counterfeit parts has been presented in the paper. The methodology consists of external visual inspection, marking permanency tests, X-ray inspection, and material evaluation and characterization, followed by identification of defects or degradations that may have been induced during the counterfeiting process, and die-marking inspection. This methodology helps in detecting signs of possible part modifications to determine the risk of a part or part lot being counterfeit. Table 5 summarizes the methodology and tools.

Table 5: Inspection Methods and Traces or Defects to Inspect

Inspection method	Items of Review
External visual inspection	Spelling errors in part markings or labels; validity of logo, part number, lot code, date code, and/or Pb-free marking; marking technique; quality of marking; mold cavities; straightness, coplanarity, scratches, bridging or other defects in terminations; surface texture
X-ray inspection	Die size; bond wire alignment; anomalies such as missing bond wires, missing die, or presence of contamination
Material evaluation and characterization	Termination plating materials, molding compound, attach materials, coatings, laminate or substrate materials
Packaging evaluation	Delamination of the molding compound from the lead frame, die, or paddle; voids and cracks in molding compound; and unbonded regions and voids in the die-attach material
Die inspection	Die markings (e.g., manufacturer logo, date code), passivation layer quality, interconnection quality, metallization layer damage (due to ESD, corrosion), contamination, bond wire defects

We expect that organizations will evaluate the sources of parts prior to purchasing parts from them and thereby eliminating the biggest risk factor of obtaining counterfeit parts. To be effective, the inspection process needs to come to a conclusion within a relatively short period of time and hence a logistics plan of performing the evaluations needs to be in place since all the equipment and expertise may not reside in the same location.

The inspection methodology presented in this paper is a tool of last resort and it is no substitute for sound supply chain management methods. The cost of inspection can add up to be significant in relation to the cost of parts. The possibility of damage of parts from additional handling associated with inspection remains even when the parts are determined not to be counterfeit. All things considered, a strict and effective inspection method will help in finding suspect counterfeit parts but it will not necessarily save time and money for an organization.

5 References

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Material Forensic Based Counterfeit Part Detection

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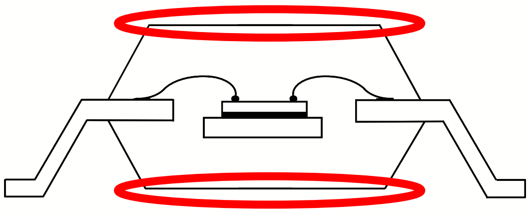
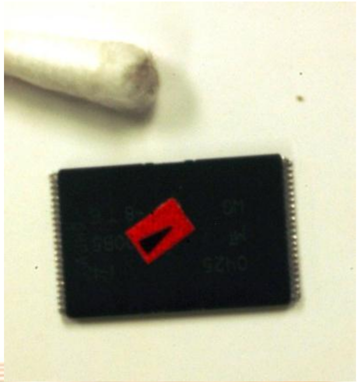
Motivation

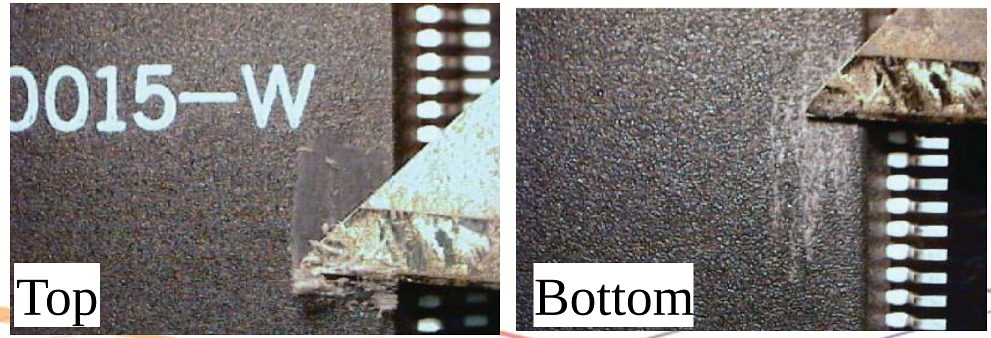
- Increasing ROIs are motivating counterfeiters to constantly upgrade materials and methods,
  - Newer materials to withstand commonly used authentication steps (solvent or mechanical scraping techniques).
  - Labs are continuously catching up with newer chemicals.
- Growing demand for set of material level tests to evaluate the material composition by comparing with an authentic part.



Resistance to Solvents

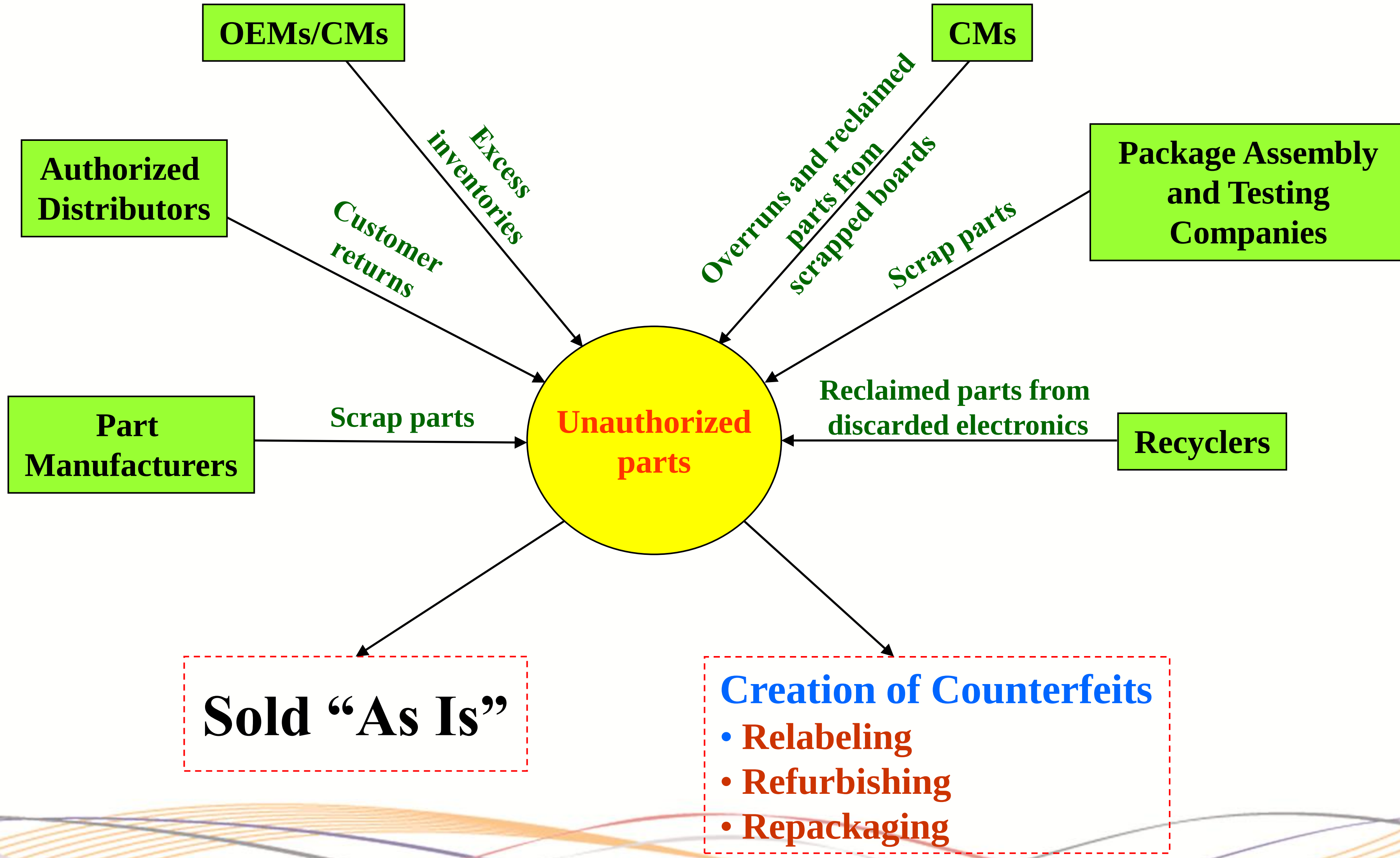


Solvent Resistant Coatings*



* - Robert Hammond – American Electronics Resource

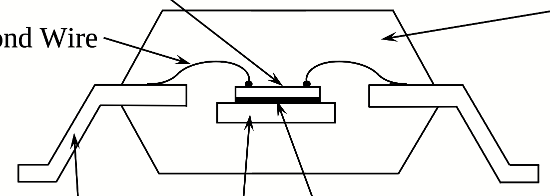
Possible Sources of Parts Used to Create Counterfeits



Anomalies and Defects Associated with Each Counterfeiting Method

Processes of counterfeiting	Anomalies and defects
Relabeling	Marking irregularities, poor quality marking, filled-in, unclean, or missing mold cavities, discrepancies between die and package, Surface texture anomalies
Refurbishing	Improperly aligned or bridged terminations; internal defects such as interfacial delamination and cracked passivation layer induced during processes such as solder dipping, reballing, and realignment of terminations; differences in termination plating material with original part
Repackaging	Discrepancies between die and package; workmanship issues such as missing bond wires or poor die paddle construction; internal defects such as moisture induced interfacial delamination; poor materials used

Typical Plastic Encapsulated Package



Component	Concentration (wt. %)	Major function	Typical agents
Inert fillers	65-80 %	lowers CTE, higher TC w/Al_2O_3), increases E, reduces resin bleed, reduces shrinkage, reduces residual stress	ground fused silica (widely used), alumina
Epoxy resin	10-20 %	binder	cresol-novolac, biphenyl
Curing agents (Hardeners)	5-10 %	improves linear/cross polymerization	amines, phenols and acid anhydrides
Stress-relief additives	2-5 %	inhibits crack initiation and propagation, lowers CTE	silicones, acrylonitrile-butadiene rubbers, polybutyl acrylate
Flame retardants	1-5 %	retards flammability	brominated epoxies, antimony trioxide
Mold-release agents	0.1-1.0 %	aids in release of package from mold	silicones, hydrocarbon waxes, fluorocarbons, inorganic salts of organic acids
Coloring agents	0.2-0.4 %	reduces photonic activity; improves device visibility	carbon black
Accelerators	0.2-0.3 %	enhances rate of polymerization	amines, imidazoles, organophosphines, ureas, Lewis acids and their organic salts (preferred)

Tabletop XRF Spectrometers

Fischerscope
X-ray xdal

This is a high performance energy dispersive XRF measuring instrument for coating thickness measurements and material analysis in the solid state, in the elemental range of aluminum (Z=13) to uranium (Z=92).

Handheld XRF Systems

- Ideal for rapid qualitative inspection of large parts or assemblies with components of large standoff variations.
- Cost efficient.
- Larger spot size than bench top XRF systems.
- Higher penetration depth.
- May be used for quantitative analysis of homogenous materials.

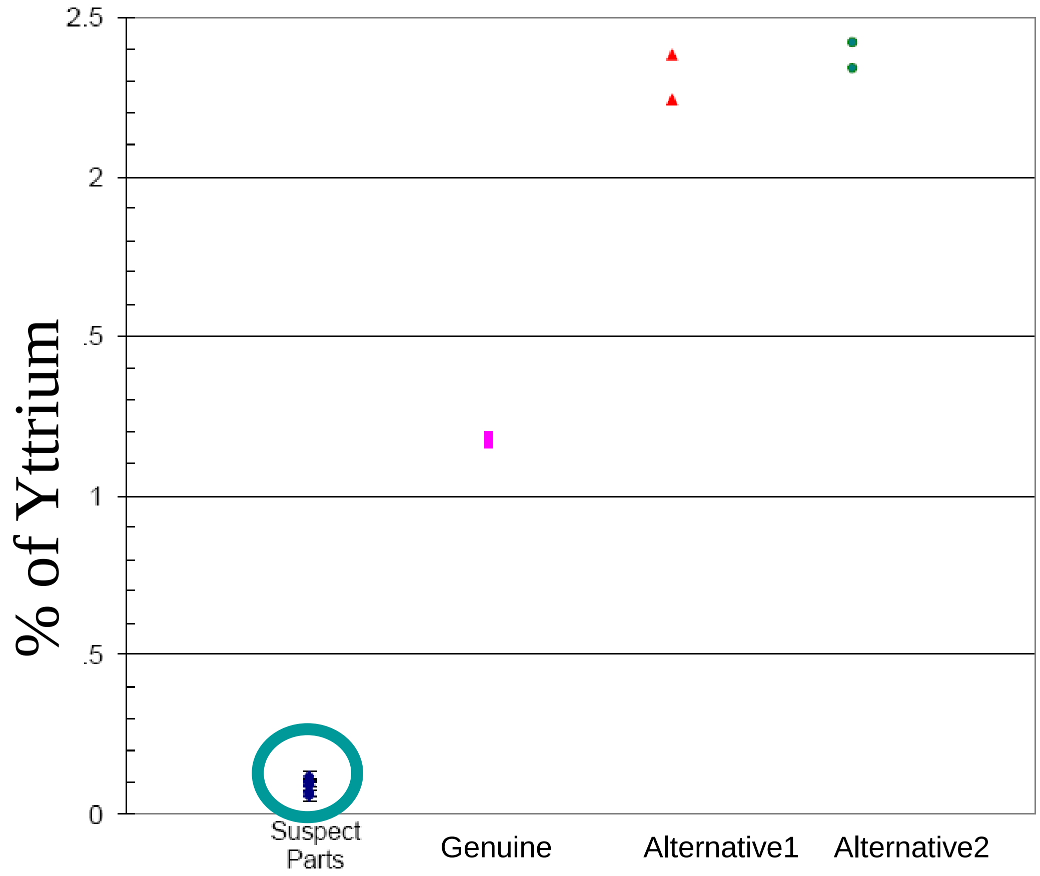
InnovX Systems' Delta Handheld XRF analyzer*.

* - **http://www.innovx.com/products/DELTA - accessed June 1, 2010**

MLCC Detection Using XRF

CALCE performed material analysis of four different multilayer ceramic capacitors (MLCC) using XRF instrument, in order to identify differences between three parts known to be genuine and a part that had capacitance stability problems.

Plot showing variation in amounts of yttrium dopant in BT dielectric among various parts.



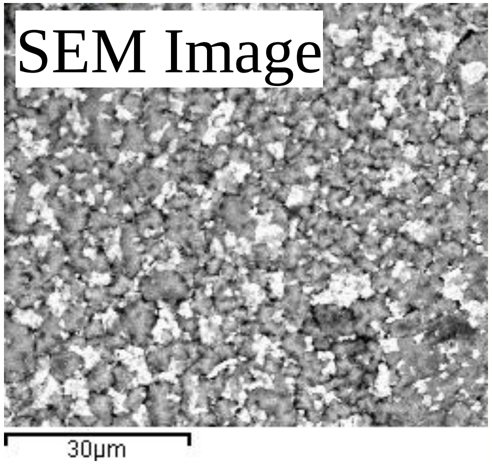
Energy Dispersive X-ray Spectroscopy (EDS)

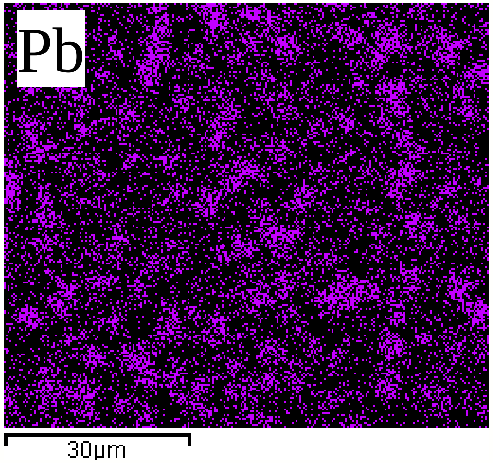
- Used inside a Scanning Electron Microscope (SEM), EDS uses the characteristic X-rays generated from a sample by bombardment with electrons to identify the elemental constituents comprising the sample.

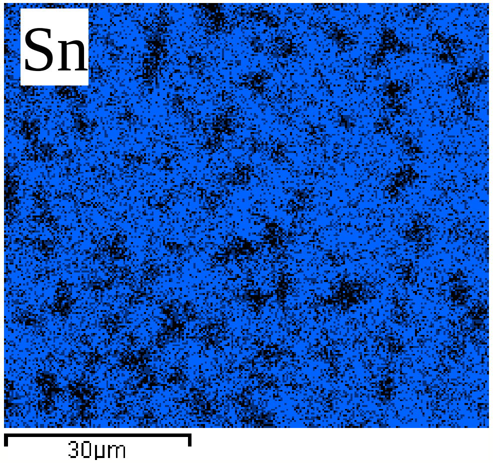
- EDS generates a spectrum in which the peaks correspond to specific X-ray lines and the elements can be identified.

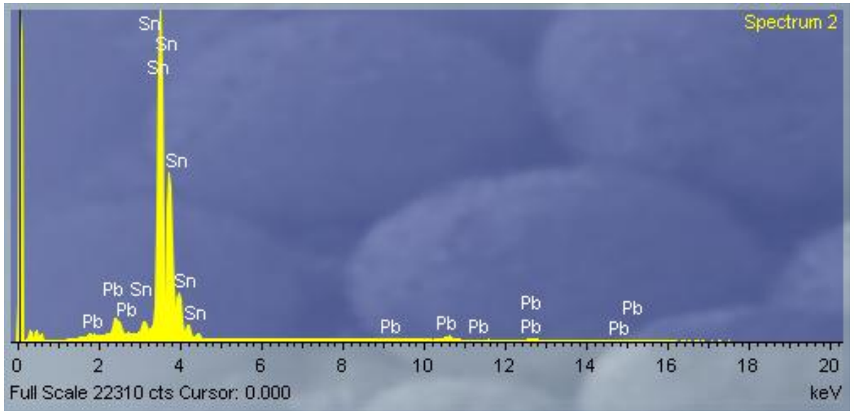
- Two major uses of EDS are:
  - Elemental mapping – depicts different elements with different color.
  - Compositional analysis – presents % composition of different elements in a given area. Surface analysis using few µm of the specimen surface for interpretation.

EDS X-ray Mapping and Limitations









An X-ray mapping of Tin (Sn) distribution (right) and Lead (center) in a eutectic solder. The associated spectrum is shown on left bottom.

Limitations of EDS:

Resolution, unable to detect trace elements and, limited quantitative analysis.

Fourier Transform Infrared Spectroscopy

Counterfeit components can be detected by FTIR spectral comparison with authentic components

But detection possibly requires:

- Significant spectral difference within a principal or major material in the component or sub-component.
- Sufficient total sampling material (e.g., > ~ 100 μm diameter, 1 μm thick).
- Sufficient concentrations (> ~ 5 to 25%).

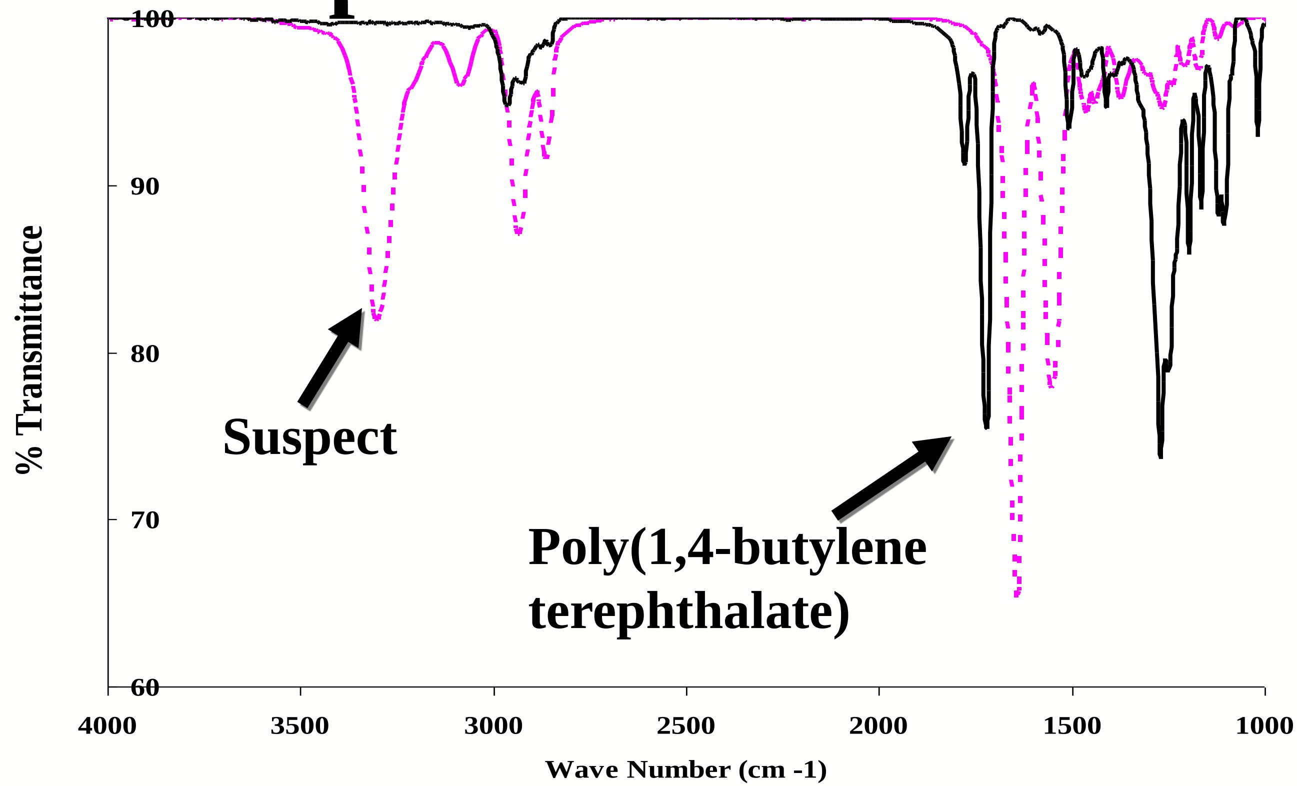
FTIR – Types of Analyzes

- FTIR microscope
  - Transmission (typically destructive – thin samples required)
  - Reflectance (non-destructive; good for 0.1 – 1 mm films over metals)
  - Micro-ATR (contact required between crystal and sample; good for thin films, coatings and laminates)

- FTIR Modes:
  - Normal transmission
  - Attenuated Total Reflectance (ATR)
  - Grazing angle reflectance

FTIR Analysis on Molding Compounds

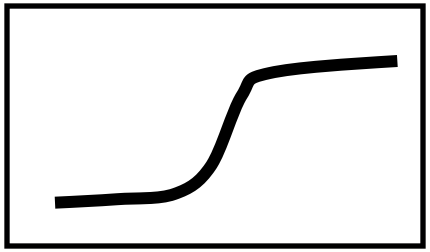
- Comparison of two FTIR spectra.
- Reference spectrum for Poly(1,4-butylene terephthalate) material was obtained from a “as-received” part.
- Spectrum of suspect part shows distinct differences.



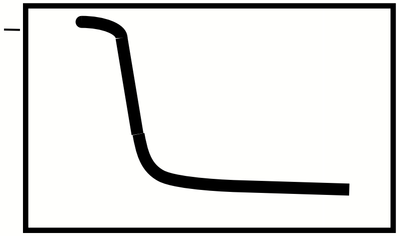
Correlation with charts of characteristic absorption frequencies → Identification of material

Thermal Analysis Techniques

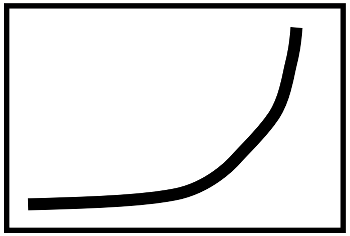
- DSC – Differential Scanning Calorimetry
  - Measures changes in heat capacity
  - Detects transitions
  - Measures Tg, Tm, % crystallinity



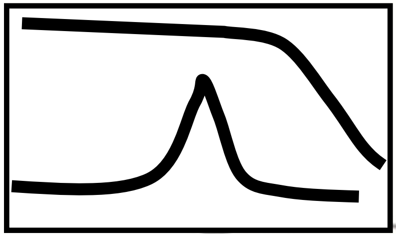
- TGA – Thermogravimetric Analysis
  - Measures changes in weight
  - Reports % weight as a function of time and temperature
  - Helps determine composition



- TMA – Thermomechanical Analysis
  - Measures changes in postion
  - Detects linear size changes
  - Calculates deflection, CTE, and transition temperature



- DMA – Dynamic Mechanical Analysis
  - Measures changes in stiffness
  - Measure deformation under oscillatory load
  - Determines moduli, damping, and transition temperature



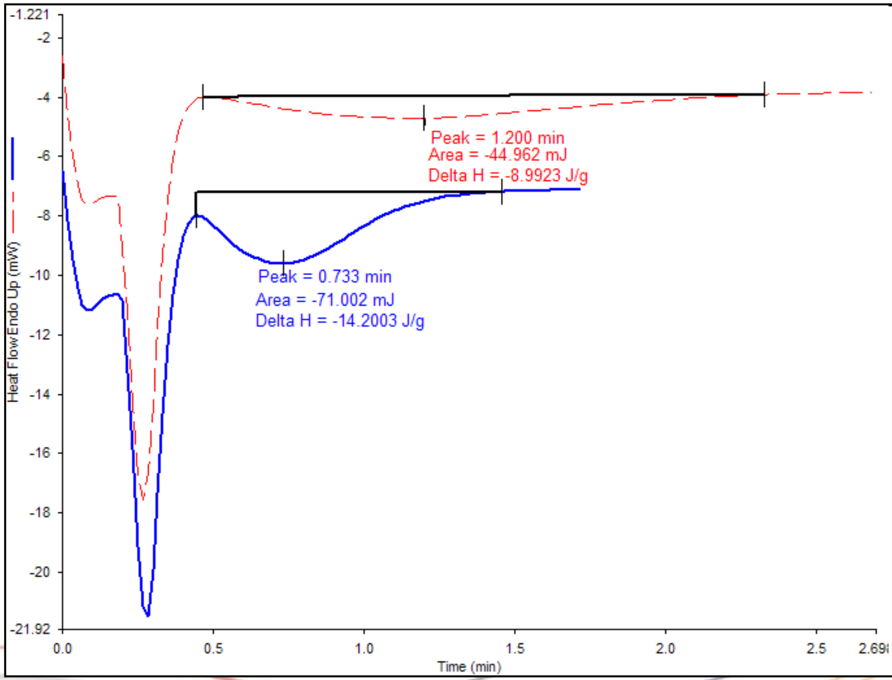
Thermal Techniques - Use

- All techniques are destructive to the sample
  - Sample will be heated above transitions
  - Will have to be cut to fit in instrument
- All techniques use small samples
  - 10 mg of so for DSC and TGA
  - Samples from 5 to 40 mm long for TMA and DMA
- Relative sensitivity to Tg
  - Based on ability to see weak Tg in epoxies
  - More of a guess than a hard rule

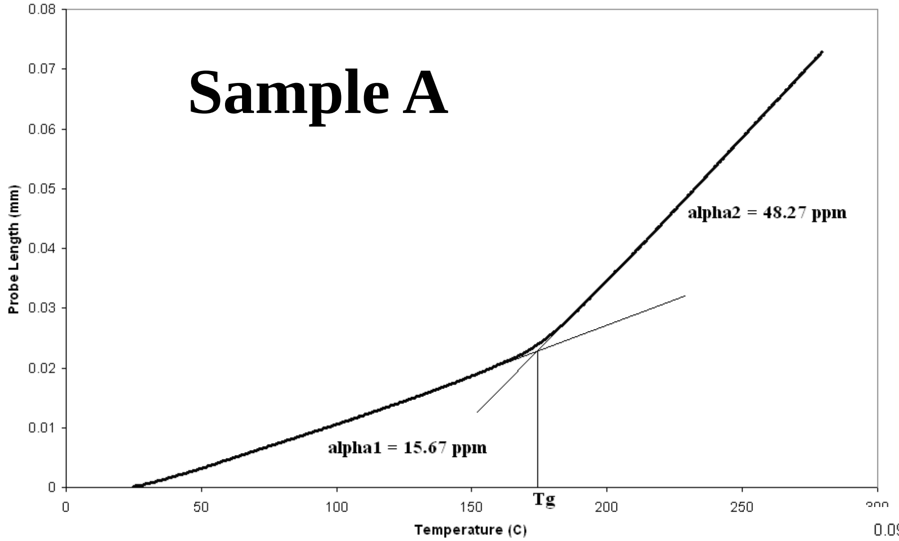
Thermal Analyzes – Detecting Counterfeits

Differences in materials used

- The material itself
- Different molecular weight and/or distribution
- Different degrees of crystallinity
- Difference in composition
- Differences in thickness and structure
- Different Fillers and Modifiers
- Hyphenated and spectroscopic techniques
  - TG-IR, TG-MS or TG-GCMS
  - FTIR Imaging
  - Raman Spectroscopy

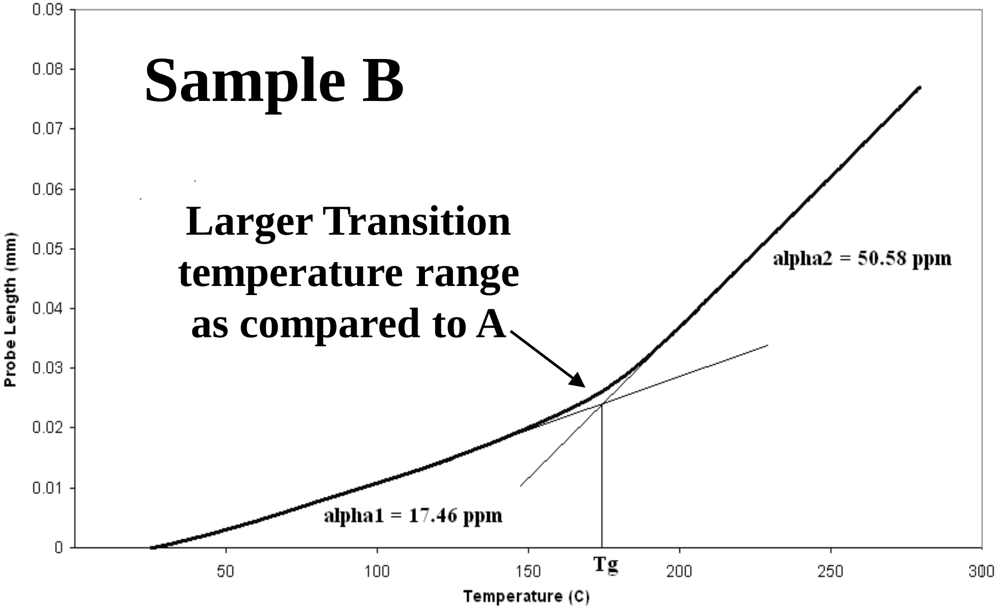


TMA (Samples A and B)



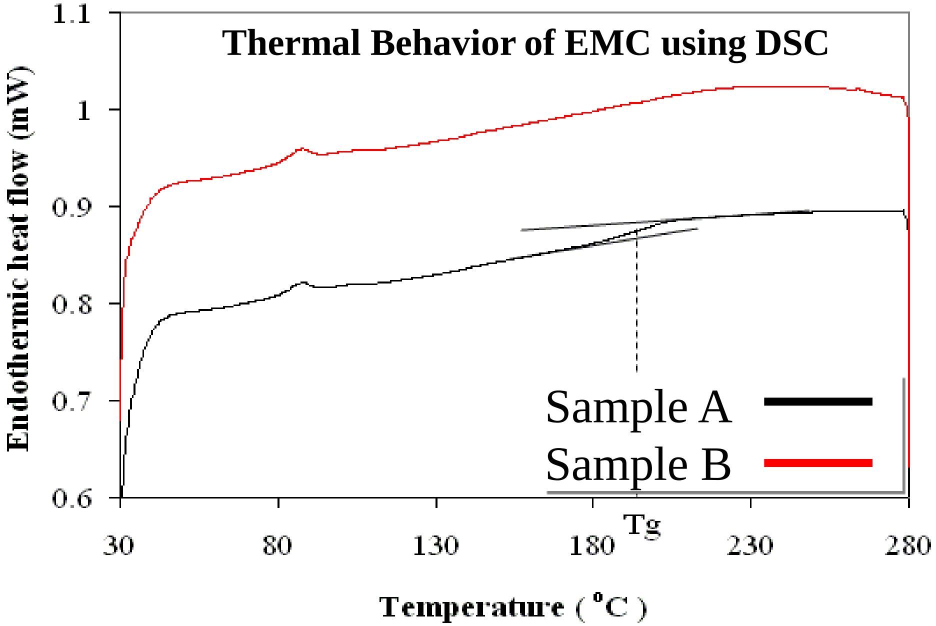
- Coefficient of thermal expansion before glass transition temperature (alpha 1) and after glass transition temperature (alpha 2) is determined.
- Glass transition temperature (Tg) is also determined.

- Constant stylus force applied on the sample: 2 mN.
- Typical scan setup:
- Hold 1 minute at 25 C.
- Heating from 25° C to 280° C at 20° C/minute.



DSC (Differential Scanning Calorimetry)

- Assess the thermal behavior of a substance when it is heated.
- DSC provides understanding of glass transition temperature (Tg), crystallization temperature and melting temperature.
- ASTM D3418 or IPC-TM-650 methods.
- Typical scan setup:
  - 1 minute at 25° C.
  - Heat from 25° C to 400° C at 20° C/minute.
  - Cool from 400° C to 25° C at 20° C/minute (optional).



Normalized DSC plot for both samples

Additional Properties

Several additional EMC properties can be measured and compared. Several are available in manufacturer datasheets, but many manufacturers skip these.

- Water Absorption
- Specific Gravity
- Flexural Strength/Modulus
- Thermal Conductivity
- Mold Shrinkage
- Volume Resistivity
- Flammability
- Ash Content
- Hydrolyzable Chloride

Outcomes of Overall Detection Process

- **Negative:** tolerable probability (no anomalies and defects present) of part being counterfeit. Proceed to next method. Accept parts based on outcomes of all methods.

- **Uncertain:** low probability (small number of anomalies, may be due to manufacturing changes or poor handling) of part being counterfeit. Proceed to next method (to reduce uncertainty level) depending on application risk tolerance level or exit at current method.

- **Positive:** high probability (large number of anomalies and defects present) of part being counterfeit. May proceed to next method to confirm the outcome or exit at the current method and take necessary steps (e.g., reject parts, report to GIDEP).

Future Research and Implementation

- Next level of counterfeiting is at material level:
  - Does not allow inspection of piece parts for counterfeit detection.
- Material level authentication tool implementation including research into manufacturability, quality, and reliability issues.
- Opportunities for test methods development for evaluation of products for accelerating the failure mechanisms caused by these additions.

Questions?

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