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Screening for counterfeit electronic parts

Bhanu Sood · Diganta Das · Michael Pecht

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Abstract Counterfeit electronic parts have become a significant cause of worry in the electronic parts supply chain. Counterfeit parts detected in the electronics industry can be new or surplus parts that are modified in some manner, or they can be salvaged scrap parts that are refurbished to look like new. In the latter case, the packaging of these parts is altered to modify their identity or disguise the effects of salvaging. The modification can be as simple as the removal of old markings and the addition of new markings, or as complicated as the recovery of a die and repackaging in a new package. In this paper, we discuss the types of parts used to create counterfeit semiconductor parts and the defects/degradation inherent in these parts due to the nature of the sources they come from. We also discuss proposed inspection standards and their limitations. 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 methodology for detecting signs of possible part modifications to determine the risk of a part or part lot being counterfeit.

B. Sood · D. Das · M. Pecht (✉)
Center for Advanced Life Cycle Engineering (CALCE),
Department of Mechanical Engineering, University of Maryland,
College Park, MD 20742, USA
e-mail: pecht@calce.umd.edu

B. Sood
e-mail: bpsood@calce.umd.edu

D. Das
e-mail: diganta@umd.edu

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 rapid obsolescence of electronic parts and the long lead time of parts from authorized sources. The absence of pedigree verification tools in the electronics part supply chain and the availability of cheap tools and parts to create counterfeits make the counterfeiting of electronic parts a relatively low risk operation for counterfeiters, while the cost of inspection/testing procedures make it harder for part users to detect counterfeits.

The effects of a counterfeit part and a sub-standard part may be similar on a finished end-product, but there are two important distinctions between the impacts of these two types of parts. First, the liability for the inclusion of a counterfeit part can be wholly on the organization that procures the counterfeit part, since the source of an original part is difficult to confirm. The judicial system and law enforcement may not be able to offer assistance in identifying the original source of the part in order to attribute liability. In addition to liability, there is limited or nonexistent root cause failure analysis support from part manufacturers in case of a counterfeit part that is purchased out of the authorized supply chain.

Unauthorized parts are parts that are circulated beyond the authorized supply chain of part manufacturers, authorized distributors, and authorized aftermarket manufacturers. These parts can originate with any or all members of the part supply chain, as shown in Fig. 1. (In this figure, OEM stands for original equipment manufacturer and CM stands for contract manufacturer.) Counterfeiters have access to reclaimed, scrapped, and excess parts, which are

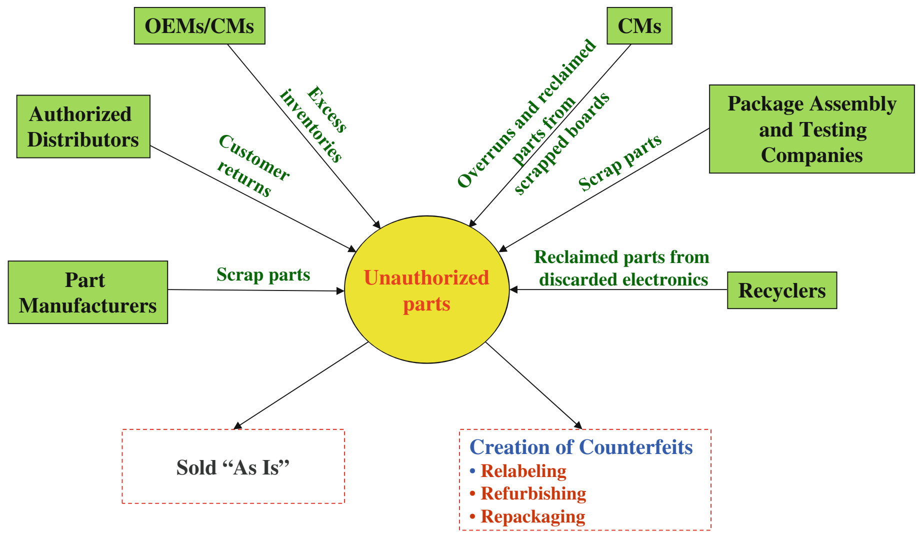

Fig. 1 Sources of unauthorized electronic parts from across the supply chain

easily available from unauthorized sources. There are relatively few incidents of illegal manufacturing of counterfeit parts in the electronics industry due to the high costs and sophisticated infrastructure involved in manufacturing electronic parts such as integrated circuits. Counterfeit parts are generally relabeled parts (e.g., marked as higher grade or with a more recent date code, or as being RoHS[1] compliant), refurbished parts (i.e., a used part reworked to appear new), or a repackaged part (e.g., recovery of die and repackaging). Table 1 shows the sources and attributes of various types of parts that can be used to create counterfeits.

Excess inventories comprise electronic parts that are no longer required by product manufacturers or contract manufacturers for normal production needs [1]. Excess inventories arise for a variety of reasons, such as differences between forecasts and actual production schedules, delays in the discontinuation of slow-moving product lines, and economic recessions [2, 3]. The excess inventory can also come from the release of parts kept as maintenance spares by OEMs or support companies. Disposal options for excess inventories include alternate use within the company; returning the parts to original suppliers (manufacturers, distributors); disposal of parts into the gray markets (unauthorized markets); and scrapping the parts. Out of these four disposal options, the selling of 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. The quality of excess parts depends on prior storage conditions, the duration of

Table 1 Types of parts used to create counterfeits

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

[a] Original equipment manufacturers

storage, and handling procedures. Depending on the construction, handling, and storage, excess parts can become unsolderable, contaminated, damaged, or otherwise degraded during their storage. It is very unlikely that the storage conditions of parts kept at any warehouse will be made known to subsequent buyers. The purchase of parts in protective packaging (e.g., moisture barrier bags, ESD bags) is no guarantee that the parts have been kept in these conditions for the complete storage period.

Part manufacturers and testing companies often scrap parts that fail quality checks and other screening tests (e.g., functional tests, burn-in). Often, part manufacturers do not destroy the parts in-house but instead rely on third parties to perform the disposal. Some of these parts can escape destruction and be salvaged by counterfeiters. Examples of attributes of scrapped parts include manufacturing defects such as the absence of die, lifted wire bonds, missing or no bond wires, and damaged terminations (e.g., broken leads,

[1] The RoHS Directive stands for the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment.

balls, or chip-out in the terminations of passive parts). Some scrapped parts may not meet the electrical specifications and get rejected in screening. Scrapped parts at the part manufacturer level can also include rejected wafers and dice that can then be processed and packaged by counterfeiters.

Reclaimed parts are parts that have been recovered from assembled printed circuit boards of discarded electronic assemblies and failed boards that 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 degradation. Reclaimed parts may also have defects induced during 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 different parts. Such parts may have handling- or packaging-related damage, such as ESD[2] damage.

Unlike material characterization (e.g., X-ray fluorescence spectroscopy) and destructive tests (e.g., die inspection after decapsulation) that require expensive tools and equipment, visual inspection can be carried out with a light optical microscope. Yet while visual inspection can be a first step in the detection process, it can never be the only method. The visual inspection process also requires access to original parts or part drawings and support from manufacturers to obtain the actual attributes of parts, e.g., date code validity.

A plastic-packaged electronic part that has been remarked 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 the 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 have been using 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 after destructive sample preparation techniques, such as delidding, have been conducted. 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 more invasive techniques such as 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.

The Independent Distributors of Electronics Association (IDEA) has developed a document providing guidelines for the acceptability of electronic parts that are distributed in the open market [6]. The document, IDEA-STD-1010A,[3] 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 IDEA document, which only covers visual inspection of the markings, surface texture, mold pin, external packaging (tray or tube), and part body. Methods that use only external visual inspection are not sufficient for detecting counterfeit parts. Besides the possibility of missing counterfeit part risks, visual inspection–based comparison with an original part is hampered by the fact that many material and geometry changes are frequently made to an electronic part by the part manufacturer, and there is no single "golden" part to compare against. Table 2 shows a summary of limitations of visual inspection.

Some test laboratories depend on electrical tests to detect sub-standard and counterfeit parts. Electrical tests include parametric and functional testing. Electrical tests are effective in detecting non-functional or failed parts. However, most counterfeit electronic parts are functional to some extent and cannot be identified by electrical tests alone. It has been a long-standing problem for all electrical testing companies to obtain or replicate the test vectors used by part manufacturers to verify a part. It is a time-consuming and expensive process to develop and program test vectors to conduct part verification. There remains a high possibility of test escape for all but the simplest of electronic parts due the test coverage problem. Even for simple parts, the detection of differences with original parts may only be found at the corners of specifications (e.g., temperature and voltage) and not at the manufacturer-recommended test conditions. 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. There have been reports of system-level failures attributed to excessive ionic contamination levels in semiconductor packages. These contaminants promote failure mechanisms, such as electrochemical migration, that can lead to a drop in insulation

[2] Electrostatic discharge.

[3] There is a new version of this document slated for release in 2011, but at the time or writing that version had not been reviewed by the authors of this paper.

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 of good quality
	Requires 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 refurbishing processes, such as interfacial delamination
Salvaged scrap parts	Markings may be original manufacturer's and thus it may be difficult to detect any discrepancies
	Internal problems such as missing die or bond wires cannot be detected

Table 3 Processes used to create counterfeits and their associated defects

Counterfeiting process	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

resistance, causing leakage current paths and catastrophic failures [7, 8]. Contaminants and other defects introduced during the counterfeit part creation process can only be detected through systematic packaging evaluation. In this paper, we present a counterfeit detection process for semiconductor parts that incorporates packaging evaluation using tools and methods to detect signs of possible part modification.

2 Creation of counterfeit parts

With the easy availability of parts to create counterfeits, counterfeiters have developed inexpensive methods of counterfeiting that rely on modifying the packaging of 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. It is possible for a counterfeiter to use a combination of these methods during various steps of the creation of a counterfeit. Table 3 shows a summary of the defects associated with the three common methods of counterfeiting.

2.1 Relabeling

Relabeling is the process of altering the markings on a part to make it appear to be a different part. A typical part marking includes part number, some type of location and time of manufacture identification, and the manufacturer's logo. The relabeling process includes erasing the original marking by methods such as blacktopping or sand blasting and applying a new marking to create a counterfeit part. Sandblasting involves 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 the old marking.

Relabeling may be carried out according to the need 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 (e.g., JAN, 883 screen). There may also be marking irregularities such as spelling errors, discrepancies in part number, or an incorrect logo.

GIDEP[4] issued an alert about the operational amplifier 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 [9].

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

[4] GIDEP: Government-Industry Data Exchange Program.

permanency tests; a filled-in or unclean pin-1 cavity; 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). 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 the reclamation of parts from circuit boards and improper handling. Refurbishing may induce defects or degradation 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. The 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 layers.

Solder dipping is frequently used to change the lead finish, e.g., from a lead-free (Pb-free) finish to a lead finish or vice versa. Solder dipping is also used to improve or restore the solderability of parts. If the quality of the finish is poor, then subsequent storage reliability and manufacturability may be degraded, or defects in the terminations, such as bridging across leads, can be introduced. Uncontrolled thermal shock experienced during a poor-quality solder dipping process can lead to internal delamination, leading to package cracking, a cracked passivation layer, and deformation in die metallization [10].

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

Many of the problems arising out of refurbishing are hard to detect at the package level by inspection alone. In many cases, their manifestation comes at the board assembly stage.

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 package (DIP) or plastic leaded chip carrier (PLCC)). The process involves recovery of the die (by removing the original packaging) and molding the die into the desired package type. The process of removal of the die can introduce defects in the die, its terminals, and passivation. Counterfeiters are unlikely to 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. The repackaged parts may also suffer from problems 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. The labeling problems seen in relabeled parts can be found in these parts too. Counterfeiters are also likely to use inferior materials of varying quality to package the die, such as low cost and low quality filler materials or flame retardants.

It can also be inferred that, in most cases, the counterfeiters will not use the qualification processes used by original part manufacturers. They are also unlikely to use process control techniques during the manufacturing steps, and, as a result, there is likely to be large part-to-part variation. In the presence of large part-to-part variation, the use of any sampling technique to inspect parts for counterfeit risk identification will be of very little value.

In addition to repackaging, counterfeiters may also package available excess dice. In that case, the steps to extract a die from its original package are eliminated, but the risks from low quality packaging processes still remain.

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 the 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 modification. 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 in the receiving department. The steps can include a thorough evaluation of shipping packages and inspection of humidity

Table 4 Inspection methods, severity, and tools or equipment required

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), 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

indicator cards, ESD bags, tube and tray materials, and shipping labels. Inspection procedures of higher sophistication levels can 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, degradation, 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. The following subsections discuss each of the inspection methods whose severity and required tools are listed in Table 4.

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, and ESD bags. Not only should the as-received state of the above materials be noted, 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 the 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. The brands of the 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. The resources required for carrying out visual inspection include the standard tools for handling electrostatic sensitive parts [11], part datasheet information (part number format, dimensions, number of pins, and package type), a microscope with at least 30× magnification (the magnification of the microscope can be adjusted to inspect certain features of the part), a camera built into the microscope (some of the processes for identifying a counterfeit require sending copies of images to different resources for evaluation), and a solvent to check for part-marking permanence.

Visual inspection begins with the inspection of the label on the packaging in which the parts were shipped. Features to inspect include spelling errors on the manufacturer labels, the validity of the manufacturer codes on the labels (such as codes that contain information on the manufacturing location), verification of whether the date codes on the external packaging match the date codes on the parts, and the validity of the date codes. The packaging inspection also includes any part-specific requirements, such as 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 the 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, even though the original manufacturer may have shifted to Pb-free manufacturing, counterfeiters might not place Pb-free marking on the parts (when they relabel the parts with newer date codes). The part should also be inspected for any dual part markings, 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 techniques used on the part. For example, an authentic part may have ink marking, whereas the counterfeit part may have laser marking. Figure 2 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. A less harsh solvent is a combination of 3 parts mineral spirits and 1 part alcohol. This is the mixture that MIL-STD-883 (Method 2015.13) [12] requires part markings to withstand. Certain harsher solvents, such as DynaSolv 711, are also frequently used in checking for marking permanency. If the

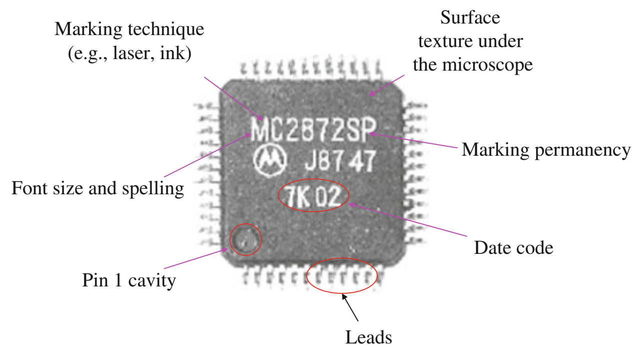

Fig. 2 Examples of items to examine for during visual inspection

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 the presence of debris or unevenness, because sandblasting or blacktopping leaves 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.

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

Visual inspection includes inspection of the quality of part terminations (leads or balls) 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 terminations are 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, leave 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

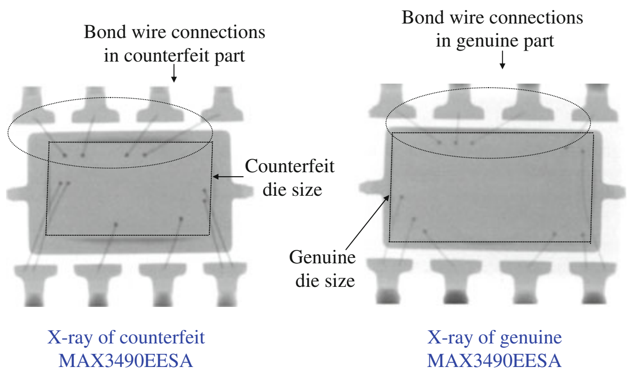

Fig. 3 Example of X-ray inspection

detect anomalies such as missing bond wires, missing dice, or the presence of contamination (Fig. 3). 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 for a particular product (however, production protocol requires a change in lot/date code). X-ray imaging is not the tool to inspect manufacturer logos and markings on the die surfaces to authenticate a device.

X-ray inspection can also be used to screen large numbers of samples of parts to determine if there is part-to-part consistency. If the parts are from a mixed source, then die size, shape, and wirebond configurations may differ, providing an indication that there is high risk of counterfeiting.

3.4 Material characterization

Counterfeit parts often exhibit discrepancies in termination material or molding compound material when compared to an authentic part. A part that has been relabeled with a newer date code might have tin–lead (SnPb) solder as the termination material, while 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. 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 applied to 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 on customer-returned multi-layer ceramic (MLCC) capacitors using X-ray fluorescence spectroscopy. The capacitors were found to be similar to authentic parts except for a low

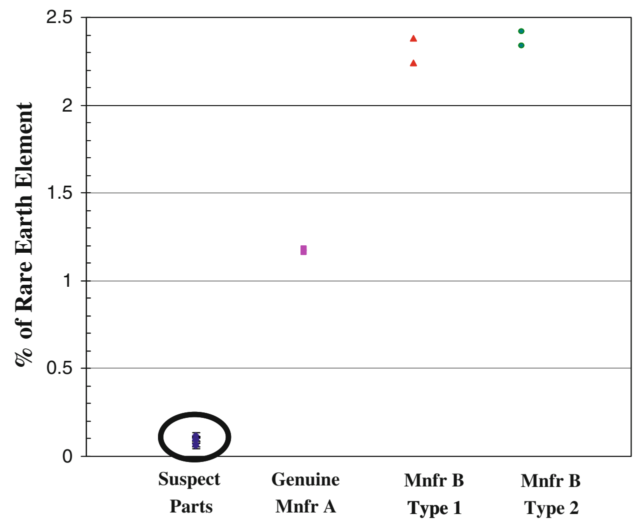

Fig. 4 Plot showing the variation in the amount of Yttrium among various parts

concentration of a critical rare-earth element, Yttrium. Figure 4 shows a plot of the variation in the amount of Yttrium among the various parts that were analyzed with XRF.

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 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 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 component molding compounds, attach materials, and coatings—need to be evaluated in comparison with authentic parts in order to detect counterfeit parts. Equipment that aid in material characterization include the differential scanning calorimeter (DSC), thermo-mechanical analyzer (TMA), dynamic mechanical analyzer (DMA), hardness testers, and the Fourier transform infrared spectroscope (FTIR). In the dynamic (temperature scanning) approach, a DSC can be used to study the cure reaction and glass transition temperatures of epoxy molding compounds, which can be compared with the cure reaction of an epoxy molding compound from a known authentic part. DSC can provide clues to levels of cure of the molding compound and the numbers and types of past thermal exposures (e.g., from reworking, reballing). The TMA can be used to measure the coefficient of thermal expansion (CTE) of the molding compounds of suspect parts, which can then be compared with the 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 the molding compound used in the original part. FTIR spectroscopy, by means of an infrared spectrum of absorption and emission characteristics of the different organic functional groups within a molding compound, can help in distinguishing between counterfeit and authentic parts. Analysis of mold compounds for determining the amount and distribution of filler material can help determine if parts are from same time period by testing samples from multiple parts.

Not all part-to-part variations detected by material characterization techniques are indications of counterfeiting. 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 exposure to significantly high temperatures. 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 variation in material properties is expected. Experienced and knowledgeable analysts can distinguish between acceptable levels of changes and changes that can be considered counterfeit risks. One sign of risk is when samples from the same lot show wide variations in material properties and varying levels of cure.

3.5 Packaging evaluation to identify hidden defects/degradation

Processes used to create counterfeits, such as relabeling, refurbishing, and repackaging, often induce internal defects/degradation 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/degradation.

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 any of the processes involved in 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 that 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 the 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 from outgassing), a lack of die attach material between the die and substrate, and delamination growing along the substrate. Procedures for acoustic microscopy for non-hermetic encapsulated electronic parts are provided in JEDEC Standard J-STD-035 [13] and NASA Standard PEM-INST-001 [14]. 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 the interface between the lead frame and the molding compound (top and back views).

3.6 Die inspection

For die inspection, a preparatory method to expose the die is necessary. Some preparation techniques that enable die access include manual wet chemical etching or fully automated chemical decapsulation, mechanical decapsulation, grinding, or plasma etching [15]. Once the die is exposed, the attributes of the die, such as die markings (e.g., manufacturer logo and date), passivation layer quality, and interconnection quality, can be verified using a high power optical microscope (Fig. 5). A part that has been counterfeited using relabeling and repackaging will usually have discrepancies in the die and package marking.

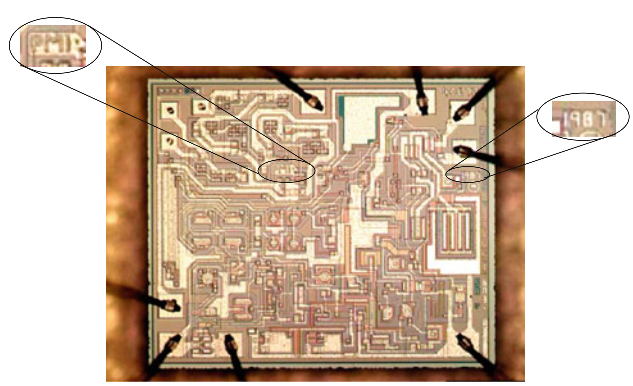

Fig. 5 Example of die inspection

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.

4 Package stress exposure

All the techniques described in Sect. 3 can be generally applied to parts as purchased to detect their counterfeit risk. However, we observed that in many cases the defects are not easily detectable. Defects caused by the process of counterfeiting can impact the interfacial strengths of parts and make them weak. However, those defects cannot be found even by material property characterization. Even if destructive measurements are performed on interfaces, such as a wirebond or die attach, the results may come out to be within an acceptable range. In some cases, it is hard to even evaluate the results since the expected values of those measurements may not be available from the manufacturers.

One way to expose the potential impact of such defects is to perform tests that are equivalent to the qualification tests for electronic packages. Exposure of parts to tests such as temperature humidity bias, temperature cycling, or HAST with evaluation before and after exposure will help determine if the quality of the parts is acceptable. By its nature, this type of stress-based evaluation can only be performed on samples of parts. When available, parts of known vintage should also be exposed to the same tests and evaluated in the same manner before and after exposure. Then the results can be compared to determine if the properties of the parts under consideration match the strength and quality of the parts of known vintage.

Typically, in the qualification process for electronic parts, the failures of the parts are defined only by electrical parameters. The techniques to be used in the tests for counterfeit detection need to include additional physical tests, such as those described in Table 4. One of the tests that can be beneficial for counterfeit risk detection for refurbished and repackaged plastic parts is the test for determining the moisture sensitivity level [16]. The failure criteria used in this standard (e.g., internal and external cracks, swelling, co-planarity change) match well with the possible weaknesses of counterfeit parts. The test needs to be performed at the same moisture sensitivity level defined by the original part manufacturer.

5 Summary and recommendations

Often there is damage inherent in parts before the counterfeiting process even begins. Such damage may have resulted from improper handling, storage, or packing procedures, as in the case of new or excess inventories or overruns. Damage can also occur when parts are reclaimed from assembled printed circuit boards. Parts may also have failed even before they were counterfeited, as in cases where parts have been 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 methodology for detecting counterfeit parts has been presented in this paper. The methodology consists of external visual inspection, marking permanency tests, X-ray inspection, and material evaluation and characterization, followed by the identification of defects or degradation that may have been induced during the counterfeiting process, and then 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. All these methods can be combined with package-level stress exposure for a higher level of confidence in the results.

The authors expect that organizations will evaluate the sources of parts prior to purchasing parts from them and

Table 5 Inspection methods and traces of defects to look for

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), passivation layer quality, interconnection quality, metallization layer damage (due to ESD, corrosion), contamination, bond wire defects

thereby eliminate the biggest risk factor for 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 for performing the evaluations needs to be in place since all the equipment and expertise may not reside in the same location.

At every step of inspection, meaningful comparisons should be drawn with known authentic parts. However, all inspection processes that depend on comparisons with original parts for counterfeit risk assessment suffer from some common problems. The availability of authentic parts may be limited. Even when original parts are available, the original part can be from a different vintage where the materials and codes can be different, resulting in false alarms of counterfeit risk. There is no escape from this problem, but individual organizations can take some long-term actions to improve their results in the future. The companies should perform inspection on a good part and record the findings to include them in the parts database of the company. Items that should be maintained in the records include: marking attributes (e.g., date code format, part number, marking technique, manufacturer logo), number of pins on the part, plating material used in the leads, die marking (e.g., date code format and its location, manufacturer logo and its location on the die), and bond wire configuration.

The only other way to improve the odds of identifying counterfeit parts by various forms of inspection is to obtain the cooperation of the part manufacturer in sharing part details, including materials and configuration. It is very unlikely that such cooperation can be obtained if the parts are not purchased through authorized supply channels. When the parts are obtained through authorized channels, the risk of counterfeits is already low and detailed inspection will not be necessary. All the planning for inspection and decision making needs to be planned and performed assuming that there will be no support from the part manufacturers. As a result, the inspection process will require time and resources (e.g., specialized laboratories), which may ultimately lead to delays in production. Even a limited inspection and analysis may cost thousands of dollars and take several weeks to complete.

The inspection methodology presented in this paper is no substitute for sound supply chain management methods that select all part distributors using a rigorous process to ensure that there is a low risk of counterfeit parts. The costs of inspection can add up to be significant in relation to the cost of parts. The possibility of damage to parts from additional handling associated with inspection exists even when the parts are determined not to be counterfeit. All contracts with part suppliers (e.g., distributors, brokers) regarding part purchase should be formed in such a manner that the burden does not fall on the part purchasers to prove that the parts are counterfeit before the parts can be rejected as suspect. Proving counterfeiting beyond a reasonable doubt is a very high bar for a part purchaser to meet, and inspection and documentation to that level will drain resources from a company.

An organization needs to be able to reject parts that have a risk of being counterfeit. Within an organization, a designated department (e.g., quality, manufacturing) or team should have the authority to reject high-risk parts and prevent them from going into products. 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.

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