An AI method for early detection of failures caused by corrosion on components during assembly - correlated to field failure analysis cases

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Abstract

Corrosion is the most dominant failure mode in electronic products. In many cases, the failure seed is corrosion contamination already on the soldering leads before the assembly that propagates over time and is accelerated by humidity, temperature, and acidity in the environment. The corrosion degrades the board to failures later in the production post-assembly testing, and during the product's life cycle.

We present a method for mass real-time early detection of corrosion contamination on electronic components during the mounting pick-and-place process. The method is based on the correlation between the light reflectance from the soldering leads during their placement photography and the extent of the corrosion. Corroded leads have significantly rougher surface and pitting spots than pristine leads. As a result, they reflect light differently. The difference in their appearance can be detected by AI forensic analysis of the component's pictures. An AI model correlating the leads finish with their corrosion content and progression level is presented, and its performance on mass scale data is analyzed.

We further present a real-life study on how corroded components were detected during the pick-and-place process only to fail during the ICT testing. The post-failure SEM/EDS and cross-section analysis confirm the AI failure predictions on multiple components with corrosion during full-scale production.

The presented method is deployed on multiple production lines inspecting all components without affecting throughput while flagging contaminated components that are unsafe. The accuracy of prediction is over 99.5% tested on over 2.5 billion components.

Introduction

Electronic components are the most expensive part of the Bill of Materials (BOM). Nevertheless, traditional production methods don't carry out systematic inspection, and seldom any tests are being made at all [1]. This is even though electronic components are the means of most of the failures in electronic products [2]. Unsafe components are more common today because of the electronic components shortage that has made the supply chain more complex and vulnerable to fraudulent falsifications[3]. As a result, components that were obtained from non-reliable sources, recycled components, components that were poorly stored, handled, or old components are more frequently used by the electronic industry. These components have a higher ratio of quality issues. The most dominant cause of the failure of aged components is corrosion propagation.

The electronics industry perceives corrosion on soldering leads as a potential risk to the solderability of the components [4]. There are several traditional methods to assess the solderability of an electronic component[5]. In the defense industry, samples from a component batch that is suspected of poor solderability must be inspected according to MIL-STD-202, Method 208[6], and SAE 26262 used in the automotive industry. Typically, samples of the tested components are selected and tested under specified conditions to gauge the solder wetting ability on the component leads and the strength of the bond. The current procedure is practiced on a very small sample of components within a batch under the assumption that few samples represent the entire batch. Unfortunately, this is not the case, as presented in [7]. However, the effect of corrosion on soldering leads to the quality of the product is rarely considered. Even though there are numerous of evidence and research on the impact of corrosion on the bond strength and its reliability[8]–[11].

In this work, we present a method to detect defective soldering leads on components during the assembly[2], [12], [13]. We demonstrate how components with corrosion and contaminations in the soldering leads can be detected early during production and avoided. We also present failures caused by corrosion on components during assembly correlated to field failure analysis cases as proof of the method's effectiveness.

The inspection was performed based on data processed by a novel electronic component authentication and qualification software [14]. The software is interfacing with the pick-and-place (PNP) machines during production and collects the images of the components [15]. The images are then processed using a deep network algorithm that is looking for visual defects in the components and flags every suspected component [12], [16]. In addition, another network is used to evaluate the texture of the soldering leads and estimate their solderability [13].

The method is put to use on real-life assembled components. We present examples of electronic components VSON-12 Gate Drivers NexFET in 12-VSON-CLIP package (see Figure 1), and QFN-12 Power switch (see Figure 2) with corrosion that was detected by the presented method in conjunction with the failure analysis of the components performed employing X-ray analysis, SEM and EDS microscopy, and visible light microscopy. The analysis clearly shows a correlation between the AI detected corrosion and the failure analysis reported corrosion and failure mode. The AI method is then calibrated to detect failures that may result in failures.

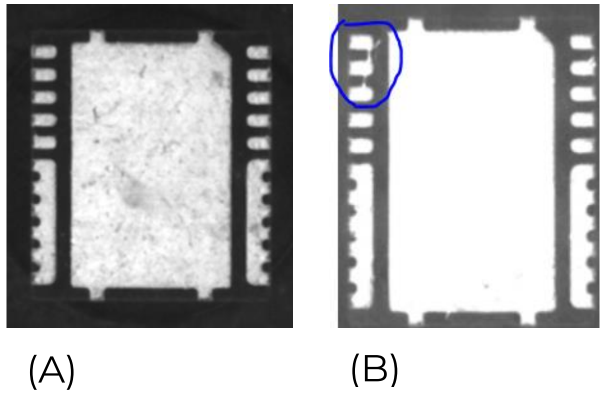


Figure 1. VSON-12 Gate Drivers NexFET images captured by an ASM Siplace SX mounting machine and detected by the system with quality issues: (A) Corrosion, (B) Shorts.

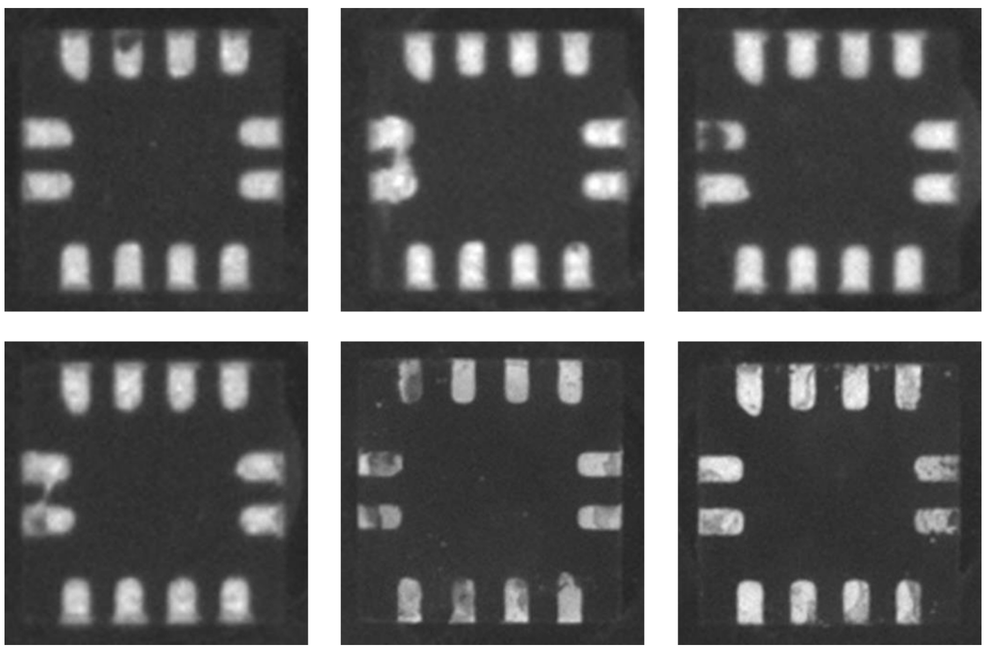


Figure 2. QFN-12 Power switch images captured by an ASM Siplace SX mounting machine and detected by the system with quality issues: Terminal contamination, Corrosion, Shorts.

The effect of corrosion on quality

Corrosion is the most predominant failure mode in electronic products. Numerous published works on the reliability of electronics caused by corrosion show that the print circuit board assembly (PCBA) materials, *dc* or *ac* bias applied, contamination by ionic on the PCBA surface, high-level humidity, dust residues, pollutants comprising ions, etc. can cause serious corrosion reliability issues [8]–[11]. Some cases of failures in electronic systems are due to corrosion powered by the formation of a water layer on the surface of the PCBA where a high level of humidity and temperature variations took place [17], [18]. These failure modes start with untainted soldering procedures that are later arranged in conditions that are in favor of corrosion development. Corrosion that is already present in the soldering leads before the soldering process has a far more devastating effect because they become a breeding seed of the corrosion epidemic.

Contaminations on the surface of the PCBA and residues left from the manufacturing process, as well as corrosion previously present on the soldering, leads before the assembly affect the reliability of the device. Electrochemical migration (ECM) also affects the functionality of devices [8], [19]. A major contributing factor to this is the flux agents used in the soldering process, and the residue contains ionic activators that are hygroscopic. Hygroscopic residues on the PCBA decrease the relative humidity and results in moisture adsorption at the lower relative humidity levels [20], [21]. These residues absorb moisture from the atmosphere until its deliquescence and dissolve in the condensed water film, and produces an electrolyte solution with a higher conductivity level [22]. Consequently, the electrolyte layer sandwiched between the conductors may have a reduced surface insulation resistance, elevated leak current, and finally corrosion contamination like ECM [23], [24].

These reported issues rarely affect solderability. This is because during the reflow process there is only a little amount of corrosion in place and therefore the effect on bond strength during production is small. However, the described phenomena affect the reliability of the product during its life cycle, and sometimes also during the post-assembly inspection as the corrosion propagates.

Detection of corrosion during the SMT pick-and-place process.

The algorithm interfacing with the pick-and-place (PNP) machines during production and collects the images of all the components [14]. The images are then processed using a deep network algorithm that is authenticating the components, looking for visual defects in the components, and flags every suspected component [12], [16]. In addition, another network is used to evaluate the texture of the soldering leads and estimate the presence of corrosion and the leads solderability [13].

Detecting corrosion evidence in electronic components is an image classification problem, in which images are classified as either normal or defective (in some cases, we may further classify the defective ones into finer levels like minor, moderate, or major) [25].

We present a new network architecture tuned to handle corrosion contamination [7] Instead of using a serial architecture used in popular image classification models, in which multiple layers of small filters, often of size 3x3, are serially connected to each other, we use a set of filters with different window sizes which are concatenated in parallel. Each filter tries to detect a type of defective region in the components' images and generates a feature that indicates the possibility that the component images contain such kinds of defects. The overall feature is the concatenation of all features produced by the set of filters. This feature is then fed to a dense layer which produces the final defects score [7]. By using this parallel architecture, the defects detection engine is efficient (can process to 3,000 images per second on a Tesla T4 GPU), while requires fewer samples of images to train (a few hundred samples are enough). This architecture is also inspired by the template matching method in traditional computer vision, which is used for object detection when there is not much data. In this architecture, the defected templates represented by the filters are learned from the training images rather than manually chosen as in the traditional template matching method. The size of the filters should be approximately the same as the size of the defected spots in the components, since there are a variety of defects with different sizes, there are different filter types with corresponding sizes. For large defect spots, the filter sizes can be large, and the processing will be slow, therefore, the filters are downscaled. The method was trained based on a dataset of over 1 billion inspected components.

Experimental Methodology

In order to demonstrate the method on real-life data, we present two cases of failure analysis for two different electronic components.
Case 1: VSON-12 Gate Drivers NexFET (see Figures 1, and 3 left) has moisture sensitivity level (MSL) 2, hence it is sensitive to moisture and must be kept according to standards in vacuum during storage and handling.
Case 2: QFN-12 Power switch (see Figures 2, and 3 right) is MSL 1.

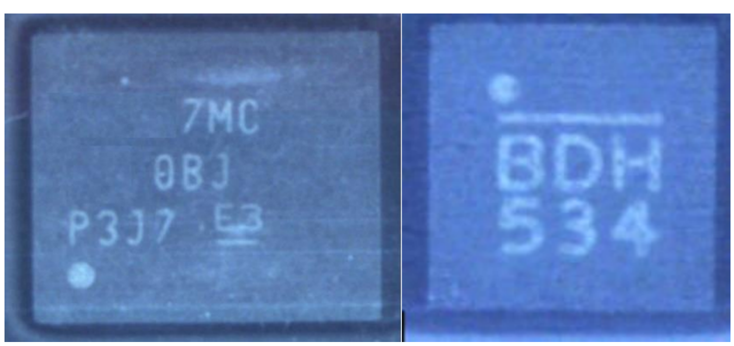


Figure 3. VSON-12 (left), and QFN-12 (right) images were taken from the top side by a reel-to-reel authentication system (an image of similar components from a different production batch).

Failure analysis timeline

The method is deployed at a full-scale, high-volume SMT production line at Flex Migdal HaEmek in Israel. The authentication system inspects all components assembled on all PCBs in real-time using the ASM-SX vision system's mounting machine. Although the platform is giving alerts in real-time, during the test period, the system only reported on deviations after the assembly, and no actions were taken in real-time. A retrospective analysis was performed only after analyzing the post-assembly test results. The post-assembly test conducted is In Circuit Test (ICT) is a basic electrical test performed on the PCB. The test consists of resistance, capacitance, and basic electrical signals in order to find shorts, disconnections, or other faults. This test provides the first level of quality assurance and gives preliminary insight into whether or not there is a problem. In this case, a high failure rate was reported on two different part numbers, in two separate production lines. The involved reels were isolated and a retrospective analysis was performed.

The involved reels were also inspected before they were used by the production line to assure the components are authentic by a reel-to-reel authentication system. The pre-production tests reported the reel is authentic.

Then the reels were used during production. The images of the electronic components are obtained by harvesting them from the pick-and-place machines [16]. The PNP machine is picking up the components and then takes their picture using a monochrome camera with a resolution of 17µm. All components' images are extracted and processed by a defects and corrosion detection algorithm. This test found a large ratio of the components originating from these reels to be contaminated with corrosion. In production, the alerts are used during production and detected faulty reels and components are blocked.

In the next section, we present the post-process analysis of the failures and compare the predictions and alerts of the AI algorithm.

Results

Case 1: Package case VSON-12

The VSON-12 is sensitive to moisture (MSL-2) and the failure is related to this sensitivity in a few different ways. The presence of corrosion on the soldering leads is an indication that the components were exposed to humidity during their storage and handling. This is because exposure to humidity results in corrosion growth on the exposed metallic parts on the component surface. In addition, the corrosion on the soldering leads is a failure mode by itself as it propagated over time into the package case. Third, the corrosion also affected the wettability of the soldering leads resulting in a partial bond. Figure 4(A) presents an image of the component taken by the SMT mounting camera during placement, evidence of corrosion is visible, and (B) an image of a failed component after removal from the board. In Figure 4(B) the top side of the image shows residues of the wetted area while the bottom side of the component appears to not contain paste, only a rough surface finish consistent with corrosion.

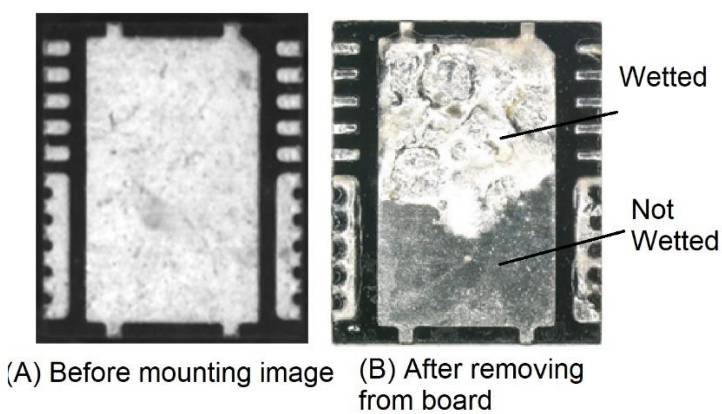


Figure 4. VSON-12 (A) Image of a component taken by the SMT mounting camera during placement, evidence of corrosion visible, and (B) image of a failed component after removal from the board. In (B) the solder paste residue is visible on the top side, whereas on the bottom side, no evidence of wetting.

To verify the condition of the inner parts of the component a Scanning Acoustic Tomography (SAT) was performed. SAT is a method for analyzing materials by measuring the reflecting speed and energy of an ultrasonic wave which is transmitted through a material of a certain thickness. A C-scan inspection with horizontally x-sectioned 2D image after focus, and a thorough T-scan (see Figure 5). The delamination is presented in red.

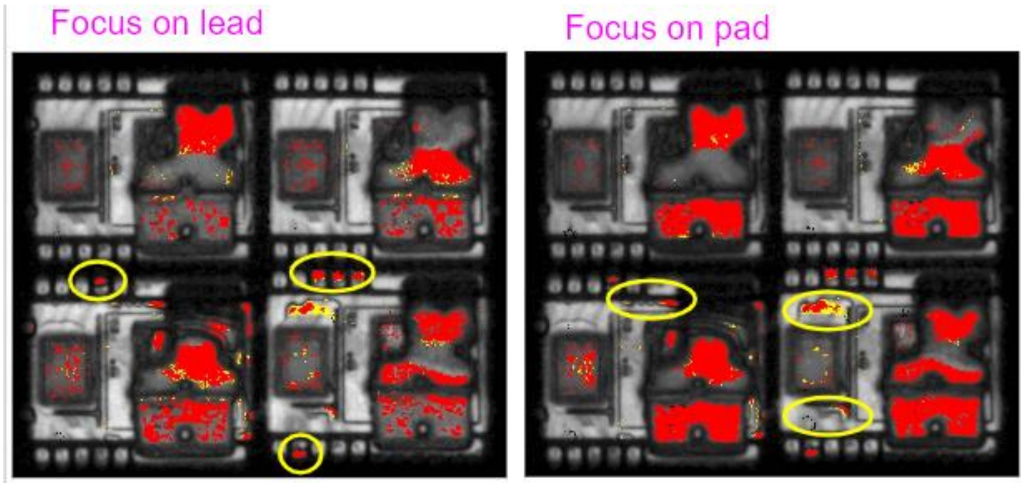


Figure 5. VSON-12 Scanning Acoustic Tomography image. The red color indicates delamination. The internal delamination appears on the inner part of the soldering leads.

It is apparent from Figure 5 that there is degradation in the internal part of the component that attacked the chip's internal metallization. The surface corrosion on the leads (Figure 4) appears to have attacked the inside part as well. From Figure 4, it is apparent that the metallic pad did not have good wettability (only the top side here was wetted well), therefore the other side did not have good heat removal capability from the component to the board via the thermal pad. The failure's root cause is corrosion affecting wettability as well as propagating into the package case and causing internal delamination.

As can be seen, the corrosion evidence was visible earlier in the image taken by the ASM vision system during the mounting (Figure 4(A), and Figure 1). The AI detection algorithm described in [7] detected corrosion evidence by analyzing the light reflectance from the soldering leads. The rough surface texture created by the corrosion on the leads was detected by the AI algorithm and cross-referenced with the failed units in the post-assembly tests where the failed units were also predicted as contaminated by the algorithm.

Case 2: Package case QFN-12

The QFN-12 is MSL-1 and is not sensitive to humidity. Nevertheless, the component was 6 years old at the time of the assembly and it was contaminated with severe corrosion and mold that affected the performance of the board. The components were inspected during the SMT process, flagged as contaminated with corrosion by the AI algorithm, and then failed in the post-assembly tests. The failure mode was shorts, solderability, and opens. Some 6-11% of the components suffered electrical failures.

The batch was then analyzed for the root cause by performing X-ray analysis, SEM – SED, Cross-sectioning, and microscopy.

The failure mode is evident from the cross-section of the component bond to the PCB (see Figure 6). Where a crack appears in the bond resulting in an open or a not reliable bond.

Figure 6. QFN-12 solder bond with the PCB cross-section. A crack is visible between the lead and the paste.

X-ray example analysis of the component did not reveal mounting issues except for a short. The short is also visible on the bottom-side image of the component taken before mounting. Shorts are easily detected automatically by the AI algorithm as there is a strong contrast between the light soldering leads and the dark component body. The X-ray shows a metallic short between the pads after the mounting on the PCB. It is impossible to say if the short was already in place before mounting or only created during the mounting. By examining the bottom view image of the component before it was mounted on the PCB it becomes apparent that the short was there even before the assembly (Figure 7-left).

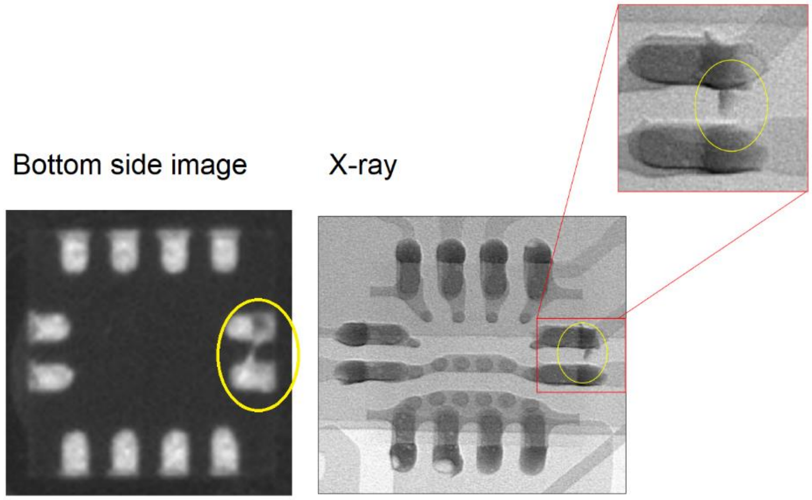


Figure 7. QFN-12 Short is visible on the bottom view image taken by the SMT pick-and-place machine during mounting (left image), later to be also detected by the X-ray post-failure analysis. (right image)

In addition to the X-ray, more analysis was made as the X-ray could not explain the massive failure rate. The failed boards were analyzed by SED-SEM microscopy. The analysis revealed contamination on the soldering leads as is visible in Figure 8 where QFN-12 SED SEM analysis example of a soldering pad with a black spot taken by the SMT pick-and-place machine during mounting (left image), compared to a microscopy image taken by the SEM-SED (right image). The black marks are visible on both the pre-assembly detection (Figure 8-left) and the SEM-SED post-failure analysis (Figure 8-right).

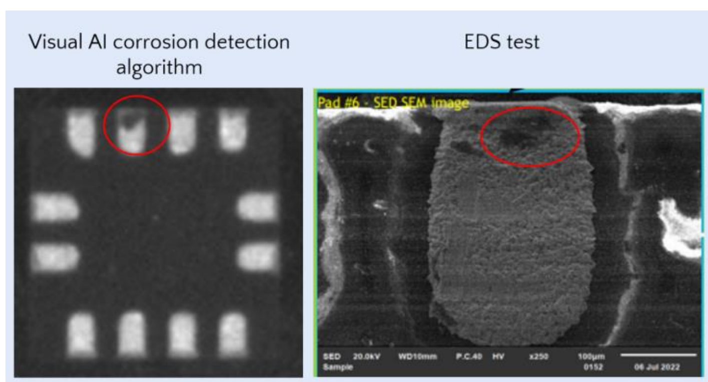


Figure 8. QFN-12 SED SEM analysis example of a soldering pad with a black spot taken by the SMT pick-and-place machine during mounting (left image), compared to a microscopy image taken by the SEM-SED (right image).

The SED analysis reveals that the contamination contains Oxygen, Silicon, and Carbon whereas clean lead doesn't contain any of these materials. Mold contains Silicon(Si), Carbon(C), and Oxygen(O), and oxidation (corrosion) contains Oxygen. From the microscopy images, it is apparent that the black marks are from mold and corrosion. Both are created by exposure to humidity under environmental stress, and both degrade the bond reliability and solderability (see Figure 9).

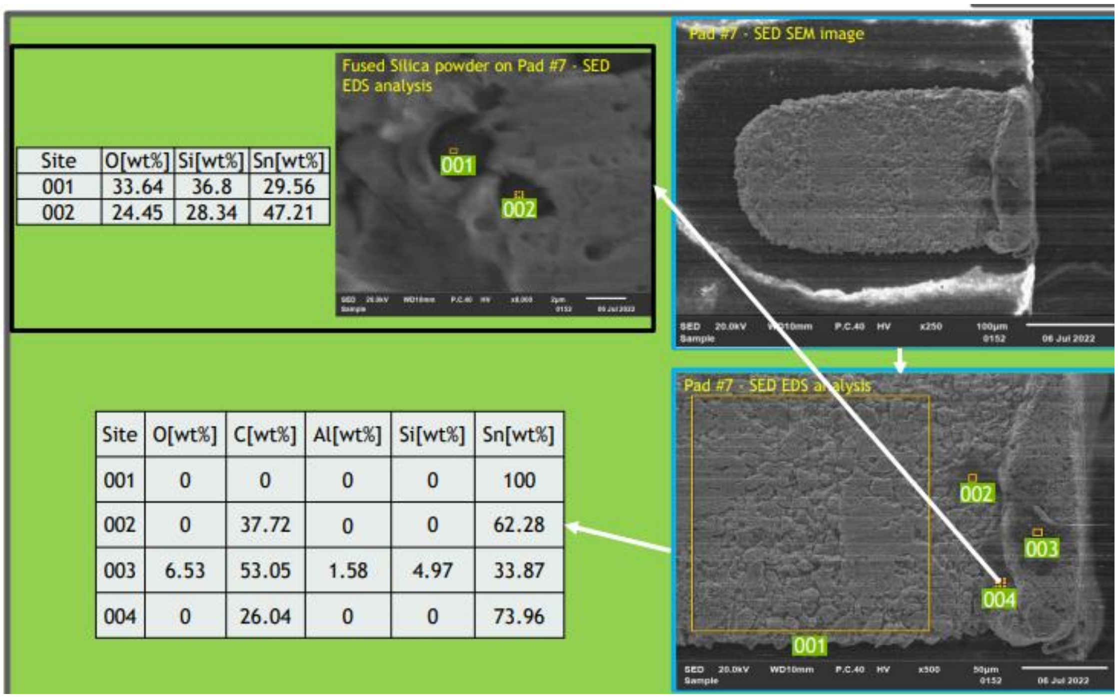
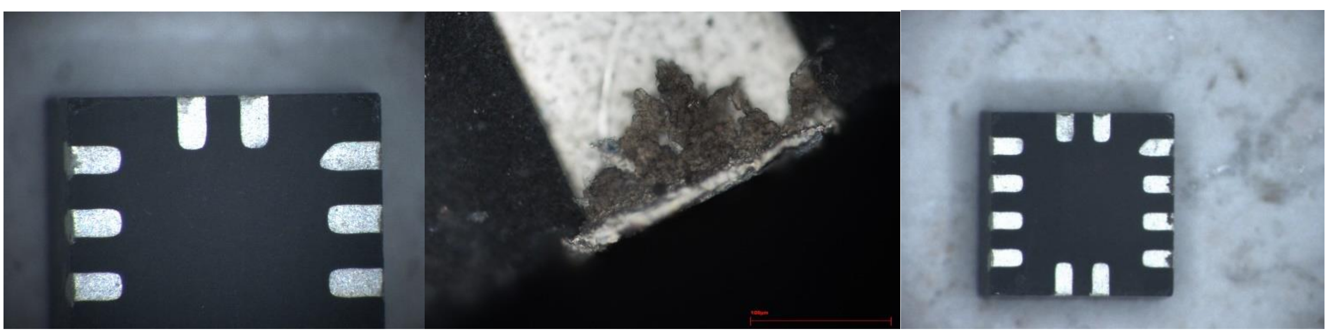


Figure 9. QFN-12 SED SEM analysis example of a soldering pad with the black spot analyzed. The black spots contain Silicon(Si), Carbon(C), and Oxygen(O), which indicate the presence of mold and oxidation (corrosion). Both are the result of exposure to humidity and environmental stress.

Further microscope inspection of components that did not go through production is presented in Figure 10. It shows the QFN-12 SED microscope images. (A, C): Rough surface finish caused by corrosion and evidence of old and corrosion at the edges of the leads. (B): zoom on mold at the edges of the soldering leads. As depicted, the surface finish, the corrosion marks, and the mold are also visible during the assembly by the SMT pick-and-place vision system.



(A) (B) (C)

Figure 10. QFN-12 SED microscope images. (A, C): Rough surface finish caused by corrosion and evidence of old and corrosion at the edges of the leads. (B): zoom on mold at the edges of the soldering leads.

Discussion

As seen in the results section, the surface finish quality of the soldering leads can be evaluated based on their image. The soldering leads and balls are made of inherently chemically unstable materials that age faster than all other parts of the electronic component. The surface of the leads grows an oxidation layer. In addition, intermetallic reactions in the leads are progressing with time [26]. Both degrade solderability in time. The degraded oxidation layer and the metallic morphology have a different appearance and reflectivity than that of the surface of a fresh lead.

The change in color and roughness changes the way light is reflected from the surface of the lead [27]. The change in reflectance is like the difference in reflectance between clear and tainted mirrors. The reason for the change in apparent texture is the morphology alterations occurring with aging. This was simulated and presented by [3] with the gradual change in surface morphology during thermal cycling, which simulates the aging of the leads. The surface is initially smooth, then during aging, it becomes curvy by the shifting of the metallic alloys and the growing of a brittle corrosion layer. It eventually produces breaks in the surface finish.

We classify the corrosion level of the leads by learning how the soldering leads of a component reflects light versus how a lead with corrosion does. In addition, the component's apparent age can be approximated based on the gradual degradation of the lead's reflectance.

This information is available by examining the surface of the soldering leads. We have found that visual analysis of the component image using artificial intelligence methods can detect the degradation of the soldering leads which causes corrosion. In order to train a model that correlates the image of the leads and its solderability, we have designed a neural network based on multiple images of leads. The corrosion level is estimated by deep learning methods performed on the images of the soldering leads of the components. It is imperative to note that the manufactured year does not directly reflect the real quality of the lead. This is due to differences in storage and handling conditions that may cause accelerated aging of the soldering leads, thus, degrading the "age" of the leads. In addition, there is a distribution of the conditions of the leads in both leads with good and poor leads conditions.

The neural network is designed to fit a linear regression model so that the distance from the input dataset to the line is minimized. The next step is to use the regression model to infer the age of components from the validation set.

We compare the predictions of the described algorithm with the failure analysis results in the production line to simulate real-life full-scale production. The detected failures in the components match the failure analysis results indicating that the method can be used to prevent failures caused by deteriorated soldering leads to corrosion contamination.

In addition, the presented cases demonstrated failure within the production site and during the post-assembly testing. The majority of corrosion-related failures will ensue after more extensive exposure to environmental stresses the product will encounter in the field. It is therefore imperative to determine a threshold that will prevent not only failure in the production site but also in the field. The presented method detection threshold can be calibrated to detect solderability issues that will fail in the production site, as well as corrosion contamination that will fail later in the field.

Conclusion

A non-destructive mass volume method for assessing the condition of the soldering leans of electronic components on deep visual inspection is presented. The method allows real-time assessment of all assembled components. It may be deployed during the SMT mounting process. The corrosion contamination level is correlated to surface reflectance and degradation in reliability caused by corrosion and intermetallic reactions on the surface of the leads. This may be illustrated as the reflection of a smooth mirror compared to an age-dulled mirror.

The inspected components' corrosion level is obtained by a multi-tier classification network that is looking into micro-features in the component's images. The network classifies leads to good and poor corrosion levels based on their apparent age and contamination detection. The method was trained based on a dataset of over 1 billion inspected components.

The method was deployed in full-scale production state-of-the-art production facility at Flex Migdal HaEmek for evaluation. Two cases of failures during the post-assembly tests were cross-checked with the AI inference results. The method was able to predict the failures and the failure modes on over 30,000 components with accuracy exceeding 99.5% tested on over 2.5 billion components.

The failure analysis revealed evidence of corrosion that penetrated the inner package of the component in one case, and corrosion and mold deteriorating the wettability and thus solderability in another case. The presented method predictions were in-line with the analysis report.

The described method avoids the placement of components with solderability and corrosion issues and verifies that only qualified components are used in production. Thus, avoiding failures in the field recalls, and reworks.

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