SOME KEY ELEMENTS FOR A BETTER RELIABILITY OF ELECTRONIC DEVICES, AND CONSUMER SATISFACTION

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1. INTRODUCTION

Reliability is one of the major attributes that define the choice of electronic components for safety-critical applications. Studying the reliability of electronic components is a natural tendency of human beings in the aim to prolong the life of a technical system on the world market; a company that manufactures electronic systems is trying to get the largest share of the market. For reaching this goal, in the design of reliable equipment, a good selection of the components to be used must be performed, with special focus on reliability issues, in order to minimize any failure risk. That is why it is recommended to study the reliability of electronic components as a necessity for obtaining a reliable system, which could be easily sold on the market [1].

Today, most of the companies understand that the reliability must be built in at the design phase and, then, monitored during the whole manufacturing process. *Reliability building* means the totality of techniques and procedures having the goal to ensure a foreseen reliability level for a given product. This concept is linked with *reliability assessing*, which cover the whole evaluation system aiming to find out and record, during and after the manufacturing process, the reliability level of the batch of products. This evaluation system contains tests, electrical measurements, failure analysis and statistical processing of data [2].

According to reliability building rules, the reliability issues must be taken into account even at the design of the process / product, the so-called design for reliability (DfR), and also during the manufacturing, by monitoring the process reliability. A special attention must be given to the selection of most reliable items from a batch of products, which could be made by screening or by burn-in.

Nearly every week, every day, we learn of another company that has failed; and this rate of failure will increase, while profit margins are shrinking, and information highway is changing the way consumers make buying decision. These changes have made it easier for consumers to choose the best product for their individual needs; they can now determine their product needs at any place, anytime, and for the best price. The information age allows today's consumer to research an entire market efficiently at any time and with little effort; conventional shopping is being replaced by "smart" shopping. A big part of smart shopping is getting the best product for the best price.

Manufacturers who did not participate in the quality revolution of the last decades were replaced by those that did. They went out of business because the companies with high-quality systems were producing products at a lower cost. Today, consumers demand products that not only meet their individual needs, but also meet these needs over time.

Reliability engineering should be an integral part in product and system development. Reliability engineering technology means all of the activities are necessary to assure that the product is safe to use, is appropriately designed and manufactured for ease of usage, is reliable in every day application, is durable over the expected useful life, and is producible at minimum cost. Reliability predictions, based on handbooks or similar approaches, are historically highly inaccurate and can lead to very poor design decisions. The design team is fully aware of the importance of high reliability, and reliability is given a high priority.

In many cases, significant improvements in reliability can be achieved at minimal cost, especially when reliability improvement is addressed as part of the design process. Without knowing the environment that a given component will see, or at least some reasonable bounds for the usage environment, a design team cannot be confident that a given component will be reliable. The manufacturer conducts early testing that is specifically designed to precipitate failures so that the design can be improved early in the program. The manufacturer conducts highly accelerated life testing and highly accelerated stress screening. These tests should be conducted with specific failure mechanisms in mind. Corrective actions need to be identified and implemented. The manufacturer uses reliability engineering and management tools like Failure Modes and Effects

Analysis (FMEA) and Reliability Growth. It is critical that these tools and analyses be directly linked to the design team.

Reliability improvement is a major goal in many applications. Accelerated life testing is a well known technique for reliability improvement of electronic systems. The reliability of a system is affected by the reliability of its components and the way they are interconnected to serve its intended mission under certain operating conditions. Failure of components due to fatigue crack growth is a major problem in industry. The failure process initiates with the presence of small cracks which can cause catastrophic fracture or slow crack growth. When treating a problem of this type, many aspects of the problem should be treated as random variables. The probabilistic finite element method (PFEM) has been shown to be a practical approach for solving problems of this type.

The reliability of an electronic system is a function of the reliability of its subsystems. The board on which the components are assembled is more important that these since its reliability seriously affect the reliability of the overall system. The reliability of the manufactured printed circuit board (PCB) is a function of both the reliability of the components used on the board itself. Many designers forget the importance of the underlying board in the reliability of the overall electronic system.

The inclusion of redundancy to a system to increase its reliability is expensive in weight and size as well as cost. At the same time operating costs decrease, as component reliability is increased, through savings in warranty costs, repairs, maintenance, shut down due to failure and restart time. An investigation into design improvements to unreliable components is likely to show that there is an overlap between the normal capability distribution curve of a particular item and its duty distribution (e.g. component strength capability and applied load distribution). To effect an improvement requires a safety margin between the two curves.

There are several ways in which designers can assist in improving the reliability and lengthen the life of products. These methods are discussed in the following sections.

2. EFFECTS OF ENVIRONMENT

The most important environmental components with respect to degradation of electronic devices are particles and water vapour.

Optoelectronics are playing increasingly important role in communications. Cost increasing bandwidth demand, and reliability are some of the reasons for the importance of optoelectronics in communication. The internet explosion, e-commerce, and the increasing data networks will continue this drive.

The reliability of most electronics is established by performing various accelerated life tests. These tests generally provide stresses that are much higher than those to be experienced in service. The purpose of these tests is to cause the component to fail, thereby identifying the weakest failure mode. The same mode of failure and the failure mechanism must be carefully characterized and observed at all the test conditions. Any deviation in the failure mode with change in stress conditions is an indication that the test may not be valid in predicting the failure at use condition.

For most electronics, these accelerated tests conditions are generally linked to the junction temperature. Hence, these components and the mechanisms that cause their failures are assumed to be thermally activated. It is also important to state that the mode of failure must not be confused with the failure mechanism.

The devices are tested at increasing time intervals; failed units are removed from test and failure analysis is performed. Cross-sectional analysis of the failed devices is performed. Scanning electron microscopy (SEM) and energy dispersive x-ray spectroscopy (EDS) are used to characterize the various interfaces. Surface sensitive Auger electron microscopy (AES) and x-ray photoelectron spectrometry / spectroscopy (XPS) are not successful in characterizing the interface to the silver epoxy.

In some instances, failed devices are revived by scratching the aluminium pad to the epoxy bleed out left behind a lot of epoxy that was difficult to sputter through, even after 24 hours, for AES or XPS analysis.

The main population failures are quite different from the weak population. Although the failure rate is decreasing in this population, it is temperature dependent.

At higher temperatures, the change in shape factor indicates that probably different degradation mechanisms are present. If the main population continues to fail at decreasing failure rates, this suggests that oxidants are being generated within the package to sustain oxide growth and cause failure.

If the failures observed within the screened population supports the assertion that at high temperatures, oxidants are being generated within the package, this proves the hypothesis. These oxidants cause aluminium oxidation and oxide growth. The oxidants are probably generated due to epoxy degradation.

Although the epoxy is cured at temperatures in excess of 110°C prior to package sealing, some of the reaction products might still be trapped within cured mass. These reaction products that are generally oxidants and high in water content subsequently outgas within the sealed package, cause device failure. Changing the metallization from the reactive aluminium to a noble element like gold can eliminate this failure mode and the associated mechanisms.

The degradation of the devices indicates that there are two distinct populations. One population is weak and fails quickly; the other, the main population, is more resistant to the degradation. The weak population is a small fraction of the total population.

A reliability model indicates that the weak population can be effectively screened from the total population.

3. ROBUST DESIGN

Robust design methodology comes a great way in improving engineering productivity. The customer satisfaction can be ensured when one considers the cost of failure of a product along with the noise factors such as environmental variation, manufacturing variation, and component deterioration. Robust design has proven to be very effective for improving quality, manufacturability, and reliability of products and processes at low cost, and simultaneously reducing development interval. Since the introduction by Taguchi [3] in the 1990s, the method has resulted in significant quality improvement in many industries.

Taguchi methods to robust design focus on the principles of producing higher quality goods faster and cheaper, with more consumer satisfaction. The idea is to develop a family of products or processes that are optimized so in the future all that is required is proper scale-up. These approaches use non-standard statistical analyses with a novel methodology to approach manufacturing processes, which can be applied in numerous ways.

The main principles behind the Taguchi method for robust design are: *(i)* Robustness is first, adjusting average to meet the target is last. *(ii)* To improve product quality, and product reliability[1], parameter design is first, tolerance design is last.

This "two-step" optimization technique utilizes the idea that improving the functionality of a process will reduce the variability, thus resulting in more precise control of the product quality. To incorporate the Taguchi method into product improvement engineering, three design criteria must be considered: (a) *System Design* - Development of a system to meet a defined objective. (b) *Parameter Design* - Selection and optimization of controllable parameters within the system. (c) *Tolerance Design* - Determination of limitations in variability for each parameter.

The most important advantages of robust design include providing a simple and systematic framework for identifying critical characteristics in products or systems, and achieving best quality and reliability characteristics while minimizing the variation and cost.

To maximize robustness engineers improve the intended function of the product and increase their noise to factors which can lead to a decrease in performance. Engineers can simplify their designs and the process to reduce the cost [4]. Results: *(i)* Improvement through quality, reliability, and durability. *(ii)* Manufacturing cost reduction. *(iii)* Design cycle time reduction. *(iv)* New knowledge.

Assuring quality, reliability, and safety is an integral part of product development. But companies often address product quality to late using disjoint processes with inadequate cross-functional communication. Non managing quality and reliability in an integrated way throughout the product lifecycle (Figure 1) is costly to companies, both in profitability and reputation.

Robust design is a very powerful tool to use during product development to minimize the sensitivity of the product performance to variations in the manufacturing condition and the variations in the environment the product is used. Robust design has been proved to be a very good tool to mitigate the sources of variation in the product development.

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[1] Product reliability is quantified as MTBF for repairable product and MTTF for non-repairable product. As the product matures, the weaker units fail, the failure rate becomes nearly constant, and products have entered what is considered the normal life period. As components begin to fatigue or wear out, failures occur at increasing rates. Wearout in industrial electronic devices is usually caused by the breakdown of electrical components that are subject to physical wear and electrical and thermal stress. It is this area that the MTBF calculated in the useful life period no longer apply. A product with an MTBF of ten years can still exhibit wearout in two years.

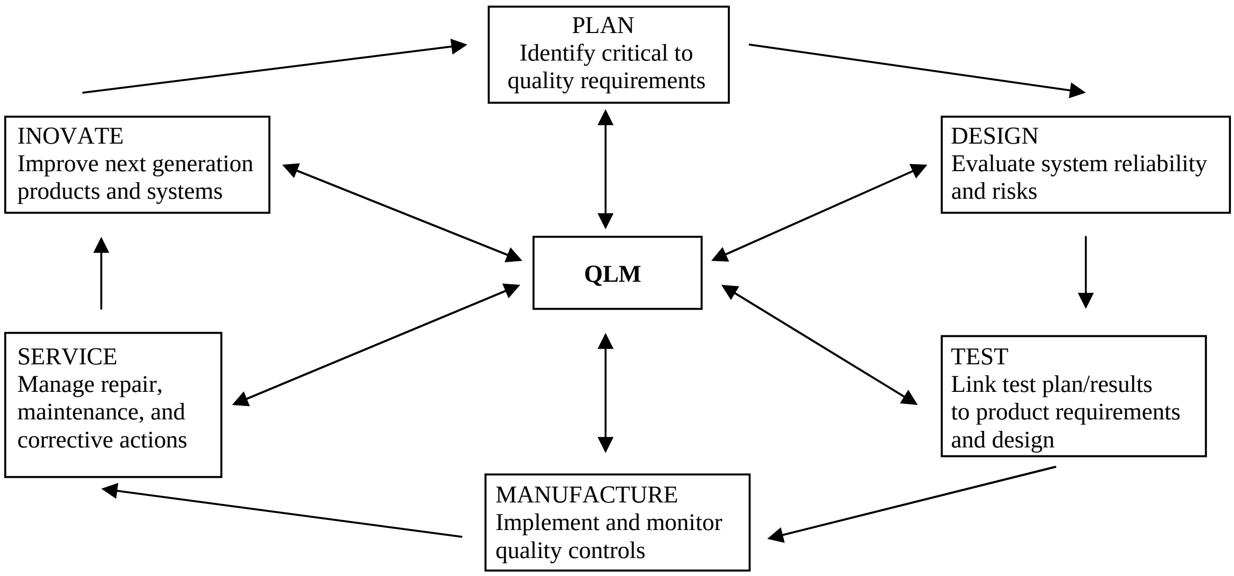

Figure 1. Quality lifecycle management (QLM) unites the quality-related activities of each stage in the product lifecycle through a single database platform (After [3]).

4. DESIGN FOR RELIABILITY (DfR)

Design for reliability aims to understand, identify and prevent underlying failures even before the devices are build. In developing the design for the products, the following characteristics are usually missed: *(a)* key failure modes and failure rate of the product, *(b)* key failure mechanisms that may be present in the service environment, *(c)* usable life of the product, *(d)* cost of maintenance required to maintain the inherent reliability, *(e)* availability, and *(f)* rigorous testing (Design for reliability and quality). This relatively new concept is an important step in building the reliability of a product or of a component (with other words, to achieve the built-in reliability), being linked with the concept called concurrent engineering (CE). CE is a feature that ensures the design is not completed before reliability requirements are identified and dealt with. Basically, the DfR consists of the following two elements:

a) A collection of design rules for making an electronic component reliable, not only electronically, but also mechanically and visually. The design rules have to be continuously updated, to reflect the best practices ensuring the maximum component reliability. *Robust design* and *thermal design* produce the major part of these rules.

b) Predictive methods able to asses the reliability of the future device, based on design data and on models describing the time and stress behaviour of similar products. An example of predictive method based on fuzzy logic, applied for the manufacturing of electronic components, is given in [5a].

The component reliability is influenced by the materials, the concept and the manufacture process, but strongly depends on the taking over input control conditions, so not only the component manufacturer, but also the equipment manufacturer may contribute to the reliability growth of the equipment. If the failure rate of the equipment is constant during the real life, this is a consequence of a good component selection during the manufacturing process. The choice of components makes the product.

The DfR approach starts with capturing the customer voice, translated in an engineering function [5b]. Then, a design immune to the action of perturbing factors must be created, and this can be done with the Taguchi methods. This means: *(i)* to develop a metric capturing the function while anticipating possible deviations downstream, and *(ii)* to design a product that ensures the stability of the metric in the presence of deviation. Finally, the design team must use reliable prediction methods. In principle, DfR means to pass from evaluate and repair to anticipate and design.

In recent years, several approaches to integrate robust design [6 - 11] have been proposed. The reliability-based design optimization (RBDO) is a method to achieve the confidence in product reliability at a given probabilistic level, while the robust design optimization (RDO) is a method to improve the product quality by minimizing variability of the output performance function. Since both design methods make use of uncertainties in design variables (and other parameters), the two different methodologies have been integrated to develop a reliability-based robust design optimization (RBRDO) method [12].

Physics of failure (PoF) is a key approach of implementing DfR in a product design and development process. PoF is knowledge of how things fail, and the root causes of failures. On the other hand, the PoF approach can be time intensive and not always definitive (limited insight into performance during operating life) [13].

A multi-objective framework for reliability-based robust design optimization was proposed, which captures degradation behaviour of quality characteristics to provide optimal design parameters [14]. The objective function of the multi-objective optimization problem is defined as quality loss function considering both desirable and undesirable deviations between target values and the actual results. The degradation behaviour is captured by using empirical model to estimate amount of degradation accumulated in time t.

5. PROCESS RELIABILITY

The reliability of a product depends directly on the quality of the manufacturing process. Once established, this quality must be kept at the same level during all the period of product fabrication, this feature being covered by the term process reliability. Process reliability is a method for identifying problems, which have significant cost reduction opportunities for improvements. Very often the problems have roots in the operations area [15].

In order to ensure appropriate process reliability, the following elements must be taken into account:

- Wafer-level reliability (WLR), notion which covers all the activities focused on achieving a reliability goal for the wafer: quality of the equipment, materials and environment, synergy of the technological factors, test structures for monitoring the reliability level, and so forth;
- Reliability-driven assembly process, meaning an assembly process which has sufficient tight controls where the reliability level is adequately monitored.

Device traceability (DT) and statistical process control (SPC) must be ensured during the previous two technological steps.

6. ENVIRONMENTAL STRESS SCREENING (ESS)

ESS is a process in which environmental stimuli, such as rapid thermal cycling and random vibration, are applied to electronic devices in order to precipitate latent defects to early failure. An equally important and inseparable aspect of the screening process is the devices electrical testing that is done as part of the screen, so as to detect and properly identify the defects that have been precipitated to failure.

Contrary to popular belief, ESS does not increase the inherent reliability of a product. The inherent reliability of a product is driven primarily by the design. ESS is not a substitute for, but an integral part of a sound reliability program conducted during the design and development phases.

Changes in manufacturing techniques may eliminate some latent defects and introduce new ones. To remain effective, the ESS program must evolve.

7. RELIABILITY CENTRED MAINTENANCE (RCM)

RCM focuses on preserving system functions by identifying, characterizing, and prioritizing the failure modes that can cause functional failures. As described by Mubray [16], the application of RCM is associated with the application of seven basic steps: *(i)* Identification of functions and their associated desired performance standards; *(ii)* Definition of functional failure; *(iii)* Identification of failure modes; *(iv)* Documentation of the effects of failure; *(v)* Quantification of failure; *(vi)* Analysis of functions, functional failures, failure modes, and their criticality to identify opportunities for improving performance or safety; *(vii)* Establishment of maintenance tasks.

Once the described methodology is applied, the desired optimization of maintenance of system is achieved, and the following too achieved: greater safety and environmental integrity; longer useful life of equipment, optimal spare parts inventory and a comprehensive database of failure modes and actions to prevent them.

8. A NEW HYBRID METHODOLOGY

The paper [17] presents a hybrid methodology for conceptual design of large systems with the goal of enhancing system reliability. It integrates the feature of several design methodologies and maintenance planning concepts with the traditional reliability analysis, characterized by technical improvements, higher reliability, and customer satisfaction at the minimum cost. By bringing the reliability early in the conceptual design stage, higher reliability and lower cost can be achieved.

9. NANOTECHNOLOGIES

Research and development pursue the further miniaturization of devices; the integration of semiconductor electronic devices with various materials and functions is essential for the sustainable development of microelectronics in the future. The “more than Moore” approach is aimed at the development of semiconductor electronic devices by the diversification of functions and the improvement of the performance of systems by the introduction of new technologies, such as MEMS technology.

Recent technologies that realize low power consumption using new materials and structures rather then by miniaturization are sometimes classified as “more than Moore” technologies. In contrast, “beyond CMOS” refers to approaches used to create devices that exhibit performance exceeding that of CMOS on the basis of different principles from those of CMOS. “Beyond CMOS” includes the approach of information processing using the degree of freedom other than electric charges (Figure 2).

10. NANOMATERIALS

In recent years nanomaterials have attracted increasing amounts of attention based on their novel electronic, mechanical, chemical, and quantum confinement effects. In particular, carbon nanomaterials such as fullerenes, nanotubes and graphene have been the focus of intense attention due to their exceptional electronic and mechanical properties. However, aside from the diverse suite of highly attractive properties of these materials it has become increasingly apparent that in order to successfully utilise these materials in real-world technological applications, novel integration strategies between the nano and the macroscopic world will be critical to their application. In order to do this, the chemical functionalisation and thus compatibilisation of nanomaterials has been identified as a principle strategy towards this goal.

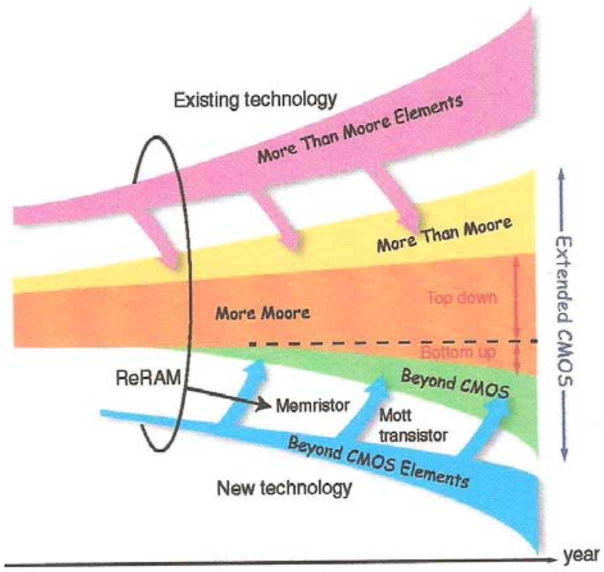

Figure 2. Relationship among three research directions of “more Moore”, “more than Moore”, and “beyond CMOS” (After [19]). The device technologies based on “more than Moore” and “beyond CMOS” are accelerating the research and development of device technologies based on “More Moore”, expanding the range of applications of CMOSs.

Research activities concerning carbon nanotubes and their chemical functionalisation have begun, in order to facilitate self-assembly with nanoparticle materials. This strategy was highlighted as a viable means to directly control the assembly of hybrid nanomaterials. It was followed the presentation of research concerning graphene and graphene oxide and the strategies of doping and chemical functionalisation in the context of electronic devices and mechanical composites. Following the enormous interest in 1D and 2D carbon nanomaterials, alternative materials have received much attention on account their electronic, mechanical and optical properties. The surface functionalisation of these novel nanotube and nanosheet materials is introduced and discussed in the context of their utilisation as electronic devices and their application as substrates, dopant, dielectric, and barrier layers for electronic devices.

11. NANOPACKAGING

We touch on two important measurement topics: evaluation of coating protection and measuring the performance of high temperature interconnects. Ranges of coating materials are now available with varied properties that can be selected for specific applications. The protection can be measured using Surface Insulation Resistance (SIR) testing; the results highlight the importance of coverage. Another key performance indication is the adhesion strength of the coating to the substrate, and a newly developed test method, where the adhesion challenges lie. Finally, measuring the whisker mitigation potential by coatings has a great importance.

There increasingly is a desire to place electronics in high temperature environments, down well applications for example. Sintered silver joints once formed with their high melting point offer an attractive solution to the interconnect issue. To date sintered silver is not offered as an interconnect solution for surface mount assembly, but have found applications in high power semiconductors. The mechanical performance and the fatigue properties of these interconnect can be measured.

12. QUALITY AND RELIABILITY IS AT RISK

Advance technology development and wide use of the World Wide Web have made it possible for new product development organizations to access multi-sources of data-related customer complaints. However, the number of customer plaints of highly innovative consumer electronic products is still increasing; that is, product quality and reliability is at risk. The paper [20] aims to understand why existing solutions from literature as well as from industry to deal with these increasingly complex multiple data sources are not able to manage product quality and reliability. Three case studies in industry are discussed. On the basis of the case study results, this paper also identifies a new research agenda that is needed to improve product quality and reliability under this circumstance.

13. CONCLUSIONS

There are many problems and challenges which must be overcome during the implementation phase of all projects. Some are overcome with engineering redesign and hard work, while others require more investment by the manufacturer.

Altering the layout of a printed circuit board (PCB), reducing the number of electronic components in a device, or choosing a capacitor with a different base material are all methods of tackling the critical issue of improving product reliability. Self regenerating systems offer an opportunity to increase life and reliability of products, with an additional benefit of an extension in the period between overhauls. Usually there will be a higher initial cost, due to greater complexity in a design that incorporates regeneration arrangements; normally this can only be justified if there is likely to be an overall saving due to reduced operating costs. One exception might be where extremely high reliability and long life are vital criteria.

It is important to recognise the value of overload protection as a method of enhancing life and reliability, especially now that electronic sensors, possibly coupled with micro-computer control, offer rapid response; the cost of an electronic protection system is unlikely to be a constraint.

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