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Editorial

Editorial for Special Issue on Reliability Analysis of Electrotechnical Devices

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1. Introduction

Advancement in electrotechnical devices has indeed revolutionize our daily lives. It will be hard to imagine going through our daily lives without cell phones, computers, and internets, to name a few. Consequently, our reliance on electrotechnical devices has been increasing significantly, and thus the dependability of these devices is becoming crucial.

Dependability of a device is determined by its reliability and its constituting components therein. Reliability is defined as the probability that a product, system, or service will perform its intended function adequately for a specified period of time or will operate in a defined environment without failure. The component of reliability is as depicted in Figure 1 to the following: The components of reliability include probability, durability, dependability, availability and quality over time [1].

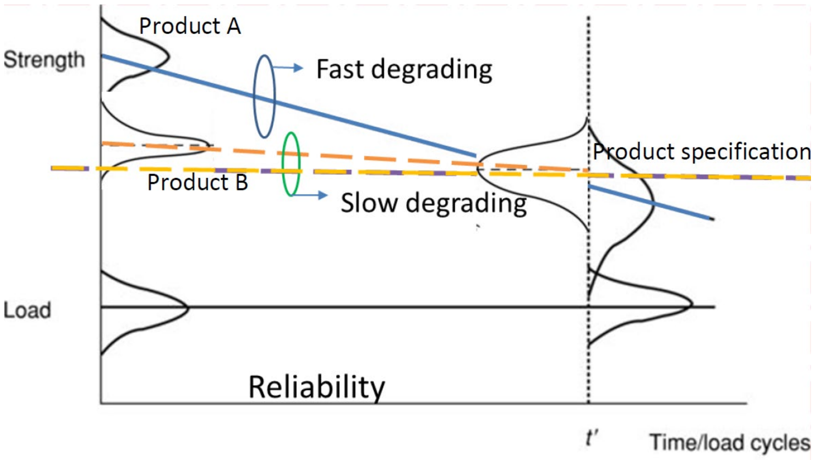

Figure 1. Different between Reliability and Current Quality Practice.

Although reliability is part of quality as can be learnt from the definition of quality according to ISO8402, which stated that quality is the totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs [2]. These stated or implied needs of course include the operation of products at prolonged period or its mission lifetime. However, due to the impossibility to check the reliability of every single product, as reliability tests usually involve time-consuming and destructive measurements, quality assurance can only assure the quality practice of the incoming materials, manufacturing processes through SPC, Cpk and yield, and product outcoming quality check against specifications. This renders a risk in the reliability of the products as depicted in Figure 1.

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Figure 1 shows the strength distributions of two product batches, A and B. As the strength of the products in batch A is well above the specification, its quality at time zero is consider excellent whilst products in batch B suffers some yield loss. In both cases, their strengths are above the expected load to be applied to them, and hence they can operate without failure. During continuous operations, the strengths of products will degrade as expected. Thus, their mean strengths will be reduced, but the spread of the strength distribution increases since not all the products in a batch will degrade equally. If the degradation rate of products in batch A is much higher than that of batch B, some products in batch A will go below the load at time t′, and some failure will occur. Such failures are considered as reliability failure. On the other hand, there is no failure for products in batch B, although its yield is not 100%. This figure explains the limitations of the current quality assurance methodology as degradation rate can only be found through reliability or accelerated life test. Even if reliability test is performed but with no failure, degradation rate will not be able to determine either.

However, the determination of the degradation rate can be time consuming and cost intensive as the number of failures in a selected accelerated life test must be sufficient to provide a good estimation of the degradation rate of a batch. Furthermore, the choice of accelerated life test must correspond to the dominant failure mechanisms of the products in normal field operating conditions, and this requires detail failure analysis of field failure if the product is already in the market or a good understanding of the possible various failure mechanisms before the products are launched.

To address the above-mentioned, and in view of the short time to market available for products, a new research area has recently emerged where the physics of failures and material sciences are employed to explore the various possible degradation mechanisms with the aid of powerful simulation tools. Statistical concept is also incorporated in the simulation to show the possible variation in the time to failure and reliability statistics is employed for the extrapolation of time to failure from accelerated test conditions to different field operating conditions. Such research area is called reliability sciences where experimentation, multi-scale simulation, atomistic finite element modelling and statistics are used concurrently, so that reliability of components can be predicted before the assembly of the final product. In this way, the reliability of a product will be determined beforehand, allowing for faster and cheaper modifications, before 'final' products are developed. This is a paradigm shift in product reliability assurance, and current reliability evaluation, when performed on the final product, would then act as secondary measurements, confirming the initially predicted reliability [3].

This special issue focusses on the exploration of the underlying degradation sciences. We focus on technical important devices, including antenna for IoT, 3D stack-chips for today high-performance integrated circuit assembly, Lithium-Ion battery (LiB) for electric vehicle and energy storage, devices in radiation environment such as space applications as the demand for satellites increases for IoT applications and medical applications, and printed circuit board assembly for wireless communication in public transport. As accelerated life tests for some highly reliable products can be too long, degradation analysis is employed. Improving the accuracy of the degradation test data analysis with respect to the measurement errors is also included in this special issue.

2. Electromagnetic Interference for Stack-Chips and Antenna

3D stack-chips are becoming common due to the increasing complexity of circuits and the requirement of small outline for an integrated circuit. Various factors can affect their reliability such as the stress induced from TSV [4], thermal dissipation effectiveness in the dense and 3D structure of the chips [5]. One of the advantages of using 3D stack-chip is the low latency of the interconnections for high-speed operation [6]. However, such high-speed operation can also induce electromagnetic field that can couple to the dices above and below, due to their proximity, resulting in serious electromagnetic interference

(EMI) between the dices. Dipesh et al. first examined such issue using electromagnetic computation method apply to integrated circuit.

They found that near field electromagnetic measurement is ineffective to identify the hot spots of electromagnetic emission within the stacked dies, and they thus developed a computational method to identify the electromagnetic emission hot spots in integrated circuits with experimental verification. They found that if the stack distance between dices is too small, the coupled magnetic field strength can be as high as 16 times as compared with an unstacked IC. Thus, a minimum distance between the stack must be maintained. The method they developed can be carried out at the IC design stage before fabrication, enabling optimization of the stack distance as well as circuit design for reducing the EMI, and eliminating the significant cost of fabrication owing to improper design.

Using the method developed, they also identified the key dimensional parameters of a miniaturized single element of T-shaped MIMO antenna which is commonly used today for data communication. They found an optimized antenna with 1 GHz improvement in the bandwidth due to the improved return loss that provides new opportunities for the antenna's utilization in different applications. This optimized antenna has lower current distribution that gives lower power dissipation, and its 1 m sphere EMI was also reduced.

These are examples of using computational power to ensure good performances and lower power dissipation, which in turn can lead to better durability.

3. Electronic Devices under Radiation Environment

Radiation on electronics is no longer limit to space application only. Advances in semiconductor technology have enhanced the functionality of integrated circuits (ICs) with reduced feature sizes down to nm. Proton and neutron radiation are always present around us but have not been detrimental to electronics at sea level. With the decreasing feature size of transistors and the increasing density of transistors in ICs, the effect of radiation on the reliability of semiconductor devices, sensors, and their electronic circuits (collectively called electronic systems) is no longer negligible, even at sea level. ISO26262 International safety standard states the requirements for automotive electronics to be radiation immune to a certain level. Thus, radiation reliability of electronics is an emerging area that cannot be neglected [7].

Although the dominant radiation source at sea level for electronics is neutron, neutron radiation test is rarely available due to the control difficult for neutron beam. Chiang et al. investigated the possibility of having proton to replace neutron for electronics using Monte Carlo simulation, and they found that 200 MeV protons closely resemble the effect from neutron radiation, and this concur with the suggestion from NASA, USA. They also used the Monte Carlo simulation to demonstrate the invalidity of the conventional concept of using linear energy transfer (LET) of radiation particles to estimate the single event effect (SEE) in electronic devices. Instead, lineal calculation of energy lost per step for each specific track should be used for the prediction of microelectronic devices failure due to SEEs. With such Monte Carlo simulation, they managed to predict the radiation reliability of microelectronics devices.

The increasing application of radiation therapy in medical treatment and diagnosis has also subjected the medical electronics to radiation. X-ray is a familiar example which subjects electronics to photon radiation, and the emerging proton therapy is another example which subjects electronics to stray proton radiation. Silicon devices are vulnerable to radiation, and to improve the reliability of the radiation system with good electronic control, Gallium Nitride (GaN) devices are suggested. Vimal et al. developed a GaN-based readout system in proton therapy treatment system. In particular, they designed an operation amplifier (OPA) which is a basic circuit module for the electronic in the readout system using GaN and simulation results indicated good performances. The proposed OPA was also configured for different applications such as transimpedance amplifier, integrator, and the adder which are needed in the prompt gamma readout system. Simulation results show successful operation for these applications. When these different applications are put together, a complete GaN-based prompt gamma readout circuit is implemented, and the result shows successful processing of the prompt gamma signal where its energy and position of the proton beam in a human body can be accurately provided for subsequent digital conversion and information extraction.

The increasing demand of IoT also prompt the significant increase in the need of satellites for communication. Radiation effects should be carefully monitored for the reliability of the electronics of satellites in the outer space, but radiation hardened electronics are too costly for IoT applications. In addition to the electronics components used, the solder joints of components onto printed circuit board also need to be reliable. It is found that the reliabilities of the commonly used Sn/Pb and SnAgCu solder joints are not good under the thermal shock conditions in the outer space. Guo et al. proposed an environmentally friendly interconnection material, namely pressureless sintered micron silver which is economical. Before predicting the reliability of this material in the proposed applications, the degradation mechanism of this material under the deep space environment was studied. They employed finite element analysis (FEA) to study the degradation physics, and their results were verified with their experiments. Their studies showed an elasticity degradation during the thermal shock, which induces lattice shift and dislocation slip in the microstructure. The dislocation piling up causes the effective elastic modulus of sintered joints to decline due to broken atomic bonds. With the understanding of the degradation physics, degradation model can be developed to extrapolate the lifetime of such material from accelerated test condition to predict its reliability and suitability in deep space usage.

The increasing important of electronics operating under radiation environment can be seen from the above description, and from the above few works, one can see that there are still a lot more work needed in this area.

4. Remaining Useful Life (RUL) of Lithium-Ion Battery (LiB)

While product lifetime can be predicted through reliability tests in most cases, field reliability is likely different. A typical rule of thumb is to expect the unreliability in the field to be twice what was observed in the lab. This is because product will usually receive harsher treatment in the field than in the lab. Units being tested in the labs are often carefully set up and adjusted by engineers prior to the beginning of the test. The tests are performed by trained technicians who are adept at operating the product being tested. Most end-use customers do not have the training and experience in its operation, thus leading to many more operator-induced failures than would be experienced during in-house testing [8].

In some cases, accelerated life test cannot be performed such as LiB and other highly reliable products. This is because accelerated test condition for LiB can affect the chemistry in LiB and the degradation mechanisms will be completely different from that operate at normal condition. For highly reliable products, the test time is simply too high and accelerated degradation tests usually employed.

Regardless of the situations, ability to estimate the remaining useful life of a product, as it might have been through various operating conditions, will be useful. Tan et al. developed a methodology to estimate the RUL for LiB. Their method combines the electrochemistry-based electrical model and semi-empirical capacity fading model on a discharge curve of a LiB for the estimation of its maximum stored charge capacity, and thus its state of health (SoH). The method developed produces a close form that relates SoH with the number of charge-discharge cycles as well as operating temperatures and currents, and its inverse application allows us to estimate the remaining useful life of LiB for a given SoH threshold level. The estimation time is less than 5 s as the combined model is a closed-form model, and hence it is suitable for real time and on-line applications.

5. Degradation Analysis

With the increasing product reliability, prediction of lifetime through accelerated life test can be too long, and degradation analysis is usually employed. However, in most degradation tests, the measuring processes may cause variation in the observed measures.

As the measuring process is inherent to the degradation testing, it is important to establish schemes that define a certain level of permissible measurement error such that a robust reliability estimation can be obtained. Rodriguez-Picon et al. proposed an approach to deal with this measurement error based on a deconvolution operation. An illustrative example based on a fatigue-crack growth dataset is presented to illustrate the applicability of the proposed scheme.

6. Failure Analysis

Failure analysis is common in electronic industry; however, the depth of analysis needs to be further to uncover the underlying science of the failure mode. Physics of failure is needed to ensure product reliability as only then root cause can be identified. Tan et al. demonstrated a step-by-step failure analysis methodology for multilayer printed circuit boards that led an observed failure mode to the root cause with verification of the root cause and the effectiveness of the corresponding corrective action. This printed circuit board (PCB) is used in public transport systems. With the identified root cause, a modified processing method was developed and the observed failure mode was no longer observed with this modified method, which verified the root cause. The PCBs with the modified processing method also underwent appropriate reliability tests and the corrective action of this modified processing method is confirmed.

Li et al. performed detail failure analysis on failure obtained from low temperature and shock test that mimic deep space exploration. They found that the failure was in the Pb-free (Sn-3.0Ag-0.5Cu) solder joint, and the low temperature changes the fracture characteristic of Sn-3.0Ag-0.5Cu (SAC305) from ductileness to brittleness. The crack occurred at solder joints from the stress loaded by shock test. When the crack reached a specific length, the failure occurred. A verification test was conducted to verify the failure mechanism. The transition temperature range of SAC305 was also confirmed as -70–-80 °C.

7. Future Outlook

Reliability of products is an implicit expectation from users, but the current quality assurance method is limited to provide sufficient information to assure product reliability. Reliability tests on products are also facing challenges as mentioned earlier, and a paradigm shift is on the reliability science. This is an important and emerging area in reliability, and it requires professional from different disciplines to come together and share their works so that we can gel the different aspects of reliability science together. With the increasing variety of electrotechnical devices in increasing application areas, many research works are expected. We look forward to seeing the explosion in this area.

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