Challenges Related to Reliability in Nano Electronics

To Build for the Future, we must achieve major advances related to reliability in addition to exploring and discovering interdisciplinary connections in important cutting-edge research areas. The technologies for today's design and manufacturing have for some time been steadily moving from the realm of the micro- to the nano-scale, but advancements in reliability have not kept up with the pace!

Reliability and Nano Technologies

New ideas and connections stimulated by modern advancements are appearing in the bio, energy, and computing fields while design, manufacturing, and reliability modeling are being left behind. For example, fabrication technologies for integrated circuits are on the edge of the nano scale, with a gate length of less than 100 nm in the most advanced microprocessors [1], [2], and some capacitors are already available on a scale of 1–2 nm equivalent oxide thickness [3]. In particular, microelectromechanical (MEM) devices are integrating mechanical motion with electronics on the micro-scale, and thereby, generating novel approaches to applications and new industries. Furthermore, we are already developing the scientific base—nano theory, fabrication science, materials sophistication, and manufacturing capabilities—for a full-scale assault on nanotechnology. But we must ask if the manufacturing community is ready for producing nano devices, and whether the reliability community is ready to certify proper use of these nano devices-based systems.

Even more fundamentally, we must ask: what is the meaning of reliability for systems that use nano or new technologies, and how do we interpret this meaning in practice? For example, are consumers likely to be satisfied with high cost plasma TVs with an estimated 4-year expected life? As reliability engineers, we must not only bridge multiple cutting-edge disciplines to complement the technology-rich industries, but also be leaders in guaranteeing that high tech products and systems perform to acceptable modern standards.

The activities associated with nano development are expected to enhance international understanding and collaboration for a bright, fast-moving future in design, manufacturing, and industrial innovation. Reliability research and development work in the past has contributed to the industrial world by enhancing the quality of the products. The academic community has also played a critical role in the process by making fundamental discoveries that have contributed to the realization of this quality enhancement. Examination of the numerous issues and papers published *by IEEE Transactions on Reliability* over the past 55 years clearly demonstrates the significance of the academic role in the advancement of our field.

However, it is also important to recognize that recently our profession seems to have stagnated in terms of making new contributions to the emerging technologies, electronics and otherwise. How much have we contributed to the reliability of the existing, reliable MEMS and nano devices?

Although reliability is very much a central concern in nano technologies, the reliability community has made little progress in developing new methodologies and standards that are applicable in this realm. Instead, we seem to be leaving that up to the industrial practitioners who had not been rigorously trained in reliability.

Four Challenges

There appear to be four major challenges related to nano electronics that currently face the field of reliability: identification of the failure mechanisms, enhancement of the low yields of nano products, management of the scarcity and secrecy of the available data, and preparation of reliability practitioners and researchers for keeping up with the nano era.

Identification of the Failure Mechanisms

As new generations of nano electronics are invented almost daily, we become less familiar with the failure mechanisms of these devices, and the reasons behind the failures. With our existing knowledge, we often can not identify the correct faults; and in fact, we are likely to see many no-fault-found failures. Nor can we manufacture reliable products with full confidence.

Shorting (e.g., inadequate etching processes or insulating structure), and opening (e.g., electromigration of nano wires) of interconnect lines caused most of the failures in traditional electronic products. Will the new trend be toward more open / resistive related failures because of the new materials, large number of contacts/vias, higher functional speeds, new circuit design rules, and other factors? Identifying the failure mechanisms in nano electronics will have impact on determining the right strategies for life testing, highly accelerated stress screening (HASS), burn-in screening for reliability enhancement, reliability prediction, warranty duration and conditions, and many other processes. The hurdle in comprehending nano failure mechanisms seems greater than previous hurdles that dealt with similar issues in the past. We are unsure as to whether much of the knowledge that is based on past technologies is still valid for reliability analysis. Understanding the failure mechanisms of nano electronics is critical for preparing system designers to better utilize nano devices, and design better fault tolerant systems.

Enhancement of the Low Yield in Nano Products

The development of nano devices, such as those used in commercial and military systems, has generated a lot of excitement. However, the low yield rate [2], [4] of current nano devices, typically 10% or lower, is very troublesome. Low yield makes production extremely expensive, and the product's expected life

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uncertain. The low yield also creates a challenge for both the designers and scientists to find better materials and fabrication tools. At the early nano product fabrication stage, low yield is actually a technology agenda, rather than a logistics issue, although some believe that scheduling & logistics optimization can improve the yield. Although low yield is a fundamental material-related problem that modern reliability engineers must face in order to improve yield at an affordable cost, it is also a design issue because many modern systems are increasingly complex, and the product life cycles are often too short to achieve better yield.

Management of the Scarcity and Secrecy of Available Data

Manufacturers have always kept reliability and yield data secret, or not kept it at all. The problem is compounded by the scarcity of failure data, which makes it almost impossible to use traditional reliability analysis tools and statistical inference to make useful predictions. Therefore, experienced analysts have to perform in-house analyses using *ad hoc* approaches. Despite that many statisticians have in the past been against using the Bayesian approach because of the "lack of credibility" associated with it, we are now forced to be more Bayesian than ever before.

In fact, many engineers have always used the Bayesian approach successfully, although in the eyes of the theoreticians, their methodology has not been mathematically rigorous. It is important to note that the Bayesian approach is more than a tool—it is also a philosophy. Many academic statisticians have contributed to theories of reliability; on the other hand, it is perhaps more obvious that the empirical approaches used by reliability engineers have improved numerous products and systems for consumer use. We predict that the Bayesian approach will be even more frequently utilized in the nano era as product life cycles based on new technologies become even shorter, and it is becoming impossible to obtain sufficient data before a new product requires reliability assessment.

Given the useful life of many products is short (not necessarily because of reliability concerns, but more because of using the new nano technologies which may provide the users with more features) before the customers express an interest in using the new products, is the traditional life-cycle analysis still valid?

Preparation of Reliability Practitioners and Researchers for Keeping Up With the Nano Era

As society adapts to the nano and bio world, and we integrate these technologies into more complex systems, it becomes ever more important to hold products accountable, and to require better quality and reliability from them. To cope with this challenge, modern statisticians and reliability engineers need to re-engineer themselves to learn about the nano world. In order not to be left behind the modern society in terms of technology advancement, researchers must become less bogged down in the old, purely academic exercise of separating hypothetical problems from real world problems, and applying only mathematically rigorous approaches.

Reliability academicians need to become more problem-driven than hypothesis-driven. Reliability faculty must update their course materials as well. Biostatisticians appear to be doing a better job of dealing with the fast-changing bio world than we are doing in dealing with the nano electronics. Perhaps they can serve as role models. Therefore, in order to be relevant, reliability specialists need to be versed in modern technology; reliability analysis, and modeling for the nano technologies will have to be more physics-based. At the system level, we need to learn how to integrate nano technologies into larger systems so that interfaces between technologies are reliable, and better understood.

New Energy

High reliability and high yield are necessary to guarantee the advancement & utilization of micro, and nano products. Reliability researchers need to be energized to tackle the very real problems that we face in the nano-rich world. Reliability practitioners and researchers need to understand the paradigms and issues, such as those listed above, involved in the nano technologies.

Keeping systems simple is important; otherwise we will add more uncertainties to the compatibility problems [5], [6]. The research dealing with the understanding and application of reliability at the nano level has demonstrated its attraction and viability. Optimal system design that considers reliability within the uniqueness of nano systems has hardly been reported in the literature, and hence deserves a lot more attention. We must share our reliability experience with designers so that, in the future, they can consider other options (e.g., to be more fault-tolerant) when dealing with large, complex systems using nano technologies.

I anticipate that our society will expect reliability specialists to take heavy responsibility for utilizing & certifying the use of nano technologies. To that end, we must break out of this period of disciplinary stagnation, and redouble our efforts to prepare ourselves to advance the state of the art of the nano technologies.

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