Solid State Lighting Technology and Application Series

W.D. van Driel
X.J. Fan
Editors

Solid State Lighting Reliability

Components to Systems

Springer

Solid State Lighting Technology and Application Series

Series Editor
G.Q. Zhang

For further volumes:
http://www.springer.com/series/8864

W.D. van Driel • X.J. Fan
Editors

Solid State Lighting Reliability

Components to Systems

Springer

Editors
W.D. van Driel
Philips Lighting
Eindhoven, The Netherlands

X.J. Fan
Department of Mechanical Engineering
Lamar University
Beaumont, TX, USA

ISBN 978-1-4614-3066-7 ISBN 978-1-4614-3067-4 (eBook)
DOI 10.1007/978-1-4614-3067-4
Springer New York Heidelberg Dordrecht London

Library of Congress Control Number: 2012943579

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

Solid state lighting (SSL) is recognized as the second revolution in the history of lighting. The primary reason is the annual global energy bill saving of €300 billion and a reduction of 1,000 MT of CO_2 emission. As such, the SSL industry is expected to exceed €80 billion by 2020, which will in turn create new employment opportunities and revenues. A second reason is the promise of a long useful lifetime, with claims up to 80,000 h. As with any products, the consistency and reliability of SSL systems need to be ensured before they can be adopted in any applications. To add to the complexity, there is also a need to ensure that the cost of this technology needs to be comparable or even lower than the current technology. Although SSL systems with low reliability requirements have already been developed, they can only be used in applications that operate in modest environments or in noncritical applications. For demanding applications in terms of environmental conditions, such as automotive application, or where strict consistency is needed, such as healthcare applications and horticulture applications, the conventional lighting sources are currently still preferred until the reliability of SSL is proven in these applications. Therefore, the knowledge of reliability is crucial for the business success of SSL, but it is also a very scientific challenge. In principle, all components (LEDs, optics, drive electronics, controls, and thermal design) as well as the integrated system must live equally long and be highly efficient in order to fully utilize the product lifetime, compete with conventional light sources, and save energy.

It is currently not possible to qualify the SSL lifetime (10 years and beyond) before these products are available in the commercial market. This is a rather new challenge, since typical consumer electronics devices are expected to function for only 2–3 years. Predicting the reliability of traditional electronics devices is already very challenging due to their multidisciplinary issues, as well as their strong dependence on materials, design, manufacturing, and application. Predicting SSL reliability will be even more challenging since they are comprised of several levels and length scales of different failure modes. The tendency towards system integration, via advanced luminaries, System-in-Package approaches, and even heterogeneous 3D integrations poses an additional challenge on SSL reliability.

A functional SSL system comprises different functional subsystems working in close collaboration. These subsystems include the optics, drive electronics, controls, and thermal design. Hence, there is also a need to address the interaction between the different subsystems. Furthermore, an added challenge for system reliability is that accelerated testing condition for one subsystem is often too harsh for another subsystem. Alternatively, even the highest acceleration rate possible for one subsystem may be too low to be of any use for yet another subsystem. Hence, new techniques and methodologies are needed to accurately predict the system-level reliability of SSL systems. This would require advanced reliability testing methods, since today's available standards are mainly providing the probability at which LEDs may fail within a certain amount of time.

Today, no open literature that covers the reliability aspects for SSL exists, ranging from the Light Emitting Diode (LED) to the total luminiare of a system of luminaries. This book will provide the state-of-the-art knowledge and information on the reliability of SSL systems. It aims to be a reference book for SSL reliability from the performance of the (sub-) components to the total system. The reliability of LEDs and all other components (optics, drive electronics, controls, and thermal design) as well as the integrated system of an SSL luminiare will be covered. Various failure modes in SSL luminiare will be discussed. Different reliability testing and luminiare reliability testing performance will be introduced. The content has an optimal balance between theoretical knowledge and industrial applications, written by the leading experts with both profound theoretical achievement and rich industrial experience. Parts of the contents are firsthand results from research and development projects.

This book is part of a series on Solid State Lighting, edited by Prof. G.Q. Zhang. The series will systematically cover all key issues of solid state lighting technologies and applications.

Eindhoven, The Netherlands W.D. van Driel
Beaumont, TX, USA X.J. Fan

Acknowledgments

We would like to thank all the authors for their contributions to the book. van Driel and Zhang would also like to make acknowledgments to many of their colleagues in Philips and the Delft University of Technology who have contributed to this book in one way or another.

van Driel is grateful to his wife Ruth Doomernik and their two sons, Juul and Mats, for their support and love. Fan is grateful to his parents for their unselfish support and love.

Delft, The Netherlands G.Q. Zhang

Contents

Chapter 1
Quality and Reliability in Solid-State Lighting

T. de Groot, T. Vos, R.J.M.J. Vogels, and W.D. van Driel

Abstract Quality is the totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs. By this definition, quality is fuzzy but the needs are quantified by so-called critical to quality parameters (CTQs). Reliability is the probability that a system will perform its intended function under stated conditions for a specified period of time without failures. By this definition, reliability is a measure as function of time and, thus, a quantity. Reliability is often said to be the "quality over time," but this in not correct. Reliability has its own measures, so-called critical to reliability parameters (CTR), that can have a relation to the CTQs. This chapter gives a brief history of quality and reliability, their interaction and the impact for the change within lighting into the solid-state era.

1.1 Brief History in Quality

Quality and reliability both have a long history [1, 2]. No individual can claim "I invented quality" or "I invented reliability." Such simplistic hero worship has no basis in fact. Archeological sites, ancient cities and modern museums provide convincing evidence that "invention" of quality and reliability has been a continuing process over the millennia. There are inventions of several crucial techniques and/or methods such as the control chart (Shewhart), the Pareto principle (Juran), Weibull functions (Weibull) and the cause-and-effect fish bone diagram (Ishikawa). The application of such techniques in a successful manner better defines quality and reliability.

T. de Groot • T. Vos • R.J.M.J. Vogels • W.D. van Driel (✉)
Philips Lighting, Mathildelaan 1, Eindhoven BD 5611, The Netherlands
e-mail: tom.de.groot@philips.com; tony.vos@philips.com; roland.vogels@philips.com; willem.van.driel@philips.com

W.D. van Driel and X.J. Fan (eds.), *Solid State Lighting Reliability: Components to Systems*, Solid State Lighting Technology and Application Series 1,
DOI 10.1007/978-1-4614-3067-4_1,

The quality movement can trace its roots back to medieval Europe, where craftsmen began organizing into unions called guilds in the late thirteenth century. These guilds followed a so-called craftsmanship model. The real need for quality and quality control did not occur until the start of the industrial revolution. It started in Great Britain in the mid-1750s and grew into the Industrial Revolution in the early 1800s. Here, quality had an emphasis on product inspection. Following this revolution, in the early twentieth century, manufacturers began to include quality processes in quality practices. After the United States entered World War II, quality became a critical component of the war effort: bullets had to work consistently in all kind of rifles. Initially every bullet was inspected; later on the military began to use sampling techniques (using Walter Shewhart's statistical process control techniques). After World War II, Japan and the United States were the main players in quality control and moved from an inspection mode to a mode to improve all organizational processes that could influence the quality of the product. Industrial sectors such as automobiles and electronics were developing so fast that total quality management (TQM) became a must. Quality has moved beyond the manufacturing sector into such areas as service, health care, education, and government. Many organizations and industries use TQM with great success and the quality toolbox is filled with numerous techniques and methods, such as the following [2]:

- The ISO 9000 standards with sector-specific versions of quality management standards, developed for such industries as automotive (QS-9000), aerospace (AS9000) and telecommunications (TL 9000 and ISO/TS 16949,) and for environmental management (ISO 14000).
- Six sigma methodology developed by Motorola to improve its business processes by minimizing defects.
- Lean manufacturing.
- 8D (discipline) approach.
- Fault tree analysis.
- Failure Modes and Effects Analysis (FMEA).
- Pugh matrix.
- And many, many more.

The following definition of quality is used:

Quality: The totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs.

1.2 Brief History in Reliability

The word reliability originates far sooner than most would guess [3, 4]. In 1816, Coleridge [5] used it in one of his poems obviously not having the same meaning to as we nowadays do so. He more used the word from a psychological perspective where reliability refers to the inconsistency of a measure. A test is consisted reliable if we get the same result repeatedly. The history of reliability as we know it now goes back to the 1950s, when electronics played a major role for the first time. During the 1950s, there was great concern within the US military where half of the vacuum tubes were estimated to be down at any given time. In these days, many meetings and ad hoc groups were created to cope with the problems. In 1952, as an initiative between the department of defense and the American electronics industry [6], a study group was initiated under the name Advisory Group on the Reliability of Electronic Equipment (AGREE). This group recommended the following three items for the creation of reliable systems:

1. The need to develop better parts.
2. Establishing quantitative reliability requirements for parts.
3. Collecting field data on actual part failures to determine their root cause.

It may seem strange today but at that time there was considerable resistance to recognizing the stochastic nature of the time to failure, and hence reliability. With the basics ready, Shewhart and Weibull [7] already published their techniques, statistics as a tool for making measurements would become inseparable with the development of reliability concepts. During this period, 1950–1960s, several working groups and conferences were held to discuss the reliability topic; examples are the IEEE Reliability Conference, the Reliability Society, Rome Air Development Center (RADC), and the already-mentioned AGREE committee. Recommendations included running formal demonstration tests with statistical confidence and running longer and harsher environmental tests that included temperature and vibration. All led to the well-known Military Standards, such as MIL781 and MIL217 [8]. In this decade, reliability was driven by the demand from the military industry.

From the 1960s onwards to the 1970s, the complexity of electronic equipment began to increase significantly, and new demands were placed on reliability. Semiconductors came into more common use as small portable transistor radios appeared. This decade brought a heightened interest in system-level reliability and safety of complex engineering systems, such as nuclear power plants. In order to do so, people began to use the Weibull function and the further developed Weibull analysis methods and applications.

During the decade of the 1970s, reliability had expanded into a number of new areas; examples are the use of Failure Mode and Effect Analysis (FMEA), risk management through the use of reliability statistics, system safety and software assurance. For the latter one, the first rudimentary models originate from this period in time [9]. System safety was introduced by the railway industry, driven by the need for timely arrivals of its travelers.

The largest changes in reliability development occurred in the 1980s. Televisions had become all semiconductors, automobiles rapidly increased their use, and communication systems began to adopt electronic switches. Standards became worldwide accepted and implemented. During this decade, the failure rate of many components dropped by a factor of 10. Thus, by the decade end, dedicated reliability programs could be purchased for performing FMEA, reliability predictions, block diagrams, and Weibull analysis. It was also the decade in which the people at home were confronted with a disaster that had a clear reliability nature: the challenger disaster, which occurred on January 28, 1986. This disaster caused people to reevaluate how to estimate risks.

By the 1990s and beyond, the pace of IC development ramped following the well-known Moore's law (number of transistors doubled every 18 months). It quickly became clear that high volume produced components often exceeded the reliability demands that came from the military specifications. Many of these military specifications became obsolete and best commercial practices were often adopted. Most self-respected industries developed their own reliability standards, examples are the JEDEC Standards for semiconductors [10] and the Automotive Standard Q100 and Q101.

The turn of the decade started with a well-known software reliability problem: Y2K. The Year 2000 problem (also known as the Y2K problem, the Millennium bug, the Y2K bug, or simply Y2K) was a problem some questioned whether the relative absence of computer failures was the result of the preparation undertaken or whether the significance of the problem had been overstated. We will never know, but it brought reliability failures and the cost of them closer to the consumer. Product development times decreased to periods below 12 months. This meant that reliability tools and tasks must be more closely tied to the development process itself.

Nowadays, products with high failure rates are logged on the Web leading to bad reputation for a company. In many ways, reliability is part of everyday life and part of consumer expectations. The word reliability is extensively used by the general public and the technical community, as illustrated by the following: there are over 3,000 published books whose title or keywords contain the word reliability; the Web of Science lists some 10,000 technical papers with "reliability" as a keyword (since 1973); and the popular search engine Google lists over 12 million occurrences of "reliability" on the World Wide Web.

The following definition of reliability is used:

> Reliability: The probability that a system will perform its intended function under stated conditions for a specified period of time without failures.

1.3 Note on Reliability Prediction

The term reliability-prediction is historically used to denote the process of applying mathematical models and data for the purpose of estimating field-reliability of a system before empirical data are available [11]. These predictions are used to evaluate design feasibility, compare design alternatives, identify potential failure areas, trade-off system design factors, and track reliability improvement. Reliability predictions are used successfully as a reliability engineering tool for at least five decades. But it is only one element of a well-structured reliability program.