Reliability Physics and Engineering

J. W. McPherson

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Time-to-Failure Modeling

Second Edition

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To my family:
Victoria, Cameron, Brandi,
Austin and Gabrielle

Preface

All engineers could benefit from at least one course in *Reliability Physics and Engineering*. It is very likely that, starting with your very first engineering position, you will be asked—how long is your newly developed device expected to last? This textbook was designed to help answer this fundamentally important question. All materials and devices are expected to degrade with time, so it is very natural to ask—how long will the device last?

The evidence for *material/device degradation* is apparent in nature. A fresh coating of paint on a house will eventually crack and peel. Doors in a house can become stuck due to the shifting of the foundation. The new finish on an automobile will oxidize with time. The tight tolerances associated with finely meshed gears will deteriorate with time. Critical parameters that are associated with precision semiconductor devices (threshold voltages, drive currents, interconnect resistances, capacitor leakages, etc.) will degrade with time. In order to understand the lifetime of the material/device, it is important to understand the *reliability physics* (*kinetics*) for each of the potential failure mechanisms and then be able to develop the required *reliability engineering* methods that can be used to prevent, or at least minimize, the occurrence of device failure.

Reliability engineering is a fundamental part of all good electrical and mechanical engineering product designs. Since proper *materials selection* can also be a critically important reliability factor, reliability engineering is also very important to *materials scientists*. Reliability is distinguished from *quality* in that quality usually refers to time-zero compliance or conformance issues for the material/device. Reliability refers to the time-dependence of material/device degradation. All devices (electrical and/or mechanical) are known to degrade with time. Measuring and modeling the *degradation rate*, the *time-to-failure*, and the *failure rate* are the subjects of reliability engineering.

Many electrical and mechanical devices, perhaps due to performance and/or cost issues, push their standard operating conditions (use conditions) very close to the intrinsic strength of the materials used in the design. Thus, it is not a question of whether the device will fail, but when. Reliability engineering methods permit the electrical engineer, armed with accelerated testing data, to claim with confidence that a newly designed integrated circuit will last at least 10 years under specified voltage and temperature operating conditions. Reliability engineering methods permit the mechanical engineer to claim that the newly-designed engine will last for 180,000 miles at 3000 rpm with an oil change required every 6,000 miles. Reliability engineering methods enable the materials scientist to select a cost-effective material which can safely withstand a specified set of high-temperature and high-stress use conditions for more than 10 years.

This textbook provides the basics of reliability physics and engineering that are needed by electrical engineers, mechanical engineers, civil engineers, biomedical engineers, materials scientists, and applied physicists to help them to build better devices/products. The information contained within should help all fields of engineering to develop better methodologies for: more *reliable product designs*, more *reliable materials selections*, and more *reliable manufacturing processes*—all of which should help to improve product reliability. A mathematics level through differential equations is needed. Also, a familiarity with the use of excel spreadsheets is assumed. Any needed statistical training and tools are contained within the text. While device failure is a statistical process (thus making statistics important), the emphasis of this book is clearly on the *physics of failure* and developing the *reliability engineering tools* required for product improvements during *device-design* and *device-fabrication* phases.

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