Ageing of Integrated Circuits

Basel Halak
Editor

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Causes, Effects and Mitigation Techniques

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Editor
Basel Halak
The School of Electronics
and Computer Science
University of Southampton
Southampton, UK

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To
my parents
as well as
Suzanne, Hanin, and Sophia
with love

Preface

The ageing of an organism in biology is defined as a progressive, irreversible process that inevitably ends with death. The maximal lifetime of an individual is significantly affected by ageing. The same is true for integrated circuits wherein ageing can be caused by several physical mechanisms, including bias temperature instability (BTI), hot carrier injection (HCI), and time-dependent dielectric breakdown (TDDB).

Ageing effects lead to a degradation in the performance and reliability of an electronic system, hence limiting its expected lifetime.

Variation-aware design techniques, such as conservative safety margins, can be used to reduce the impact of ageing on system reliability; however, the applications of such methods make it harder to develop competitive products and may lead to the elimination of performance gains of technology scaling. Therefore, there is a need for innovative approaches to improve the resilience of integrated circuit to ageing-induced failure without affecting its performance.

The prime objective of this book is to provide a timely and coherent account of the latest advances in the key research areas of IC's ageing; it has been developed as a collaborative effort among several international research groups, each providing an up-to-date summary of their latest findings and highlighting the remaining challenges and research opportunities. To facilitate the understanding of the material, each chapter includes a background section explaining related terminologies and principles, in addition to a comprehensive list of relevant references. The book is divided into three parts to enhance its readability, namely, physical mechanisms, mitigation techniques, and monitoring and adaptation approaches.

The Contents at Glance

This book explains the physical mechanism causing the ageing of integrated circuits, including a comprehensive analysis of its effects on the performance and reliability of integrated circuits. Afterwards, the book presents a number of mitigation

techniques that can be applied at different stages of the life cycle of silicon chips. At the design stage, the book presents a synthesis algorithm that help produce ageing-resilient digital systems; in addition, it explores a number of application-dependent methods to improve system reliability. The book also discusses the state-of-the-art approaches for predicting ageing-induced failures and associated design adaptation techniques. More details on each chapter are provided below:

Part I: Ageing Physical Mechanisms and Effects

Chapter 1 provides a comprehensive review of the physical mechanisms causing the ageing of CMOS circuits.
Chapter 2 provides a detailed analysis of the impact of ageing on the reliability and performance of integrated circuits.

Part II: Ageing Mitigation Techniques

Chapter 3 presents an application-level solution to mitigate the impact of ageing on microprocessors using an anti-ageing software.
Chapter 4 discusses the impact of ageing on SRAM memories and review different approaches to mitigate against such effects.
Chapter 5 reviews the state-of-the-art techniques employed to enhance BTI lifetime reliability during digital synthesis.

Part III: Ageing Monitoring and Adaptation Techniques

Chapter 6 discusses the latest techniques used in ageing monitoring, including monitor designs and on-chip insertion methods.
Chapter 7 discusses the design of an ageing monitor to detect ageing-induced performance degradation in SRAM memories.
Chapter 8 presents a new design for a multipath delay monitor that used to predict ageing-induced timing errors.

Book Audience

The book is intended to provide a comprehensive coverage of the latest research advances in the key research areas of integrated circuits' ageing; this makes it a valuable resource for graduate students, researchers, and engineers working in these areas. I hope this book will complement the ongoing research and teaching activities in this field.

Southampton, UK Basel Halak
March 2019

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About the Editor

Basel Halak is the founder and director of the embedded system program at the University of Southampton and a fellow of the royal academy of engineering. He is currently a member of sustainable electronics and materials research group, as well as the cyber security group. He has written over 70 refereed conference and journal papers and authored two books, including the first textbook on physically unclonable functions. He received his PhD degree in Microelectronics System Design from Newcastle University and was then awarded a Knowledge Transfer Fellowship to develop secure and energy-efficient design for portable healthcare monitoring systems. He joined Southampton University in 2011 where he continued pursuing his research on developing reliable and secure systems. He has a long experience of the implementation flow of intergraded circuit from concept to silicon. His research expertise include the evaluation of security of hardware devices, the development of appropriate countermeasures and mathematical formalisms of reliability issues in CMOS circuits (e.g., cross talk, radiation, ageing), and the use of fault tolerance techniques to improve the robustness of electronics systems against such issues. He serves in several technical program committees such as HOST, IEEE IVSW, ICCCA, ICCCS, MTV, and EWME. Furthermore, he is an associate editor of *IEEE Access* and an editor of the *IET Circuits, Devices & Systems* journal and is also member of hardware security working group of the World Wide Web Consortium (W3C).