Carbon Nanotubes for Interconnects

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Editors

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Process, Design and Applications

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To our families!

Preface

Our modern society has gained enormously from novel miniaturized microelectronic products with enhanced functionality at ever-decreasing cost. However, as size goes down, interconnects become major bottlenecks irrespective of the application domain. Current electrical copper (Cu) interconnects will approach their physical limits and may no longer be able to keep pace with a processor's data throughput. Aggressive scaling has aggravated Cu resistivity increase due to electron scattering, and even more severely, it introduced electromigration issues. Mass transport along interfaces and grain boundaries in Cu interconnects is one of the most imminent issues to be addressed for future technology nodes.

Interconnect innovation with novel material such as carbon nanotubes has been the focus of extensive research with the goal of propagating terabits/second at femtoJoule per bit. Carbon nanotubes have sparked a lot of interest because of their desirable properties such as large electron mean free path, mechanical strength, high thermal conductivity, and large current carrying capacity. The advent of carbon nanotube as new material for back-end of line interconnects is a direct result of active research in academia, research laboratories, and industry over the past decade. Today, carbon nanotube integration takes many forms depending on the applications. As of the time of writing, there are already some prototypes driven to characterize the performance, alignment density, ampacity, and energy efficiency of carbon nanotubes.

As a direct outcome of many years of active research, there are many important documentations on carbon nanotubes. However, a book dedicated to carbon nanotube interconnects covering aspects from process, design, and application is lacking. The idea of a book on carbon nanotube interconnects dates back to more than 2 years ago. While, our initial idea was to co-author a book, we soon realized that such endeavor would be challenging given the required multidisciplinary knowledge from material science, nanosciences, physics, modeling, and simulation to circuit analysis. We revisited our plan and decided to edit a book instead with contributions from experts in academia, research laboratories, and industry.

After careful planning, we identified and invited chapter contributions from an impressive lineup of highly qualified scientists. It took a full 1 year for planning, writing, and editing.

This book aims to give an in-depth look into the process, growth, characterization, modeling, and simulation of carbon nanotube interconnects as local and global on-chip interconnects for 2D, 3D, and monolithic 3D integration. The book is organized into two parts. The first part provides an in-depth overview of the process and growth of carbon nanotubes and their electrical and thermal properties. In the second part, each chapter is dedicated to investigate carbon nanotube interconnects for different applications such as signaling interconnects, power delivery network interconnects, through-silicon-via material, and monolithic 3D integration interconnect material. This book is particularly beneficial to researchers, students, and engineers that are already working or beginning to work on carbon nanotube interconnects.

This book would have not been possible without a team of highly qualified and dedicated people. We are particularly grateful to Charles Glaser for initiating this undertaking and for his encouragements. Jessica Lauffer worked along side with us and provided us with the necessary editorial support. Aida Todri-Sanial is grateful to the continued support of her work on carbon nanotubes from the French National Center for Scientific Research (CNRS) and European Commission on H2020 CONNECT project. Jean Dijon is grateful to the continued support from his work on carbon nanotube by the "Commissariat à l'énergie atomique et aux énergies alternatives" (CEA) and by the European Commission which is funding carbon interconnect projects since 2005.

Last but not least, we are extremely thankful to authors who accepted our invitation and contributed chapters to this book. We hope that the readers will find this book useful in their pursuits of carbon nanotube interconnects.

Aida Todri-Sanial dedicates this book to Tom, Arnaud, Pellumbesha, Pandeli, Parid, Arnisa, and David. Jean Dijon dedicates this book to Marie-Lise, Pierre-Luc, Laury-Anne, and his grand-children. Antonio Maffucci dedicates this book to Michela, Lucrezia, Bea, and Minù.

Montpellier, France — Aida Todri-Sanial
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