

Preface

The second half of the twentieth century and the beginning of the twenty first have been characterized by the most impressive industrial revolution ever seen. In approximately 40 years, the complexity of integrated circuits (ICs) has increased by a factor of 10^9 , with a corresponding reduction of the cost per bit by eight orders of magnitude.

Not only has this evolution allowed dramatic progress in all scientific fields (large computers, space probes, etc.), but also has fueled the economic development with the raise of new markets (personal computers, cellular phones, etc.) and even social revolutions (world wide web, global village, etc.).

In last years, however, the situation has significantly changed: the continuous scaling down of device size has eventually brought the IC major technique, photolithography, to its limits. Overcoming its original limits has been proved to be possible, but the price to pay for that has changed the playing rules – while at the beginning of the IC history the evolution was driven by technology, now it is driven by economy, the cost of a medium size production plant being in the range of a few billion dollars.

The predicted evolution is based on the assumption that future ICs will be based on the same basic constituent, the MOS-FET (metal–oxide–semiconductor field-effect transistor), suitably scaled to smaller and smaller sizes. The International Technology Roadmap for Semiconductors (the “Roadmap”) has thus identified which progress is necessary to allow the increase of IC complexity to continue with the current exponential growth.

The number of researchers involved in the actions identified by the Roadmap is huge (about 10^5) and it is certainly possible that the limits it has identified will be beaten, but the cost of IC production plants is expected to increase by one order in a decade, putting it beyond the economic possibilities of most players.

In the light of these considerations, alternative solutions to the current top-down evolution of ICs have been considered. In particular, the fast development of nanotechnology (permitting the control of size effect, self-assembly, hydrophobic–hydrophilic properties, etc.) and the discovery of exploitable conformation, charge storage, and conduction properties of single molecules (π -conjugated moieties, rotaxanes, proteins, etc.) have attracted a large interest, suggesting the possibility of developing nanoelectronics in a different fashion – bottom-up.

In my opinion, in order to be viable that development requires the solution of the following problems:

- The design of new architectures based on electrically programmable molecules rather than on FETs
- The development of nonexpensive techniques for the synthesis, separation, and purification of such molecules
- The setup of an economically sustainable technology for the preparation of a distribution of active elements at a density (say, 10^{11} cm^{-2}) higher than the final one projected by the Roadmap
- The functionalization of such elements with the electrically programmable molecules
- The linkage of the functionalized elements to the external world to allow their actuation and sensing

An important point not considered in the above menu, and commented separately to emphasize it, is the temporal factor – *all the listed objectives must be achieved at a time appreciably closer than the end of Roadmap*. This need discards all alternatives not based on *conservative extension of the current technology*.

This book is written in that spirit: I intend to show that circuits formed by a planar arrangement of nanoscopic devices with density of the order of 10^{11} cm^{-2} can in principle be prepared via the combination of existing architectures, materials, and techniques. Whether or not that combination may indeed become a technology for nanoelectronics is essentially related to the effort spent in the solution of detailed problems that certainly will arise in such an attempt.

Although the temporal constraint does not apply to other devices (like sensors or electromechanical systems), their practical implementation would be greatly simplified if they too were based on some conservative extension of the current technology.

Although the topics considered in this book are highly technical, I have tried to maintain unity of style, privileging logical connections with respect to detailed information. Because of its formative, rather than informative character, this book (or at least its first part) might be used for courses on Nanoscience or Nanotechnology. A possible use of this book as a textbook is sketched in Fig. 0.1, where the backbone sketches the main body of the course, whereas the sides show possible additional topics.

The core of this book is based on two review articles: “Molecular electronics in silico,” *Appl. Phys. A* **91**, 181 (2008), with E. Romano; and “Multispacer patterning: a technology for the nano era,” to appear in *Handbook of Nanophysics*, edited by K. Sattler for Taylor & Francis (to be published), with E. Romano and P. Amato. In turn, they had origin from a series of lectures prepared for the 2007 and 2008 Summer Schools on Nanoelectronic Circuits at Tools held at the Ecole Polytechnique Fédérale de Lausanne (Swiss).

While acknowledging the contribution of my present coworkers [Paolo Amato (Numonyx) and Elisabetta Romano (Department of Materials Science, University of Milano–Bicocca)], I cannot, however, ignore the work carried out with my past collaborators [Clelia Galati, Sergio Reina, Lucio Renna, and Natalia Spinella

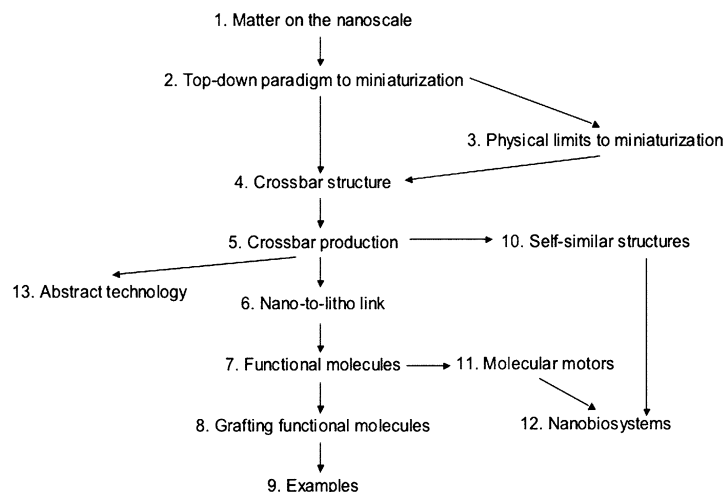


Fig. 0.1 Logical organization of the topics

(STMicroelectronics), whose activity was mainly addressed to the functionalization of the silicon surface, and Danilo Mascolo (STMicroelectronics) whose activity was addressed to the architecture of nanoelectronic circuits]. It is also a pleasure to thank a few colleagues (Eric Garfunkel, Rutgers University; Mark A. Reed, Yale University; and James M. Tour, Rice University) who read and commented the said article on molecular electronics. At last, I wish to express my thanks to Dario Narducci for supporting my position at the University of Milano–Bicocca where I completed this book, and to Hans J. Queisser for his warm suggestion of transforming my review paper on molecular electronics into a book.

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