

Preface

In this book, we introduce computing innovation in progress: green computing for a sustainable world. We have done our best to provide a compact overview of a green computing scheme, including cutting-edge CMOS low-power devices, comprehensive spintronics knowledge, trends in low-voltage memory and non-volatile RAM, low voltage (low leakage) computing circuits and systems, and a low-power computing plan that uses non-volatile memory. Our objective is to provide a reference material that can be simultaneously used by device engineers, circuit engineers, and computer engineers as they strive for innovative green computing that moves beyond conventional low-voltage operation and toward the new low-power computer technology of the future. From the perspective of computing architecture, historically, innovation in memory technology has led to progress (and vice versa). Now, non-volatile RAM has nearly approached the stage of practical application. It offers an infinite number of fast write and read operations as well as non-volatility, and relies on the development of spintronics technology. We are confident that this memory innovation will function as one of the main propulsion in the realization of green computing.

The goal of higher performance has always been at odds with increased power consumption. In the 1980s, CMOS device technology was widely introduced for low power operation, while in the 1990s, low-voltage circuit technology was intensively developed, and in the 2000s, system level handling with low-voltage circuitry was accelerated. Now, we need to find a new direction for further advancement that by necessity must feature an interdisciplinary approach. One component could be the use of emerging memory, described above. Another component is likely to originate from our daily habit of saving power consumption by turning off electrical devices when not in use. Ideally, we would like to expand such habits to IT equipment in such a way that, even though a particular device seems to be turned off, it is actually achieving maximum performance. Is this even possible? An experimental trial is included in this book. What we need is a fusion of power control technology and IT technology. The key to achieving this is to ensure that any internal computation status is memorized before the power is

turned off and retained without consuming power. Yes, this is the use of the first component, memory.

This book is organized as follows. After we discuss the background and motivation in [Chap. 1](#), readers comprehensively learn an overview of cutting-edge CMOS low-power devices in [Chap. 2](#) and spintronics technology that utilizes the properties of both the charge and spin of electrons in [Chap. 3](#). Though both aspects are indispensable for the future development of LSI technology, there seem to be very few cases in which both are discussed in an easy-to-understand manner in one book. We describe the trends of low-voltage memory in [Chaps. 4 and 5](#). While these belong to the realm of conventional memory, we summarize the key points of low-voltage SRAM ([Chap. 4](#)) and low-voltage DRAM ([Chap. 5](#)) to provide readers with insights into how power can be lowered. We show the evolution of the interface between memory and processor as well as the predicted development of memory hierarchy systems in the future. [Chapter 6](#) is devoted to STT-RAM (or SPRAM, spin-transfer torque RAM) technology. How to take advantage of non-volatile RAM is the key to achieving low power consumption and high performance for IT equipment, and since STT-RAM is the most promising (or up to now, only possible) solution among various candidates, it is described in detail. The next two chapters are devoted to descriptions of low-power computing technology in circuits and system levels. In [Chap. 7](#), the latest low-voltage computing technology, which is being used to prevent leakage currents, is explained in minute detail, covering many aspects from basic circuitry elements to the system as a whole. In [Chap. 8](#), we present an example of a low-power computing technology using non-volatile RAM. This includes a proposal to turn off IT equipment frequently when not in use, which will hopefully function as an example for future green computing. Our summary is presented in [Chap. 9](#), along with a brief mention of the direction we intend to take in the future.

This book should prove useful to both computing engineers and device engineers due to its description of a new computing innovation for low power consumption that does not sacrifice performance over the conventional low-voltage operation.

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Green Computing with Emerging Memory
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