The Institution of Engineering and Technology

Advanced Technologies for Next Generation Integrated Circuits

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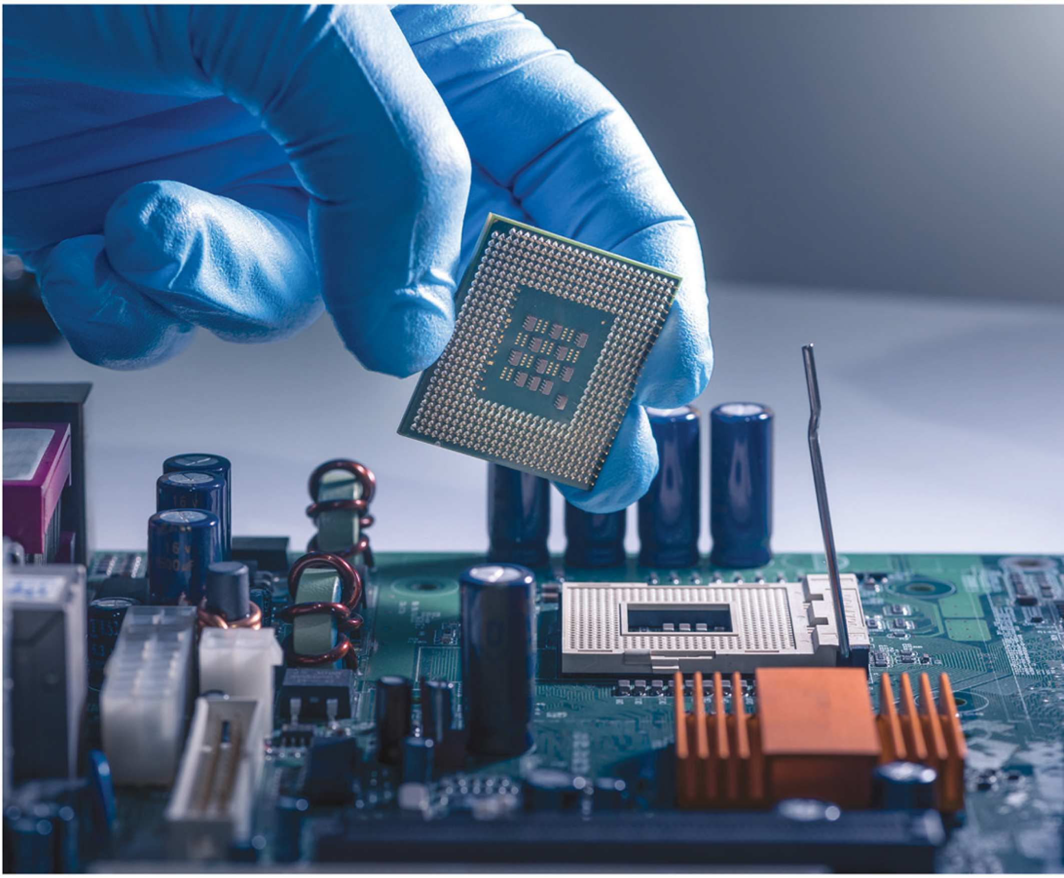

Chapter 5

Memristor Devices and Memristor-based Circuits

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There are four fundamental circuit variables: voltage, current, charge and magnetic flux. Until the year 1971, there were only three fundamental components: resistor, capacitor and the inductor. In that year 1971, Leon O. Chua proposed a new device named "Memristor" which relates charge and flux. At the time, due to lack of sophisticated fabrication facilities, the new device did not receive much attention until HP Labs successfully fabricated one in 2007. This fabrication of the new device has provided device research with a new perspective as the memristor exhibits a new hysteresis phenomenon named as "Pinched Hysteresis". The memristor can remember the voltage that passed through it even when the supply is turned off. Hence the name Memory + Resistor, Memristor. After the device was fabricated successfully, research has being done extensively implementing the memristor in various applications which require reconfigurability. The memristor has been used from oscillators to neural networks and logic gates to security applications giving it a wide range of applications. This chapter presents the device description, characteristics and various applications of the memristor in analog and digital applications.

This chapter is organized as follows: Different types of memristors are presented in section 2. Fabrication principles of the memristor and how it works are presented in section 3. For simulation purposes, various models for memristors have been proposed. Such models are presented in Section 4. The electrical characteristics of the memristor are presented in section 5. Applications of memristors in analog and digital nanoelectronics are presented in section 6 and section 7, respectively. Summary and future directions are presented in section 8. Table 1 summarizes the notations and symbols used in the current chapter.

1 Introduction

1.1 Brief History of Memristor

There were only three fundamental circuit elements known in 1971: resistor, capacitor and inductor. In that year, Leon O. Chua presented in his article titled "Memristor – The Missing Circuit Element", a device named memristor [18]. There are four fundamental circuit variables: voltage (v), current (i), charge (q) and magnetic flux (ϕ). Because there are four variables and three fundamental devices, Chua wanted to attain symmetry and theoretically presented the memristor. The relation between voltage and current is used by the resistor, voltage and charge by the capacitor and current and magnetic flux by the inductor. The memristor uses the relation between charge and magnetic flux [80], as shown in figure 1. It was demonstrated by Chua mathematically that the device he proposed would be able to provide a non-linear relationship between the flux and the charge. But even before Chua published his work, there had been some current-voltage behaviors observed that could not be explained. In 2015, a new research was published by Leon O. Chua and researchers at Hong Kong University which revealed that the first man-made memristor was actually developed in 1801 [49]. Humphry Davy conducted a carbon arc discharge experiment, which can generate light without the use of fire. The same experiment was repeated with a modern power supply and observed which revealed the fingerprint of the memristor.

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Advanced Technologies for Next Generation Integrated Circuits

Although existing nanometer CMOS technology is expected to remain dominant for the next decade, new non-classical devices are being developed as the potential replacements of silicon CMOS, in order to meet the ever-present demand for faster, smaller, more efficient integrate circuits.

Many new devices are based on novel emerging materials such as one-dimensional carbon nanotubes and two-dimensional graphene, non-graphene two-dimensional materials, and transition metal dichalcogenides. Such devices use on/off operations based on quantum mechanical current transport, and so their design and fabrication require an understanding of the electronic structures of materials and technologies. Moreover, new electronic design automation (EDA) tools and techniques need to be developed based on integrating devices from emerging novel material-based technologies.

The aim of this book is to explore the materials and design requirements of these emerging integrated circuit technologies, and to outline their prospective applications. It will be useful for academics and research scientists interested in future directions and developments in design, materials and applications of novel integrated circuit technologies, and for research and development professionals working at the cutting edge of integrated circuit development.

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