Analysis Of the Development History, Key Technologies, And Future Development of Integrated Circuits

Zimo Li *
TsingHuaZhiQing High School,100084, Beijing, China
* Corresponding Author Email: wrivera81414@student.napavalley.edu

Abstract. Integrated circuits (ICs) are pivotal in propelling the advancement of contemporary human technology. This article delves into the definition and evolution of integrated circuits, while also examining various collaborative technologies. Notable among these are EDR technology, VLSI testing technology, and High-Speed signal integrity testing assurance technology. The roots of integrated circuits can be traced back to their inception, with innovations occurring at a rapid pace over the years. EDR technology, for instance, has been instrumental in enhancing the efficiency of ICs by enabling data transmission at high speeds. Similarly, VLSI testing technology has played a crucial role in ensuring the reliability and quality of ICs. High-Speed signal integrity testing assurance technology has emerged as a fundamental aspect of IC development, ensuring that signals remain stable and accurate even at high speeds. These collaborative technologies have propelled ICs to new heights, paving the way for more powerful and efficient electronic devices. Furthermore, this article explores the challenges and prospects associated with integrated circuits on both a national and global scale.

Keywords: EDR technology, VLSI, High-Speed signal, challenges and development.

1. Introduction

Integrated circuits are widely distributed in various aspects of life. Covering industry, military, communications, aerospace, consumer electronics, automotive, medical equipment, household appliances, and bioelectronics [1]. It is the cornerstone of modern information society, playing an essential role in promoting the development of a new era for humanity and bringing huge benefits to people worldwide. In the development of integrated circuits, many key technologies have emerged, such as protection technology, design technology, and testing technology, which have solved problems in integrated circuits and laid a foundation for future larger, more efficient, safe, and reliable integrated circuits. These key technologies are worth analyzing and understanding. In addition, with the continuous advancement of integrated circuit manufacturing technology and equipment, chip's extreme technology continues to make breakthroughs. The continuous reduction of process size leads to the continuous expansion of chip circuit scale. The challenges faced by integrated circuits are increasingly big. More and more people are paying attention to the development prospect of this industry [2].

Therefore, this article will describe the definition of integrated circuits in detail, describe the development process of integrated circuits, and analyze some of the key technologies involved. For example, EDR technology, VLSI testing technology, and High-Speed signal integrity testing assurance technology. In addition, this article also analyzes the challenges faced by integrated circuits and their future development, such as the challenges faced by the integrated circuit industry in China, as well as intellectual property and protection of integrated circuits and development and challenge prospects of integrated circuits in the world. Integrated circuits are a bright pearl of human industry, contributing to the advancement and development of society, and setting the direction for future technological advancement.

2. The theoretical basis of integrated circuits

2.1. Definition of integrated circuits

An integrated circuit is a type of micro-electronic device or component. By using a particular process, the required details such as transistors, resistors, capacitors, and inductors in a circuit are interconnected with wiring and then fabricated onto a small or several small semiconductor chips or dielectric substrates. They are then packaged in a tube shell to form a microstructure with the required circuit functions.

2.2. The development history of integrated circuits

Integrated circuits originated in 1947. John Barding, Bratton, and Shockley from Bell Laboratories in the United States invented the transistor. In the following decade, people began to develop transistors until 1958, when the world's first integrated circuit was produced, marking the arrival of the era of integrated circuits. Subsequently, in 1964, Moore proposed the famous Moore's Law: the integration of transistors will double every 18 months. Shortly thereafter, in 1966, RCA Corporation in the United States developed CMOS integrated circuits and the first gate array. Five years later, with Intel's release of 1kb Dynamic Memory (DRAM) and the world's first microprocessor 4004, it marked the emergence of large-scale integrated circuits. In 1978, a 64kb dynamic random-access memory appeared, integrating 140000 transistors on silicon wafers of less than 0.5 square centimeters. Human beings have been constantly moving towards ultra-large-scale integrated circuits. In 1988, 16M DRAM emerged, integrating 35 million transistors on a 1 square centimeter silicon wafer. At this point, people have entered the era of ultra-large-scale integrated circuits. The development history of integrated circuits is shown in Figure 1.

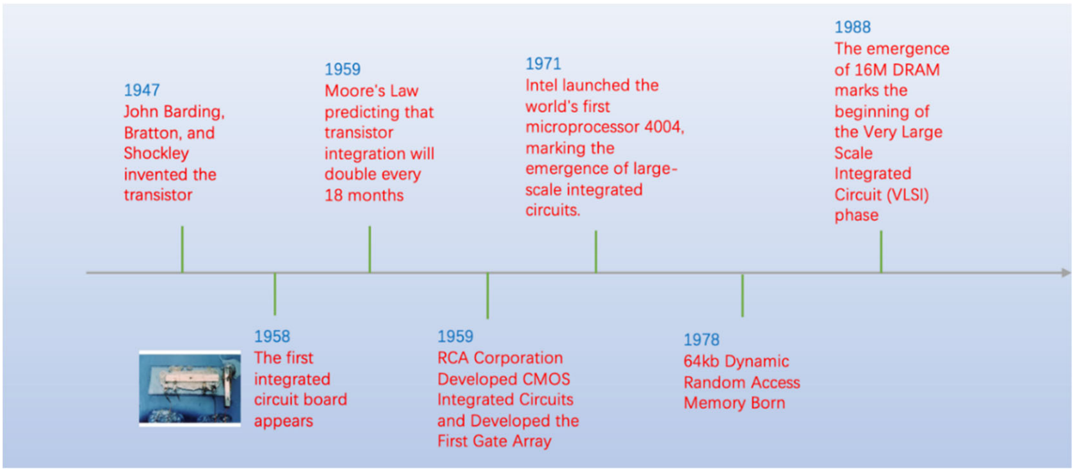

Fig. 1 The development history of integrated circuit (Photo/Picture credit: Original)

3. Key Technology Analysis

3.1. Analysis of ESD technology

The ESD phenomenon is because two objects at different potentials cause static charges to move through electrostatic field induction or direct contact. When the charge generated is large enough, the inability to generate enough charge in the circuit system will concentrate and sum up. This can lead to excessive voltage in the integrated circuit, which can generate a lot of heat and damage the circuit.

Therefore, people have formulated the design principle of the ESD protection circuit of the integrated circuit. When the integrated circuit is working normally, the ESD protection circuit should be in the off state. When the ESD phenomenon occurs, the ESD protection circuit will be opened quickly. At the same time, when designing ESD protection, it should be designed in layers according to different protection levels to ensure that the core of the integrated circuit cannot be damaged. In addition, during the occurrence of ESD, each device of the protection circuit should be turned off to avoid device failure and damage to the core of the integrated circuit [3].

The devices in the ESD protection circuit are very diverse, among which diodes, resistors, and bipolar transistors are the main ones. As one of the most critical components in integrated circuits, diodes are widely used in various protection circuits. In ESD, since diodes have no hysteresis characteristics, the detection method of diodes is mainly rail-to-rail. The resistors are mostly N-type well capacitors. The bipolar transistor plays the role of amplifying the current. It is a crystal triode composed of two back-to-back PN structures.

Most ESD protection circuits use SCR protection technology, which mainly uses thyristors. The application process of SCR protection technology includes two kinds of resistors and two parasitic triodes. When performing ESD protection, the thyristor is connected to the integrated circuit as a two-terminal device, its anode is connected to the N-well and its cathode is connected to the P-well. By connecting the thyristor to PN in the bipolar transistor in the integrated circuit, the effective ESD protection function can be played by triggering the thyristor.

3.2. VLSI Testing Status and Key Technologies

Integrated circuits mainly include four significant sectors: design, manufacturing, packaging, and testing. Among them, the test section is very important. Regarding the ATE testing technology of integrated circuits, Luo Hongwei and his team conducted a detailed analysis. The integrated circuit ATE test system is a collection of various electronic circuits, mainly including the following modules [4].

Firstly, about the Time Test Unit. The purpose of the timing test unit is to measure timing parameters, including period, pulse width, pulse duty cycle, signal rise/fall time, and transmission delay. The hardware circuit of the time measurement unit generally includes a logic control FPGA, a signal conditioning circuit, and a time measurement circuit.

Secondly, about the Arbitrary Waveform Generator. The purpose of the arbitrary waveform generator is to synthesize the test vector waveform, by synthesizing the driving front and back edges of the test vector graphics and measuring the front and back edges, to realize different test waveforms and timing information of the test vector.

Thirdly, about Digital instrument. The digital instrument which is used to collect the output measurement value of the chip pin and compare the collected output high-impedance state, output high level, and output low level with the expected output value of the test vector.

Fourthly, about the Precision Measuring Unit. The precision measurement unit is used to measure current and voltage. By applying a certain current or voltage to the pins of the chip under test, the voltage or current of the corresponding pins is measured to realize the open circuit/short circuit test and leakage test of the pins.

3.3. High-Speed Signal Integrity Testing Assurance Technology

In addition, they also analyzed the guaranteed technology of high-speed signal integrity testing [4]. They analyzed that high-speed signal integrity testing is a huge challenge in the current development of high-speed, high-frequency, and high-bandwidth integrated circuit technology. Among them, high-speed signals can cause problems such as reflection, crosstalk, and radiation during transmission, leading to false digital circuit triggering, output signal waveform distortion, and system instability. This will affect the testing of integrated circuits.

Yuan Weiqun and their research on signal integrity-based high-speed PCB optimization design sine waves are commonly used to obtain time-domain responses through testing software, and the technical means are to analyze the key properties of high-speed transmission channels using vector network analyzers with wide coverage frequency and fast testing speed [5]. Therefore, in practical applications, quality issues of cables, connectors, and PCBs can be inspected in the early stages of design to reduce subsequent impacts.

4. Development and Challenge Prospects of Integrated Circuits

4.1. Development and Challenge Prospects of Integrated Circuits in China

According to Li Jianming's research data on the problems and challenges faced by the integrated circuit manufacturing industry, China's domestic demand for integrated circuits is large but the supply is small, lacking competitiveness [6]. Li Jianming pointed out that talent and technology are fundamental to the development of the industry. We should accelerate the pace of talent cultivation. Therefore, in order to solve the problem of insufficient supply capacity in China's integrated circuit industry, it is necessary to focus on technological innovation and talent cultivation, and the government should continue to increase investment in the integrated circuit industry [7].

4.2. Intellectual Property and Protection of Integrated Circuits

In recent years, the continuous flow of piracy and infringement has greatly hindered the development of integrated circuits. The intellectual property rights of integrated circuits are not only an institutional guarantee but also a driving force to stimulate their development. Qiu Dongdong proposed three contradictory points in the intellectual property rights and protection of integrated circuits, namely the contradiction between the technical performance and creativity of integrated circuit technology, the contradiction between the limitations and patentability of integrated circuit technology, and the contradiction between the replicability of integrated circuit technology and the content of patent rights.

Based on the above three contradictions, Qiu Dongdong proposed three solutions [8]. The first one is deterrence, which relies heavily on citizens' quality to protect integrated circuits. The second type is protection, which uses encryption algorithms and other operations to protect the integrated circuit IP core from theft and commercial use. The third method is detection, which embeds watermark technology into integrated circuit technology for easy detection. At present, the path of intellectual property protection for integrated circuits is still arduous and requires the unremitting efforts of the entire industry.

4.3. Development and Challenge Prospects of Integrated Circuits in the World.

Sun Jinkai pointed out in his research on the status quo and development prospects of the semiconductor integrated circuit industry [9]. With the progress of mainstream processes, the development of technology and materials, the reduction of technical standards in the integrated circuit industry, the physical mechanisms and process technologies that lead to the semiconductor integrated circuit industry face great challenges in the development process in terms of size effects, The process scale is decreasing, and the thickness of gate insulation layer of the integrated circuit is limited. The IC conductive region distance is reduced. In terms of materials, the size of integrated circuit components is decreasing, and in order to avoid leakage, process and material requirements are becoming more stringent. Also, In the future development of integrated circuits, Sun Jinkai pointed out that the slowdown in the growth rate of integrated circuits will not cause the microelectronics industry to stagnate. The integrated circuit industry can focus on product diversity and energy consumption optimization to meet modern market needs [10]. At the same time, the reduction in the growth rate of integrated circuits brings more time to relevant researchers. We will put more energy into computer systems and software development and improve the performance of integrated circuit products.

5. Conclusion

Integrated circuits (ICs) continue to advance steadily, with ongoing efforts aimed at enhancing process technology and minimizing energy consumption still undergoing refinement. As we look to the future, the integrated circuit industry is poised to place greater emphasis on safeguarding its innovations and fostering practical applications, all the while surmounting persisting technical challenges. The quest to optimize process technology remains a focal point in the IC industry's ongoing journey. The intricacies of improving IC manufacturing processes are multifaceted and ever evolving. Researchers and engineers are tirelessly working to unlock more efficient and sustainable production methods that can further propel the capabilities of ICs.

Moreover, the relentless pursuit of energy efficiency remains an essential objective. As the world grapples with environmental concerns, reducing the energy footprint of ICs is of paramount importance. Innovations in power management, heat dissipation, and energy-efficient designs are at the forefront of these endeavors. In the coming years, the integrated circuit industry's dedication to safeguarding its innovations and fostering practical applications will continue to shape its trajectory. This commitment involves not only protecting intellectual property but also ensuring that the benefits of IC technology are accessible to a broader spectrum of individuals.

Ultimately, the vision is to democratize the advantages of integrated circuits, making them more affordable, accessible, and applicable to a wide range of industries and everyday life. This commitment to progress, efficiency, and accessibility will be the driving force behind the continued evolution of integrated circuits in our technologically advancing world.

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