DOI: 10.54254/2755-2721/125/2025.20344

A Review of the Application and Development of Ultra-thin Silicon Chips

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Abstract: The widespread applications of ultra-thin silicon chips across industries such as healthcare, telecommunications, automotive, artificial intelligence, and energy management underscore their pivotal role in driving technological advancements and societal progress by enhancing efficiency, sustainability, and overall performance in various electronic systems. This paper provides an in-depth review of the application and development of ultra-thin silicon chips in modern electronic technology. Ultra-thin silicon chips, characterized by small size, low power consumption, and efficient heat dissipation, offer significant advantages over traditional chips in various electronic products such as smartphones, tablets, and smart wearable devices. The paper discusses the basic principles, fabrication methods, and advantages of ultra-thin silicon chips, highlighting their potential applications in emerging fields like artificial intelligence and the Internet of Things. Furthermore, the paper explores the evolving trends in ultra-thin silicon chip manufacturing technology, emphasizing advancements in nano-technology applications and intelligent manufacturing practices. The diverse applications of ultra-thin silicon chips across industries such as healthcare, telecommunications, automotive, artificial intelligence, and energy management underscore their pivotal role in driving technological advancements and societal progress.

Keywords: Ultra-thin silicon chips, Electronic technology, Intelligent manufacturing, Applications in healthcare, Smart devices

1. Introduction

As a new chip technology, the ultra-thin silicon chip has attracted much attention and has been widely studied recently. Its thinness and unique performance characteristics present promising application prospects in the field of electronic technology. With the continuous development and popularization of electronic products, problems such as the volume, power consumption and heat dissipation of traditional silicon chips have gradually become prominent. Therefore, the ultra-thin silicon chip has emerged as a critical innovation, offering advantages in size, power efficiency, and heat dissipation that better align with the demands of modern electronic devices [1].

Microelectronic developments in the context of More-than-Moore are heading towards smart systems which are intelligent, compact, flexible, and cost effective for applications in medical and consumer electronics or the Internet of Things (IoT).

In order to cope with the trend of electronic products becoming smaller and thinner, it is very important to develop ultra-thin silicon chip technology. Ultra-thin silicon chips can enable the design of electronic products to be smaller, reduce power consumption, and improve energy efficiency while ensuring performance. In addition, the ultra-thin silicon chip has excellent heat dissipation performance, which can effectively reduce the temperature of the equipment and improve the stability and reliability of the equipment. Therefore, the development of ultra-thin silicon chip technology can not only promote the innovative development of electronic products, but also contribute to the efficient use of the environment and energy resources. This article provides an overview of the basic principles, manufacturing methods, and extensive applications of ultra-thin silicon chips in electronic technology, emphasizing their importance in driving innovation and improving energy efficiency in modern electronic products.

2. Ultra-thin silicon chip

2.1. Principles or Definition

Silicon, a material with excellent properties, is a good material for making chips. In addition to its extraordinary mechanical properties like Young's Module and ultimate strength, ultra-thin silicon—measuring less than 50 µm—possesses good flexibility, which is important in complex surface stress measurement enlarging the test range of silicon stress chips[2]. Thin chips are recognized for their numerous advantages over traditional chips; however, challenges arise when the chips are excessively thin, as this may lead to the formation of micro-cracks during the fabrication process.

2.2. Ultra-thin Silicon Chip Manufacturing

Conceptually, thinner chips tend to mean higher costs. So the cost of ultra-thin silicon chips is higher than other chips. A more precise control of the final chip thickness is possible when using silicon-on-insulator (SOI) instead of bulk silicon wafers, which, however, considerably increases cost [3]. This is because the production of ultra-thin silicon chips requires more advanced and sophisticated manufacturing techniques. These methods typically include wafer thinning and cutting, silicon-on-insulator (SOI) technology, and chip film technology.

2.3. Wafer Thinning and Cutting: Nanodiamond Grinding Method

Wafer thinning and cutting is a method of thinning silicon wafers after the completion of chip production, and then cutting thin sheets after thinning. This method is commonly used in the fabrication of ultra-thin silicon chips due to its precise control over chip thickness, improved production efficiency, and cost-effectiveness [3]. Alternative techniques, such as IBM’s spalling, allow for separating the top part of the wafer while conserving and reusing the bulk substrate [4]. This is particularly important for costly wafer substrates such as GaAs, GaN and SiC but of lesser significance for silicon. All such subtractive technologies suffer from the difficulty in handling the resulting ultra-thin wafer and in separating the thin dies. The dicing before grinding (DBG) technique provides the technological advantage by avoiding separation of the thin chips by means of sawing. However, this approach also comes with certain drawbacks, including challenges in handling thin chips, potential for higher wastage rates, and the need for additional stress management. Thinner chips will be harder to make because thinner chips require more sophisticated and complex processing. Materials with higher hardness can cut materials with lower hardness, and diamond is much harder than silicon. So nano diamond can be used for wafer thinning and cutting methods. Single-wafer thinning commonly utilizes the nano-diamond grinding method, which involves using nano-diamond particles as abrasives to embed into the silicon surface and gradually thin the silicon wafer to the desired thickness under uniform pressure and rotational force. Under uniform pressure, diamond particles will be embedded in the surface of silicon. Meanwhile, under the action of rotating force,

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diamond particles constantly grind the surface of silicon, and then continuously thin the silicon wafer [5]. This method is a purely physical process suitable for semiconductor materials like silicon, enhancing material flexibility and applicability.

2.4. Silicon-on-insulator (SOI) Technology

Future electronics device development has focused for decades on improving the control of the charges in the channel. This benefit is achieved by improving the device electrostatic coupling between the gate and channel through the dimensions scaling, new materials, and new device structures [6].

The SOI technology, used in the preparation of ultra-thin silicon chips, involves the process of forming an insulating layer on a silicon substrate, separating the silicon layer from the substrate with the insulating layer. This process includes growing a layer of insulation (typically silicon dioxide) on the silicon substrate, followed by growing a thin silicon layer on top of the insulation layer. This structural formation provides better electrical isolation and reduces crosstalk effects in electronic devices. While the FD-SOI technology intrinsically exhibits significantly lower leakage than bulk silicon, its software-controlled body bias (back gate) makes it an even more promising choice for automotive radar with its inherent trade-offs between high speed and low power consumption for both digital and millimeter wave circuitry [7]. SOI technology offers numerous advantages, including enhanced device performance and reliability, reduced power consumption and circuit noise, as well as increased speed and density of integrated circuits. Additionally, SOI technology improves the radiation hardness and radiation resistance of devices, giving them better stability in certain environments.

However, there are also disadvantages to SOI technology. These include high manufacturing costs, complex production processes, demanding material and equipment requirements, and potential thermal management and electromagnetic compatibility issues in specific applications. Furthermore, some device designs and processes may be limited by SOI technology, necessitating more research and optimization to address these challenges.

2.5. Chip Film Technology

Chip Film technology is a common process used in the preparation of ultra-thin silicon chips. The process involves coating a thin film (Chip Film) on a silicon substrate, followed by the formation of a silicon layer on top of the film. This allows for directional growth and optimization of the silicon layer, leading to improved performance and stability of the silicon chip. The advantages of Chip Film technology include lower manufacturing costs, high production efficiency, simple processes, and the ability to control the quality of the silicon layer. Additionally, Chip Film technology enables customization of the microstructure and electrical properties of silicon chips [8]. In order to increase compactness, chemical luminescence-based [4] or electrochemistry-based methods have been used [9]. Both approaches provide high detectability and easy implementation of miniaturization [10-11].

However, there are some disadvantages to Chip Film technology. For example, issues with bonding between the thin film and the silicon substrate may affect the quality and stability of the silicon layer. Additionally, the choice and quality control of the thin film are also factors that constrain the development of this technology. In conclusion, Chip Film technology offers certain advantages and limitations in the preparation of ultra-thin silicon chips, and further optimization and research are needed for practical applications.

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2.6. Development and Future of Ultra-thin Silicon Chip Manufacturing Process

Over the past decade, significant advancements have been made in the manufacturing technology of ultra-thin silicon chips. In 2014, the industry began to shift focus towards enhancing production efficiency and reducing costs in the manufacturing processes. By 2016, notable improvements were observed in process optimization and materials innovation, leading to more effective production methods. In 2018, a trend emerged towards refinement and intelligent automation aimed at boosting both the performance and stability of silicon chips during manufacturing. Advancements in nano-technology applications and intelligent manufacturing practices began to shape the future direction of ultra-thin silicon chip production by 2020, addressing the increasing demands of the market.

Looking forward, the future development of ultra-thin silicon chips is expected to encompass various trajectories. One of these trajectories involves the utilization of nano-technology applications, which will allow for more compact dimensions and enhanced performance benchmarks in chip manufacturing. Furthermore, the integration of intelligent manufacturing practices is anticipated to foster automated, intelligent, and sustainable production processes. The adoption of novel material concepts will likely refine both the performance and stability of silicon chips, while continuous optimization of the manufacturing processes is expected to elevate production efficiency and enhance quality standards in silicon chip production.

These evolving trends are set to drive the advancement of ultra-thin silicon chip manufacturing technology towards greater efficiency, sophistication, and adaptability, ultimately catering to the expanding market demands and technological requirements.

3. The application of ultra-thin silicon chips in various fields

When it comes to the specific applications of ultra-thin silicon chips in various fields, the breakdown can be further refined as follows:

3.1. Electronics Industry

Ultra-thin silicon chips are integrated into various components of smartphones, including processors, memory units, and sensors, which enable high performance and intelligent functionalities within these devices. In addition, tablets and laptops utilize ultra-thin silicon chips for controlling panels, processing data, and rendering graphics, thereby facilitating efficient computing and display functions. Ultra-thin chips (UTCs), with a thickness below 50 μm, are essential for meeting high-performance demands, such as fast communication and computing capabilities [9].

3.2. Medical Sector

Ultra-thin silicon chips are employed in various medical devices, including medical imaging equipment and diagnostic instruments, where they support the processing and transmission of medical data. Additionally, these chips play a crucial role in monitoring and controlling implantable medical devices, such as pacemakers and neural stimulators. In the medical field, technologies like flexible electronics and flexible sensors can be effectively applied to enhance the functionality of medical devices and medical monitoring systems.

Flexible packages have already been extensively investigated for use in wearable electronics, exemplified by chip-on-flex (COF) packages that utilize anisotropic conductive film as interconnection material, which have shown great potential [10]. Flexible sensors can monitor patients' physiological parameters, such as heart rate and respiratory rate, enabling real-time monitoring and telemedicine. Besides, flexible displays can be used for the interface display of medical devices to provide a more convenient operation and information display. Therefore, the flexible electronic products supported by COF packaging technology have potential application prospects in the medical field.

3.3. Telecommunication Field

Routers and switches benefit greatly from the integration of ultra-thin silicon chips in their systems. These chips are essential for tasks such as packet processing and network management, enabling the seamless operation of communication devices by ensuring efficient data routing and handling.

When it comes to fiber optic communication, ultra-thin silicon chips are instrumental in the pivotal process of optoelectronic conversion and data transmission. Their role in driving advancements in fiber optic communication technology cannot be overstated, as they play a crucial part in enhancing the speed and reliability of data transmission over fiber optic networks.

The high-density silicon-based capacitors would reduce the overall area along with high integration and reliability. These capacitors serve various applications, ranging from pico-farads to micro-farads, and are used in devices such as energy storage systems, switch capacitive filters in electrocardiograms (ECGs), and switched capacitor converters [11].

3.4. Automotive Industry

In the realm of smart vehicles, the integration of ultra-thin silicon chips within in-vehicle systems and Advanced Driver Assistance Systems (ADAS) serves as a cornerstone for enabling intelligent driving capabilities and automation functionalities. These chips play a pivotal role in enhancing the overall intelligence and automation features within modern vehicles, contributing to improved safety and efficiency on the road.

Almost every physical object will be tasked to communicate with each other. A substantial fraction of these devices will be placed on locations that would undergo repeated bending deformation (such as sensors for prosthetics, human body, and robots) or on curved surfaces (like the interior as well as the exterior of automobiles, buildings, and industrial equipment) [12].

When delving into the domain of autonomous driving technology, ultra-thin silicon chips are indispensable components crucial for various aspects of the system. From processing sensor data to facilitating seamless human-machine interaction, these chips support the intricate mechanisms of real-time decision-making and control within autonomous driving systems. Their presence and functionality are instrumental in ensuring the smooth operation and advancement of autonomous vehicle technologies.

3.5. Artificial Intelligence (AI)

In the sphere of machine learning, the utilization of ultra-thin silicon chips significantly speeds up processes such as model training, inference, and optimization. By leveraging these chips, the efficiency and effectiveness of machine learning algorithms are enhanced, ultimately leading to improved performance and faster computations in various applications.

Ultra-thin silicon chips also play a critical role in neural networks by enabling neural emulation and advancing deep learning processes, thereby advancing artificial intelligence technologies. Through their implementation, these chips contribute to the development and optimization of neural network architectures, supporting the complex computations and data processing required for cutting-edge AI applications. By powering neural networks with their capabilities, ultra-thin silicon chips drive innovation in artificial intelligence and pave the way for future advancements in the field.

3.6. Energy Management

In the context of Smart Grids, ultra-thin silicon chips serve as essential components for energy data acquisition, monitoring, and analysis, playing a key role in the efficient operation and management of smart grid systems. By enabling precise and real-time data processing, these chips facilitate the optimization of energy distribution and resource utilization within smart grid networks, contributing to enhanced efficiency and reliability in energy management.

Furthermore, in energy-efficient devices, ultra-thin silicon chips play a pivotal role in controlling energy consumption and enhancing energy utilization efficiency. This is particularly relevant in applications such as smart homes and smart lighting systems. Through their ability to regulate and optimize energy usage, these chips support the development of sustainable and eco-friendly technologies, driving the transition towards greener and more energy-efficient solutions for modern living environments.

The widespread applications of ultra-thin silicon chips across diverse industries not only foster technological advancements but also fuel innovation and progress in societal development. By underpinning key functions and processes in various sectors, these chips contribute significantly to driving efficiency, sustainability, and overall advancement in the modern era.

Fundamental package warpage, largely driven by mismatches in the coefficient of thermal expansion (CTE) between various packaging materials, is induced by residual stresses during molding and other thermal processes [4].

4. Conclusion

This paper has explored the application and development of ultra-thin silicon chips, highlighting their significance and potential within the modern field of electronic science. With its compact size, low power consumption, and efficient heat dissipation characteristics, ultra-thin silicon chips offer possibilities for enhancing the performance and size optimization of electronic products such as smartphones, tablets, and smart wearable devices. By introducing the fundamental principles, fabrication methods, and applications in various fields of ultra-thin silicon chips, the extensive prospects for the utilization of this technology is demonstrated.

With the continuous advancement and optimization of the manufacturing technology of ultra-thin silicon chips, significant progress has been made in terms of production efficiency, cost reduction, material innovation, and other aspects. In the future, as nanotechnology applications and smart manufacturing practices advance, the manufacturing technology of ultra-thin silicon chips will continuously adapt to market demands to achieve more efficient, intelligent, and sustainable production processes.

From the electronics industry to the field of communications, and further to sectors such as healthcare, automotive, artificial intelligence, and energy management, the applications of ultra-thin silicon chips are wide-ranging and diverse. These chips not only drive technological innovation but also propel progress in societal development. By supporting key functions and processes in various industries, ultra-thin silicon chips have made significant contributions to the efficiency, sustainability, and overall advancement of modern society. Therefore, the development of ultra-thin silicon chips will continue to lead the field of electronic science, meeting the growing market demands and technological challenges.

While this paper has provided a comprehensive overview of the application and development of ultra-thin silicon chips, it is important to acknowledge certain limitations. The discussion primarily focused on the current advancements and potential applications, but it did not delve deeply into the specific challenges and limitations faced in the manufacturing processes or the long-term reliability of these chips in various environments. Furthermore, the rapid pace of technological evolution

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necessitates ongoing research and development to address emerging issues and optimize performance. Moving forward, it is essential to continue exploring innovative solutions and refining manufacturing techniques to enhance the capabilities of ultra-thin silicon chips, ensuring they meet the growing demands of diverse industries and contribute to sustainable technological progress.

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