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Analysis on the Development of Semiconductor Manufacturing Processes

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Abstract

The computing speed of chips depends on the number of transistors. In other words, if you have more transistors, the computing speed of chips will be faster. Supposing the area of a chip is limited, we need to develop ways to fit in more transistors. To put more transistors in chips, minimizing the existing microelectronic device is a good way. To achieve that goal, we need to develop effective semiconductor manufacturing process to develop the performance of chips. In this paper, the research topic is to introduce the development of processes and also show their relevant applications of process. This paper intends to let more people realize the importance of semiconductor manufacturing processes and how it applies to our daily lives. This paper will investigate the following question: until October 2021, which is the most advanced manufacturing process? What are some other areas that we can expand through manufacturing process? The conclusion is that until October 2021, the most advanced process is N5P. Semiconductor manufacturing processes apply to areas like Adaptive Substatistical PCA, complicated material modeling tools and methods.

Keywords

Semiconductor Manufacturing Process; Transistor; Performance; TSMC; EUV Extreme Ultraviolet Photolithography.

1. Introduction

Semiconductor manufacturing processes develop quickly and the performance of chips also ascends rapidly. Many companies use powerful chip architectures with the best process technology to give customers great product experiences. To produce higher-quality chips and gain bigger profits, many companies invest a lot of money in the semiconductor manufacturing process and investigate further for leading positions worldwide such as Intel, Samsung, TSMC. TSMC is Taiwan Semiconductor Manufacturing Company (also called TSMC) in Taiwan, China. Nowadays, this company is developing 4nm chips and planning to launch it at the end of 2021. Meanwhile, people are investigating other areas related to semiconductor processing. Currently, the leading manufacturing processes are N5, N5P, 5 LPE. However, since processes have developed rapidly, here comes a challenge: how to better manage energy efficiency. For this paper, the research topic is to introduce the development of process and show the applications of process. The paper will investigate the following question: until October 2021, which is the most advanced manufacturing process? What are some other areas that we can expand through manufacturing process? The method of investigation is to read reports and understand the professional knowledge about recent development of processes with corresponding technologies and products. This paper intends to let more people realize the importance of semiconductor manufacturing processes and how it applies to our daily lives. In the future, there will be more advanced processes coming out and the performance of chips is expected

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to increase at the same time. Suggestions for further processes are using advanced frames that can balance the performance and consumption within a good range.

2. Analysis of the Semiconductor Manufacturing Process

2.1 The Development in Recent Ten Years

Semiconductors can be applied to various facets of our daily life. For example, no matter artificial intelligence, smartphones or the utilization of 5G, none of them could work without semiconductors. Therefore, an advanced process will help a company in the electronics field gain more competitiveness over its rivals. According to the research about global semiconductor market from 2006 to 2021, the expense of semiconductor rises because of new materials and increasing of processing cost. Because of COVID-19, the global chip market underwent another round of price increase in 2021. One reason is that the pandemic interferes with the supply of raw material. The other reason is that advanced manufacturing processes are becoming more complicated and thus costs more money. [2].

From 2011 to 2021, people experienced the development of the semiconductor manufacturing process from 32 nm to 5 nm. During the development, every company used its own advanced transistors. Let's take Intel as an example; in 2012, which was the year for the 22 nm lithography process, companies used the first generation of Tri-gate FinFET transistors. The company spent a lot of money pursuing and developing more advanced techniques. However, this also reflects some shortages there. The development of semiconductor manufacturing process became more challenging as the company developed further--the more advanced the process is, the more challenging is the development of it. This also enlarges the gaps among different companies. 5 nm LPE and N5 are two manufacturing processes that were developed by Samsung and TSMC. However, the power consumptions of the chips that use these to processes are totally different. Thus, companies need to figure out how to solve the problem of power consumption as they develop their chips' performances performance. The latest chip, Snapdragon 888, uses 5 nm LPE had has higher power consumption. Some researchers said they experienced 50℃ on the back when they played of the chip.

2.2 Application of Semiconductor Manufacturing Process Semiconductor Manufacturing Process Monitoring based on Adaptive Substatistical PCA

By using the PCA(MPCA) method, companies can have higher interest in monitoring semiconductor manufacturing. The purpose of statistical process control is to improve the quality of the process that is required to be quick when figuring out process abnormalities and diagnosing the sources of the detected process abnormalities. According to the paper from a professor who do research about this area, there are also some drawbacks that include future value estimation, a limited number of batches, and non-Gaussian behavior of the process data. The paper mentions that an industrial example can demonstrate the performance of the proposed method. Three experiments were carried out to produce a total of 129 wafers; 21 failed, deliberately caused by changing transformer coupled plasma radio frequency (RF), RF power, pressure, CI or BCI flow rate. The data sets used herein are collected from the Al stacked etching process, and are carried out on the Texas Instruments on the LAM 9600 plasma etching tools of the commercial scale. Time complexities and correlations among ASSP, MMPCA, and MPCA are analyzed. For comparison and to demonstrate the advantage of SVDD, monitoring results of ASSP without SVDD are given in the chart. In the following case study, 95 normal batches are randomly selected as the training datasets. The rest of the batches are 12 normal and 20 faulty batches used for testing. They defined a standard of fault detection. The paper tells that a fault is considered to be detected if three data points in a batch operation violate the statistic confidence limit. Detailed monitoring results of ASSP_SVDD, ASSP, MMPCA, and MPCA are given and analyzed as follows. After that, they tested 12 normal batches and 20 faulty batches. All the monitoring results were listed in the table that is clear to show the readers. According to the calculation, The time complexities of ASSP and MMP are comparable, and both are lower than MP. There is a sudden change in the middle of the batch duration. According to the principle of the similarity factor, the

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stage of the process may be changed. That's why the value of sudden change can be used for stage-change detection of the batch process. Advantages of the proposed method are low time complexity, future value-estimation is avoided and no Gaussian supposition for the data of the process is needed. However, the method is limited in linear and stationary cases. The extension of nonlinear and dynamic process monitoring is under consideration.

2.3 Current Manufacturing Process

At present, the latest manufacturing lithography process is 5 nm. It was achieved around 2020. The density is between 130-230 million transistors per square millimeter for 5 nm nodes. For the density of 7 nm process, it is just between 90-102 million transistors per square millimeter. TSMC claims that 5 nm process is 1.84 times denser than its 7 nm process. Therefore, it is an amazing promotion around the world. N5, which was developed by TSMC, launched in Q1 2020. N5 has 15% of improvement in performance with 30% less power consumption compared with N7. Up until Oct 21st, 2021, the greatest semiconductor manufacturing process is 5nm N5P that is developed by TSMC. N5P is called N5 Performance-enhanced version (N5P) and it is an optimistic version of N5. Some chips like Apple's latest three chips, M1 Max, M1 Pro and A15 chips all use the latest N5P manufacturing process. In contrast, chips that use N5P processing can enhance performance by 7% and reduce power consumption by 15% compared with N5, which is the previous manufacturing process of TSMC. [1] Cirmall TSMC 5nm uses the fifth generation FINFET transistor technology, EUV extreme ultraviolet photolithography technique is also extended to more than 10 photoresist layers, and the overall transistor density is increased by 84%. [1].

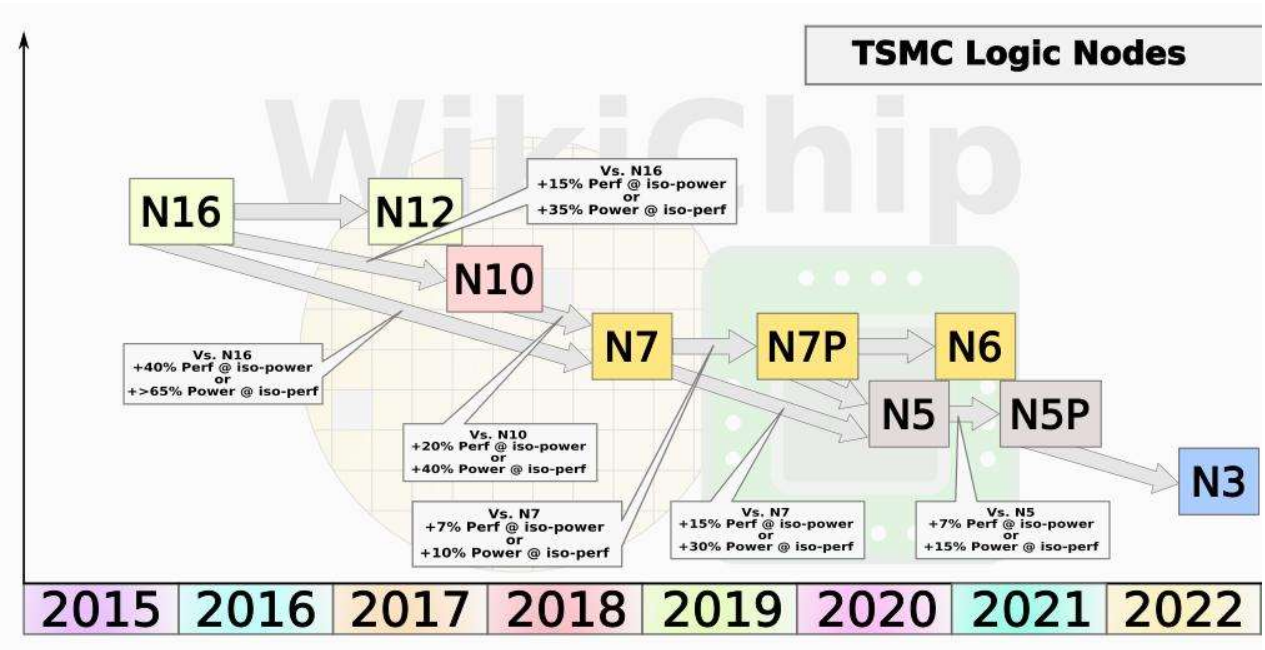

Figure 1. TSMC Logic Node [1]

Another company that achieves 5nm semiconductor manufacturing process is Samsung. It launched its own design development called 5LPE, which is Samsung 5-Nanometer Low-Power Early in early 2019. In contrast with TSMC's development, it is only a quarter node successor compared with its 7-nanometer, which is 7LPP manufacturing process, delivering 1.3x density improvement through a new standard cell library as well as new scaling boosters. Moving to a similar 7.5T library will increase 11% performance for various transistor optimizations (Low-k spacer, DC enhancement, etc.) and provide about 33% higher density by moving to a 6T library. Chips like Snapdragon 888 and Snapdragon 888 plus both used this chip manufacturing process. [4].

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2.4 Technological Process of Semiconductor Manufacturing Processes

2.4.1 Wafer Processing

During the integrated circuit process, electronic circuits with transistors are formed on the surface of a silicon crystal wafer. The wiring, transistors, and other components are formed by a film layer that is deposited on the wafer (deposition).

The thin film is coated with photoresist. Using Photolithography technology, the circuit pattern of the photomask (reticle) is projected onto the photoresist. The use of developed photoresist is to change from the film to the shape of the wiring and other components by processing, which serves as an etching mask. [3].

2.4.2 Front-end Process and Back-end Process

Through the front-end process, which is the operation of wafer processing, and also the back-end process, semiconductor devices are formed. Then, a tiny area is amplified in a wafer surface and then shown schematically. Finally, semiconductor devices can be utilized in multiple products such as laptops, mobile phones, and even new-energy vehicles in daily life. [3].

3. Future Expectations

The next stage of the semiconductor manufacturing process is 3 nm. It said that in 2023, chips with 3 nm process will come out. The performance and power consumption will be better. Chips will have a smaller density to fit in more transistors. Thus, intense competitions between companies are possible in the future. Customers will give their feedback and decide on which process technology is the best for them. However, based on the current situation, the price of the manufacturing process will keep increasing inevitably because of the pandemic. Therefore, the situation will not be friendly for customers for the next several years.will not be friendly to the customers for several years. Under this difficult situation, further investigations will not be stopped. Take China as an example, because of the sanctions from the American Government, the semiconductor industry in China mainland ascends rapidly. All people in the semiconductor industry--no matter people from China mainland, Taiwan, or other countries or regions-- share a common wish for seeing the development of semiconductor manufacturing process and its significant benefits for the whole society.

4. Conclusion

The semiconductor manufacturing process is closely associated with the performance and power consumption of chips. Good manufacturing process will give consumers good experience of a product like smartphones and computers. This paper demonstrates the importance of advanced semiconductor manufacturing process and how it applies to our daily life. Until October 2021, the most advanced process is developed by TSMC and called N5P, but in the future it also may be changed. Humans enjoy a lot of benefits from manufacturing process, which can be applied to many state-of-the-art areas like Adaptive Substatistical PCA, complicated material modeling tools and methods. Limitations of this paper are: firstly, the topic of the paper is quite challenging, and the information is scarce. Secondly, I did not go further on this topic with specific details. As for the future research, investigations can focus more on the development of frames within recent decades. That will trigger developers to learn from the weaknesses of the past and invent more advanced processes. In the future, the performance and power consumption will be better in the future. Chips will have a smaller density to fit in more transistors.

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