A summary of the current development of developing technology in the field of integrated circuit manufacturing

LIU Xue-ping[1, a], XU Qiang[1,b], Ning Feng[1,c]and WANG Han[1,d]

[1] Division of Advanced Manufacturing, Graduate School at Shenzhen, Tsinghua University, Shenzhen 518055, Guangdong Province, China;

[a] liuxpyh@aliyun.com, [b]xugongsui521@126.com (corresponding author), [c]snoopy068@126.com,[d]wanghan_ts@163.com

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Abstract Developing technology is critical for the lithography technology in the field of integrated circuit (IC). The developing nozzle and process are the "hard" and "soft" technology, respectively. It is the continuous improvement and innovation of developing nozzle and process that drive the rapid development of lithography technology and IC technology, and promote the reform of information technology. In this paper, we emphatically introduce the development status of developing nozzle and process, and put forward the development trend of developing technology based on the current situation of IC technology in China.

Introduction

Nowadays, Information Technology (IT) is the foundation of the economic activities and social life, and has changed human's life [1]. Things including refrigerators, color TVs, mobile phones, computers, etc, are all based on IT. The 21st century is the information technology era. The integrated Circuit (IC) chip technology support the IT technology to develop fast. According to Moore's Law, referred by one of Intel founder Moore, the number of transistors in a dense integrated circuit will be doubled approximately every 18 months; while the prices and transistors performance remain the same [2]. This theory reveals the speed of IT. In fact, over the past 30 years, the development of IT technology has followed Moore's Law, and the number of transistors on a single chip is up to 10^9 order of magnitudes, compared with the number of 10^1 before 30 years. Driven by the rapid development of IT technology, the society and economy have sped up.

Photolithography as a critical process in IC chip manufacturing field, determines the critical dimensions of the devices. Photolithography occupies 40% to 60% of the process, and its cost almost equals to 1/3 of the entire IC chip manufacturing [3]. Photolithography is a process that creates graphic on the substrate. This process need to copy the graphics on the wafer surface by mask and photoresist accurately, then leaves a thin film with tiny graphics on the wafer surface. Photolithography need several steps to be combined, including wafer surface cleaning and drying, spin coating, soft baking, alignment and exposure, developing, hard baking, etching, photoresist removal, detecting, etc.[4].

Developing as an important part of the photolithography, has a deep impact on the final IC chip quality. This paper focuses on the developing nozzles and the development of developing process by combining the recent progress of the developing technology, and proposes the improvement trend of developing technology.

Developing process

Overview

The developing process is an intermediate step of the photolithographic procedure. It need duplicate the graphics onto the wafer surface by mask and photoresist, and then remove the surplus photoresist of wafer， as show in figure1. Developing is to ensure the feature size, which means the minimum line width of the semiconductor devices to meet the requirements [5]. If the feature size meets the requirements, it is assured that all geometric features in the processing are all controlled. It is obvious that the feature size is important and difficult in developing technology. Wherein, photoresist removal in the developing process is chemical reactions. First, developer solution reacts with photoresists, then unwanted part need dissolving to form a certain photolithographic pattern, that is the circuit pattern.

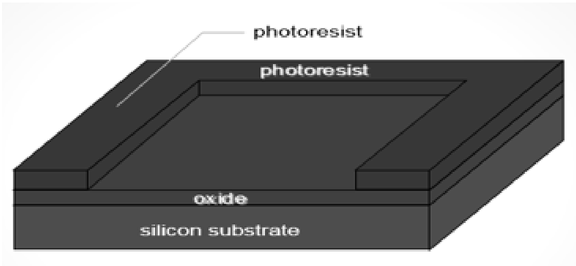

Figure 1. the pattern after developer

Common developing defect

Due to the deficiency of developing nozzle or the developing process, photolithographic process may lead to defects, resulting chip unqualified. The common development defects are peeling, bridging, adhesion, etc. [6]. The defective developing nozzle or the process is the root reason, which lead to unevenly developing and developing defects. In addition, excessive pressure coming from the shock between developer and photoresist may also cause developing defects.

Development defects can lead to unqualified chips, thereby reducing the yield of integrated circuit chips. Therefore, it is critical to minimize the developing defects in the chip manufacturing process.

Difficulties in developing technology

The difficulty in developing technology is to reduce defects in the process. The key is to achieve the developing uniformity and low impact resistance. Next, we will introduce the development status of the nozzle and the developing process, and focus on innovation of developing nozzle, the optimization of the developing process, in order to improve uniformity and low impact in the field development process.

Development of developing nozzle technology

IC technology is driven by two "wheels" [7], one is the increasing wafer size, and the other is the decreasing critical dimensions (CD). With wafer size expanded, more chips can be integrated on a single wafer. As the decreasing critical dimensions, the developing and photolithography process are required more stringently. Developing nozzle as a key component, has also been improved with the constant development of IC technology.

The initial semiconductor developing process uses H-nozzle (see figure 2), which is mainly applied to the photolithography process of no less than 1μm. H-nozzle is a multi-outlet spraying nozzle, which is placed above the center of the wafer. When the wafer is rotated, the developer sprayed from the nozzle outlets onto the wafer surface. In order to expose the wafer entirely, a larger amount of developer is required. The biggest advantages of H-nozzle are the large liquid spray volume, the strong developing ability, and the low probability of residue defect in the wafer surface. However, the biggest drawback of the H-nozzle is that the over developed in the center of the wafer by the H-nozzle position, which will lead to uneven defect in the developing of the entire wafer. This is the main reason the H-nozzle occur rarely in the photolithographic process under 1μm.

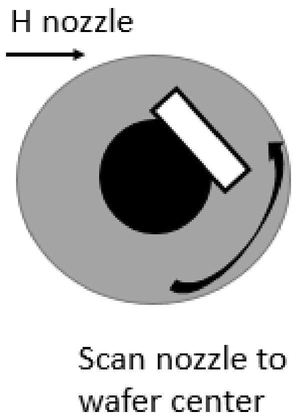

Figure 2. H Nozzle

After H-nozzle, the E2 and E3 (see figure 2 and figure 3) nozzle are developed [8], and they are both the typical developing nozzle products of Japanese TEL's. Compared with H-nozzle, the E2 nozzle (Figure) increase the number of outlets, and reduce the orifice aperture, therefore reducing the amount of spray liquid, and improving the uniformity of spraying. Meanwhile, the nozzles increase insulation pipe and diversion pipe structures. The diversion pipe structure ensure the stability of the liquid flow inside the nozzle, and mitigate the flow impact of photoresist on the wafer surface. The insulation pipe is to ensure the stability properties of the liquid developer substance. E2 nozzle has improved the homogeneity and stability of liquid spray. Therefore E2 nozzle gradually becomes the mainstream in no more than 0.35μm photolithography process.

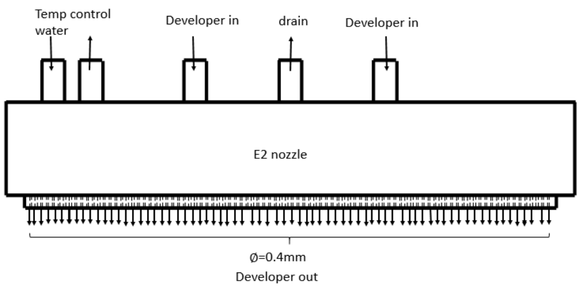

Figure 3. E2 Nozzle

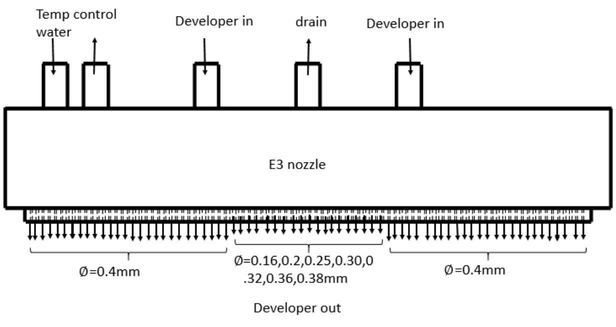

Figure 4. E3 Nozzle

Another nozzle is called E3. Compared with E2 nozzle, the biggest difference in the structure of E3 nozzle is that the nozzle number of outlets and aperture orifice. E3 nozzle increases the orifice number, and its aperture size increases from the center to the end. The main reason of the E3 nozzle structure is congenital defects in the E2 and E3 nozzle spray process. They are both fixed and developing while the wafer rotating Since the same size of each aperture in E2 nozzle, the process may lead to over developing in the center of the wafer and bring the uneven defect. To make up for deficiencies in the spraying process of E2 nozzle, E3 nozzle uses the different aperture distribution. The increasing number of outlets is to increase the uniformity of spray.

Though E2 and E3 nozzles have a better uniformity and lower shock resistance than H-nozzle, the requirements of photolithography process equipment's also become more stringent. Particularly, when photolithographic process reaches 0.13 μm , peeling would occur if the liquid has big pressure with the reduced chip CD size . To solve this problem, Japan TEL Company launched LD nozzle (see figure 5).

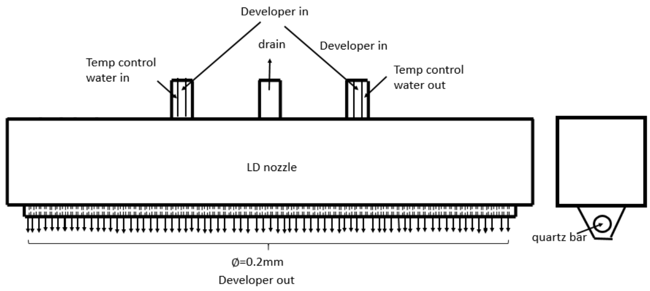

Figure 5. LD Nozzle

The most prominent improvement of LD nozzle in the structure is that it adds the stream diversion rod structure in front of the nozzle orifice. The stream diversion rod is generally made of quartz, which has good hydrophobicity and prevents liquid from dropping after the developing. Such a structure can slow the impact of the liquid flow. When the liquid flows through the diversion rods, pressure has been released, then flows from the orifice. So LD nozzle has achieved a soft impact on the wafer surface, and reduced inverted plastic defects in the developing process.

There is a structure named flapper outflow developing nozzle (see figure 6) designed by C. Bürgel [9]. The structural features of the developer are that nozzle flows out through the outflow slits, impacts the developing baffle plate, then flows down outside of the nozzle and forms a stable film, eventually sprays on the wafer surface. Baffle design can greatly release the impact that liquid sprayed directly to the wafer surface, while the water film greatly improves the uniformity of spray.

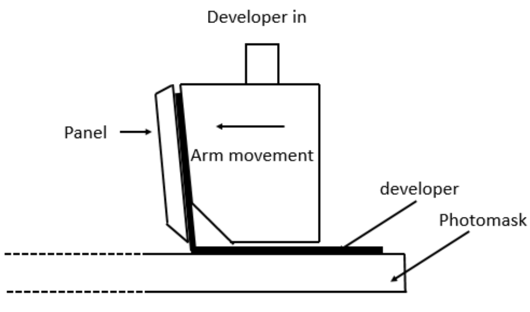

Figure 6. Flapper outflow developing nozzle

However, flapper nozzle has a big problem for application that is the form a uniform and stable water film in the bottom of the bezel is difficult. The main reason is that the liquid flow pressure is not balanced in each position of the longitudinal direction, resulting in non-uniform distribution when fluid through the slit. Finally, non-uniform distribution may lead to fractures in the water film and make the water film unstable.

Overall, the structure of nozzle has been improved with the process of IC technology and photolithography technology. Though research on developing nozzle starts late in China, it has also made certain achievements. Liu Xueping, from Tsinghua University, has developed the domestic developing nozzle that passed the whole test and can meet the requirements of 300 mm wafers and 90 nm photolithography process. The static pressure developing nozzle follows hydrostatic principle, and provides vents, head flow channel, secondary flow channel, jet channel and heat preservation channel. The vents role is to exhaust bubbles in the head and secondary flow channel, and make the pressure in the flow channel balanced and stable. Liquid flows from the entrance, rectified in the head flow channel, then into the secondary flow channel, finally outflow from the jet channel. The pore size and spacing of the jet channel are selected through theory, simulation [10], and passed through experimental verification.

Development of developing process technology

With the innovation of the nozzle, developing process is constantly optimizing. Developing process generally refers as developing spraying. There are three traditional developing process, namely, immersion developing, continuous spray developing and rotary immersion developing.

Immersion developing is immersing wafer in the developing tank completely. This method has been rarely used nowadays for the impurities to developing tank and the consummation of the developer. The concentration of developing solution in the tank becomes low, which changes the operating conditions in the next wafer developing, and makes it difficult to control certain parameters unchanged in mass production. Thus the consumption of the developer is large, and the developing uniformity is poor[11].

Continuous spray developing is that the developer is sprayed to the rotating wafer at a low speed (100-500 rpm). Adjusting the nozzle spray pattern and the wafer rotational speed can control the spray uniformity. However, the atomized droplets will adhere to the wafer surface to form "small lenses", and affect subsequent exposure process.

Rotary immersion developing generally contain four steps. First, dropping a sufficient amount of developer onto the stationary or the low-speed rotating wafer surface, and the developer forms puddle shape. Secondly, the wafer rotates accelerative and obtains the uniform developer film with different thickness. This step expands the area that the developer can reach. Thirdly, the wafer speeds up the rotation to make the developer distributed uniformly at the silicon surface [12]. The last step is to to make the reaction sufficiently between developer and photoresist for a period of time. Repeating the four steps for several times and let the photoresist completely dissolved in the soluble region. This method has the advantage with less developer use. The biggest drawback is that the surface tension and centrifugal force lead to the developing film not tiled, and it’s thin in the center and thick near the edge, due to. Therefore, this developer distribution can’t guarantee uniformity on the entire wafer.

With the rapid development of Micro-electromechanical Systems (MEMS) the developer coatings are need for geometric features with a high aspect ratio as show in figure 7. It’s inconvenient with the ordinary rotary immersion developing process. To implement a uniform developer coating on the non-planar wafer surface only by using inertia force is difficult, so is non-circular wafer. Subsequent improvement of developing process are rotating spraying process and linear scanning process. Rotating spraying process keeps the wafer rotating when sprayed by the nozzle fixed above the wafer. This process mainly uses the H-nozzle and the E2/E3 nozzle. Linear scan process fixes the wafer and makes the developing nozzle rectilinear scanning the entire surface of the wafer to complete developing process. Japan LD nozzle and China static pressure nozzle are mainly applicated in this developing process.

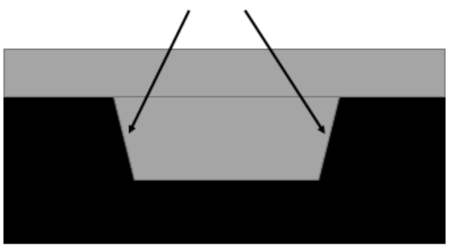

Figure 7. V-groove

The main advantage of the rotating spraying process and linear scanning process is that it can control the spray amount by the flow rate reasonably. In addition, it has more flow orifices, and covers large area more uniformly. Especially when the photolithography process gradually reaches the nanoscale, the reduced CD size and the linear complexity make more defects in the spin coating. However, the defects can be reduced by linear scanning process in some extent. Japan LD nozzle, Germany flapper nozzle and Chinese static pressure nozzle are all used in the linear scanning process.

The mainstream developing process is linear scanning process. Along with the improvement of photolithography technology, there are still some shortcomings of the existing technology. Many researchers have proposed a series of new improved schemes. For linear scanning process, Li Bingzong and Cheng Meng [13] from Fudan University, change the developing spray parameters (height between the nozzle and wafer, the scanning time) to optimize the developing process and improve the quality. . Hideharu Kyoda and Atsushi Okouchi from Japan, optimize the developing process, and enhance the developing quality by controlling the photoresist solubility difference before and after the developing process to [14]. Masakazu Sanada, and Osamu Tamada use new apparatus system to shorten developing time, and improve the developing quality ultimately [15].

Trends of developing technology in China

The research in IC technology starts late in China. We has not mastered the core technology in mass production of 90nm process, but 21nm manufacturing in photolithography process is applied at abroad. , . Some local IC companies are rising, such as SMIC, JCET, Histon NEC, NFME.. In 2004, SMIC has completed the first 300mm wafer production line in mainland. . But, Until 2010, the intellectual property rights of the representative IC manufacturing companies, such as Grace, Histon NEC and SMIC, still remain in the level of "125mm diameter wafers, 0.13um" [15]. Compared with international semiconductor technology blueprint and the worldwide leading semiconductor companies, 21nm linewidth feature size IC chip production line put into operation, the 21nm linewidth IC chip has already been applied, and China is lagging behind. Developing process is a key technology in the IC field. Improving developing equipment and the level of developing process has a great significance on the IC technology in China. Currently, the IC technology in China develops moderately, and has a weak foundation. With the expanded investment and attention on IC equipment manufacturing industry, there will be some breakthroughs in the developing technology. First, IC industry chains need strong financial support both in equipment and research investment. In foreign countries, countries and companies invest together. In China, we may continue to increase capital investment, focus on supporting strong IC technology companies, integrate financial and technical advantages, promote IC equipment manufacturing industry, and improve the developing technology and innovation. Secondly, the related IC industry companies should be get the tax revenue preferential, rewards, and incentives. Thirdly, cooperation education of enterprise will likely become the new model. We can make use of university research capabilities and business field conditions, bring different developing technology companies together.

Conclusion

This paper focuses on the developing technologies in IC technology, discusses on the improvement of developing nozzle and developing process. In the end, based on the current process of IC technology, we gave our advice on the trends of future IC and developing technologies in China.

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References

[1] The forecast for 2010: market growth in demand driven semiconductor industry rapid recovery [CSIA]: http://www.csia.net.cn/Article/ShowInfo.asp?InfoID=12562:2011.

[2] Wang chen. The research of semiconductor MOS devices based on High k gate dielectric III-V compound [M]. Shanghai: Fuan University, 2012.

[3] K. A. Jackson. Tu hailing Wan Qun's Translation. Processing of semiconductors[M]. Beijing: Science Press, 1999.

[4] Peter Van Zant. Microchip fabrication a practical guide to semiconductor processing[M]. Beijing: Publishing House of Electronics Industry, 2014.

[5] He Jiao, Guo Wen-xun, Peng Dang, He Qian. Synthesis and properties of methylacrylate photoresist matrix resi [J]. Applied Chemical Industry, 2011, 40(2): 210-214.

[6] Neil Bradon , K. Nafus, H. Shite, J. Kitano, H. Kosugi, M. Goethals, S. Cheng. Further investigation of EUV process sensitivities for wafer track processing. EXTREME ULTRAVIOLET (EUV) LITHOGRAPHY,2010(7636).

[7] WENG Shou-song. Two wheel that drive the development of the semiconductor industry chain. Semiconductor Technology, 2004, 29（5）: 25-26.

[8] Tan xia. The research of integrated circuit lithography platform optimization and lithography resolution enhancement technology for 0.13 μm [M]. Shanghai: Fuan University, 2010.

[9] C. Bürgel, W. Saule, M. Strobl, P. Dress, A. Schwersenz, M. Tschinkl. Comparison of new film nozzle with standard nozzle for aqueous puddle develop of photomasks. Proceeding of SPIE, 2003(5130):213-219.

[10] Liu Xue Ping, Wang Han, Xu Qiang. Research on the effects of the capillary wall and the different flow rate to the process of the drop formation in the developing nozzle. Advanced Materials Research. 2014(997):599-604.

[11] Liu feng. Wafer Defects Issue Study In Lithography [M]. Tianjin: Tianjin University, 2012.d

[12] K. Tanaka,H. Iwaki, Y. Yamada, Y. Kiba, S. Kamei and K. Goto, Application of Diluted Developer solution. Process to 193 ㎚ Photolithography Process, 2002(4690)：557-570.

[13] Leo cheng, NLD Develop Process Optimization and Defect Research[M].Shanghai：Fudan University, 2006.

[14] Hideharu Kyoda, Atsushi Okouchi, Hirofumi Takeguchi, Hyun Woo Kim
Taro Yamamoto and Kosuke Yoshihara. Improvement of CD Controllability in Development Process. Proceedings of SPIE, 2003(5039):1353-1365.

[15] Masakazu Sanada, Osamu Tamada, Masahiko Harumoto. Short Develop Time Process with Novel Develop Application System. Proceedings of SPIE, 2004(5376):1243-1254.
[16] WENG Shou-song. Developmental trend for processing technology of 300mm wafer chip manufacturing. Semiconductor Technology, 2004(1): 24-29.