DOI: 10.21062/mft.2025.009 http://www.journalmt.com

Optimized for Silicon Wafer Dicing Blade Machining and Grinding Parameters of Structure

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When diamond scribing knives are used to grind silicon wafers at ultra-high speeds, slight changes in the structure of the diamond scribing knives and changes in the grinding parameters will have a large impact on the processing accuracy and appearance of the silicon wafers. In order to reduce the defective rate of silicon wafers, improve the service life of diamond scribing knives and grinding efficiency. To address this issue, the working mechanism of the scribing knife grinding is analysed in the paper, the influence of spindle speed and feed rate on the quality of the silicon wafer slit when the scribing knife is grinding is studied, and the chipping of silicon wafers is observed through the scanning electron microscope and optical microscope, so as to analyse the shape of the cross-section, length of the cutting edge, concentration of diamond particles in the cutting edge, thickness of the cutting edge and determine the structure of the scribing knife, and to test its influence on the silicon wafer slit by means of the grinding experiments. The structure of the scribing knife was determined, and its influence on the quality of silicon wafer slit was tested by grinding experiment. The results show that the wear rate of diamond particles, slit quality and processing efficiency of the scribing knife are optimal when grinding silicon wafers at 50,000 r/min and 60-80 mm.sec^{-1}. The above study can help to further understand the wear mechanism of the scribing knife in the process of ultra-high-speed grinding of silicon wafers, improve the machining efficiency, and prolong the service life of the tool.

Keywords: Scribing knife, Grinding mechanism, Tool structure optimization, Parameter optimization

1 Introduction

Wafer scribing knives are mainly used in the semiconductor industry for slotting and cutting in the manufacturing process of integrated circuits and discrete devices, and the main cutting materials are silicon wafers, semiconductor compound wafers (GaAs, GaP, etc.), oxide wafers (LiTaO3, etc.), glass, ceramics, quartz, semiconductor composite materials, etc. The diamond scribing knives are composed of diamond particles and binder, which are wrapped in the binder. Diamond scribing knife is composed of diamond particles and binder, diamond particles wrapped in the binder, diamond particles in the cutting and binder to form a kind of diamond particles protruding called 'chip slot' structure [1], due to the mechanical cutting method is easy to introduce a large amount of stress in the chip, resulting in cracks chipping or even fracture, etc., the quality of cutting The quality of cutting is very critical to the reliability and yield of the chip. The diamond grinding wheel for cutting silicon wafers is chosen as the research theme, which is also known as a scribing knife, and adopts aluminium alloy as the cylindrical substrate and its structure is schematically shown in Fig. 1. Due to the grinding process under the ultra-high-speed grinding environment, the selection of different grinding parameters and blade shape for workpiece grinding process will produce different grinding effects on the surface quality of the workpiece, the main study in this paper is the scribing knife substrate and blade shape, the structure of the blade plating layer, and the grinding of the workpiece under different grinding parameters, the scribing knife blade wear and the surface quality of the workpiece to analyse, and ultimately selected The optimised grinding wheel structure and grinding parameters were finally selected. Through the study on the change of the grinding wheel structure and grinding parameters of the scribing knife under the environment of ultra-high-speed grinding, we can better study the selection of reasonable grinding parameters under the conditions of ultra-high-speed grinding to process the workpiece, so that the dimensional accuracy and surface quality of the workpiece can reach the required range.

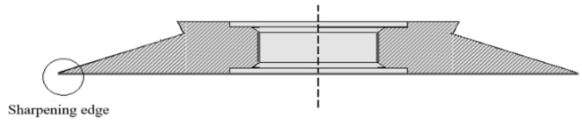


Fig. 1 *Schematic diagram of the structure of the blade substrate*

The current grinding method for silicon wafers mainly uses Single Point Diamond Turning (SPDT); among them, Venkatesh et al. [2] used a diamond grinding wheel with 0° front angle and a tip radius of O.75 mm to process silicon wafers, and selected the grinding depth of 1 um, the feed rate of 0.4 mm/min, and the spindle speed of 400 m/min, and the surface roughness obtained could reach 1 nm when using AFM measurement method; Zhou et al. [3] used the developed ultra-thin electroplated diamond to process silicon wafers. min, the surface roughness obtained can reach 1 nm by using AFM measurement method; Zhou et al.[3] conducted a high-speed scribing test on silicon wafers using developed ultra-thin electroplated diamond blades, and the experiments showed that changing the microstructure of the blades can significantly improve the cutting quality; Lin and Cheng [4] cut silicon wafers using scribing blades with two different diamond grain sizes, and investigated the relationship between the surface characteristics of the scribing blade and cutting dosage, and found that the surface condition of the scribing knife is an important factor affecting the cutting quality, and the cutting quality is optimal when the height of abrasive grains tends to be uniform; L.A.O. Araujo et al. [5] analysed the blade wear, straightness, and cutting quality through the experiments of cutting high alumina substrate, and found that changing the spindle speed during the cutting process can improve the cutting quality of the scribing knife; Su et al.[6] used a scribing knife to cut silicon wafers with a block width of 60 µm and a thickness of 200 µm, the experimental data were analysed using ANOVA, and the results showed that the spindle speed of 50,000 rpm and the half-cut depth of 50 µm have a better surface cutting performance; Li et al. [7] proposed to describe the change of the scribing knife's outer diameter in the process of high-speed machining using the dynamic diameter (Dd), and through a large number of experiments to derive the calculation formulas related to the parameters of rotational speed, static diameter, elastic modulus, Poisson's ratio, density, cutting length and radial wear rate of the scribing knife, and derive a method to improve the performance of the scribing knife by changing its rotational speed, static diameter and elastic modulus; Yuan et al. [8] took the radial wear amount of the scribing knife, the spindle current loading, the number of chips larger than 50 µm and the maximum cutting size as the test parameters for testing, to achieve the optimisation of the use of the performance of the scribing knife; Leung et al. [9]on cutting single crystal silicon cutting parameters (depth of cut, feed speed, tool front angle) on the machining of the surface quality of the impact of the study, that brittle materials processing in the plastic domain to ensure that the maximum thickness of the undeformed chip is less than the depth of the material brittle plastic transition. Yan and Gao [10] introduced the principle of scribing machine scribing, and scribing process affects the quality of scribing the key factors for systematic analysis and research, found that the blade exposure is 20-30 times the thickness of the blade, the scribing depth is the blade exposure of 1/3-1/2 of the scribing knife when the use of performance is optimal; Lang et al. [11] through the test found that the 4800 # abrasive grain size than the 3500 # scribe GaAs wafers with smoother frontal edges, pointing out that the cutting performance can be improved by selecting the grain size of the scribing knife; Wang et al. [12]investigated the effect of cutting parameters on the cutting force of monocrystalline silicon in the ultra-precision cutting process; through the analysis of process tests and experimental results, the cutting process parameters were determined; Zhang [13] used the method of experimental research to detect surface/subsurface damage of silicon wafers generated by the ultra-precision grinding process, and feedback to the silicon wafer surface damage, and feedback to the silicon wafer surface. /subsurface damage, and feedback to the process parameters, to optimise the process parameters to provide reference; according to the above research grinding silicon wafers, the paper adopts the scribing knife set up different structural shapes and grinding parameters and experimental analysis method, to derive a reasonable structural shapes and grinding parameters, so that the workpiece after its grinding to achieve the required precision.

2 Overview of the scribing knife grinding model and mechanism

The grinding model for cutting silicon wafers using a scribing knife is shown in Fig. 2, which is mainly composed of the knife blade, aluminium hub, workpiece, table, grinding fluid and grinding parameters.

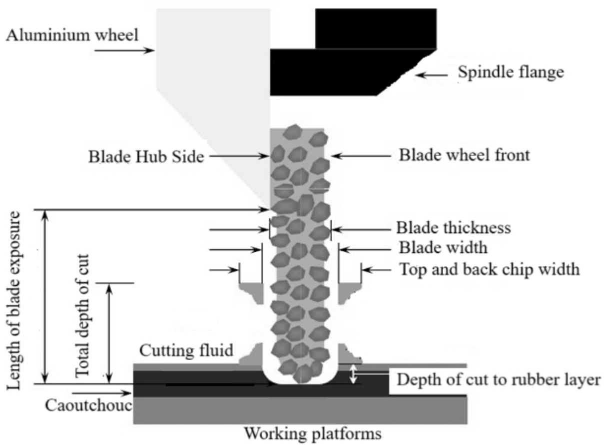


Fig. 2 *Model diagram of a scribing knife grinding a silicon wafer*

By the characteristics of the silicon wafer determines the impact of the scribing knife grinding silicon wafers, especially grinding thin silicon wafers (thickness less than 200 microns), due to the residual stress generated by grinding leads to cracks in the kerf, the diamond particles as abrasive grains, bonding agent for the abrasive material and the workpiece of the interaction between the three, the principle of its grinding is shown in Fig. 3. Under the action of alternating stress its abrasive grains grinding to produce cracks in the mechanism shown in Fig. 4.By analysing the contact state between the grinding wheel and the workpiece during the grinding process, the maximum depth of cut of a single grit of the grinding wheel is obtained:

$$h_{cmax} = \left(\frac{4v_w}{v_s N_d C}\sqrt{a_p/d_e}\right)^{1/2} \quad (1)$$

Where:

h_{cmax}…Maximum depth of cut of a single abrasive grain, in mm;

v_s…Grinding wheel speed, unit is m/s;

v_w…Workpiece feed speed in mm/s;

a_p…Grinding depth in mm;

N_d …Dynamic effective grinding edge of the grinding wheel, in mm-2;

C…Grinding constant;

d_e…Equivalent diameter of the grinding wheel, in mm.

Considering that the top angle of the diamond grinding wheel's abrasive grains is triangular, the dynamic effective number of grinding edges of the wheel can be obtained.

$$N_d = A_g(c_1)^{2/3}\left(\frac{2}{k_s}\right)^{1/3}\left(\frac{v_w}{v_s}\right)^{1/3}\left(\frac{a_p}{d_e}\right)^{1/6} \quad (2)$$

Where:

A_g…A proportionality coefficient related to the number of static grinding edges, Ag≈1.2;

c_1…Coefficient related to the density of the grinding edge, in mm3;

k_s…Coefficient related to the shape of the grinding edge of the grinding wheel.

From this formula, it can be seen that the average abrasive grain size of the grinding wheel has the greatest influence on the way of removing brittle materials, followed by the speed of the grinding wheel and the speed of the workpiece.

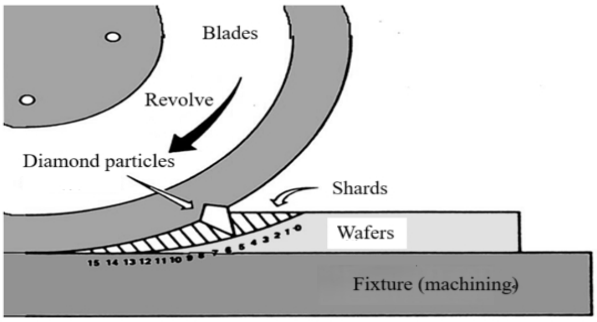


Fig. 3 *Grinding schematic*

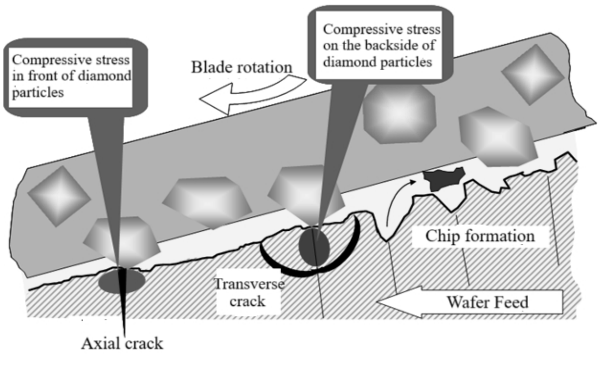


Fig. 4 *Schematic diagram of crack formation mechanism*

The grinding process is a process in which all the abrasive grains discretely distributed on the grinding wheel act together on the workpiece. Therefore, the true cutting thickness of a single grit on the grinding wheel is not the grinding depth of the entire wheel. The geometrical relationship between the motion of the abrasive grains and the workpiece observed at the micro-scale shows that the cross-section of the true cutting path of a single abrasive grain is wedge-shaped, and the depth of cut gradually increases along the arc length. It is shown that the exact formula for calculating the cutting thickness a_{gmax} of a single grit is related to the effective grit spacing λ of the grinding wheel, the grinding speed v_s, the workpiece feed rate v_w, the depth of cut a_p, and the diameter d_s of the grinding wheel, as shown in the following equation:

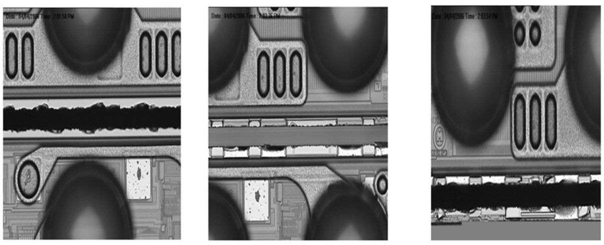
$$a_{gmax} = 2\lambda\frac{v_w}{v_s}\sqrt{\frac{a_p}{d_s}} \quad (3)$$

3 Optimisation of grinding parameters

The grinding parameters in the machine tool grinding process mainly include: grinding depth ap, spindle speed S, grinding speed V, feed speed Vf, feed f; the specific value of the grinding dosage should be determined according to the performance of the machine tool, the relevant manuals, and combined with the actual experience using the analogy method. At the same time, the spindle speed, grinding depth and feed speed can be adapted to each other, in order to form the optimal grinding dosage, so that the grinding out of the work to meet the corresponding technical requirements. Through the scribing knife on its silicon wafer grinding elements for experimental analysis, so as to derive a reasonable grinding parameters, to achieve the grinding of qualified parts, mainly from the grinding elements of the spindle speed and feed speed to select two factors for analysis, through a large number of experiments to demonstrate its optimal grinding parameters and reasonable structure [14].

3.1 Influence of spindle speed on workpiece quality

Increase the spindle speed, you can get high grinding quality and feed speed; at the same time, it will increase the wear of the grinding wheel, spindle vibration, debris increase; therefore, a reasonable choice of spindle speed on the grinding quality of the workpiece has a great impact; cutting on the DISCO DFD6314 machine, the diamond particle size of 3500 mesh, soft binder; we chose a scribing knife through the machine tool to set up different speeds To observe the quality of the cut seam, in order to make a reasonable choice of spindle speed and reduce the appearance of scrap. Three speeds of 45000, 50000 and 53000 r/min were chosen for the grinding experiments, and the quality of the slit was enlarged through a microscope to observe the quality of the slit, as shown in Fig. 5(a), (b) and (c) below, and we can see that the quality of the slit with a spindle speed of 50000 r/min is the best.



(a) 45000r/min **(b) 50000r/min** **(c) 53000r/min**

Fig. 5 *Enlarged view of the cut seam*

3.2 Influence of feed speed on the quality of the workpiece

Feed speed directly affects the processing surface roughness, when the feed speed is very small, because the grinding wheel always has a certain grinding edge blunt radius, so it may not be easy to grind, resulting in nibbling, surface roughness becomes bad, the grinding force increases, the slit cracks increase; when the feed speed increases to a certain value, the chips are easy to form, the surface roughness becomes better, the quality of the slit becomes better; if you continue to increase the feed speed, then the value of surface roughness will also increase, so that the slit cracks increase. Through the experiment to choose a reasonable feed rate to ensure the quality of the cut. We mainly discuss the relationship between the wear rate of the grinding wheel and the quality of the slit and the feed rate, because the life of the grinding wheel is mainly reflected by the wear rate, and the quality of the workpiece is mainly determined by the detection of the quality of the slit; the scribing knife cuts the slit in two, the groove corresponding to the front side of the knife blade is the front groove, and the groove corresponding to the back side of the knife blade is the back groove.

Two types of scribing knives were selected to observe the effect of feed rate on wheel wear and slit quality at different spindle speeds, where wheel wear rate is the ratio of wheel wear size (um) to the length of the ground workpiece (km). The width of the slit corresponding to the front side of the grinding wheel blade can reflect the quality of the slit of the workpiece, i.e., the silicon wafer, and we use the grade of the groove produced by the front side of the grinding wheel to indicate the quality of the slit, and the higher the grade, the poorer the slit quality; we choose two types of scribing knives, SQ3 and JQ3, to carry out the grinding experiments under the spindle speeds of 30,000, 45,000, and 59,000 r/min, respectively, with SQ3 denoting the recommended thickness. SQ3 is the recommended thickness of granular diamond scribing knife, and JQ3 is the dense granular diamond scribing knife; the relationship between the grinding wheel wear rate and feed speed is shown in Fig. 6, under the premise of guaranteeing the wear rate of the grinding wheel, selecting a reasonable feed speed to make the grinding efficiency optimal, and at the same time, guaranteeing the quality of the slit as a prerequisite; the relationship between the quality of the slit of the workpiece and the feed speed is shown in Fig. 7.

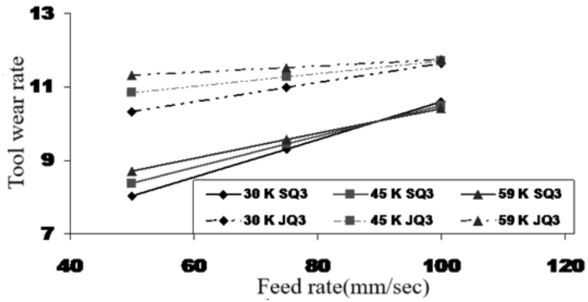


Fig. 6 *Plot of grinding wheel wear versus feed rate*

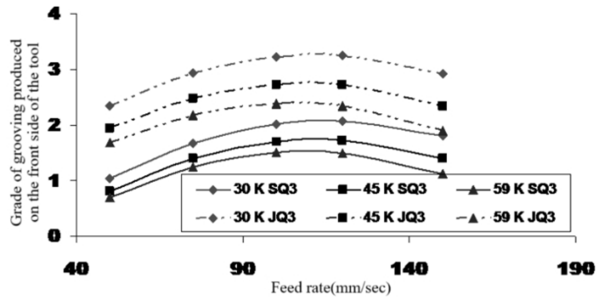


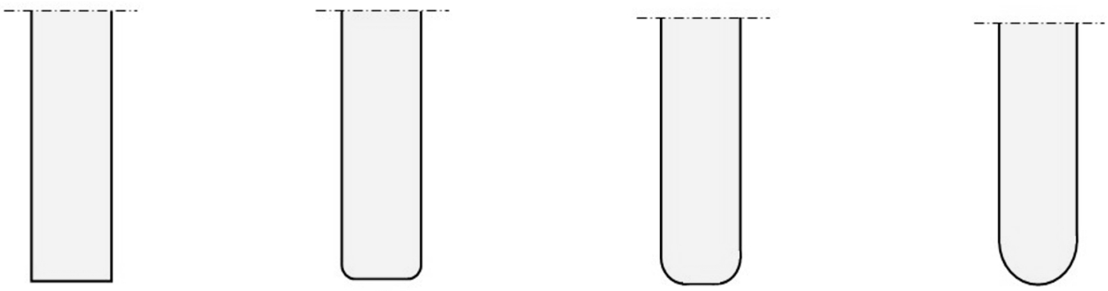
Fig. 7 *Plot of slit quality versus feed rate*

Fig. 6 can be concluded as follows: diamond particles are small, high wear rate; spindle speed basically has no effect; the larger the feed speed is, the higher the wear rate is; as the feed speed increases, the quality of the slit is getting worse and worse, and when the feed speed increases to a certain value, it does not have a big effect on the quality of the slit, and the grade of the quality of the slit decreases when it continues to increase. Fig. 7 can be concluded that: the diamond particles are small, the better the quality of the slit; spindle speed basically has no effect; with the increase of feed speed, the quality of the slit is decreasing, the feed speed increases to a certain value, the quality of the slit has a tendency to become better.

4 Optimisation of the blade structure

4.1 Cross-section shape of the flute cutter

The blade shape of the scribing knife is modified from the initial cross-section shape to the shaped end face shape as shown in Fig. 8(a), (b), (c) and (d). The appropriate cross-section shape can be selected according to the needs of grinding to meet the needs of use.



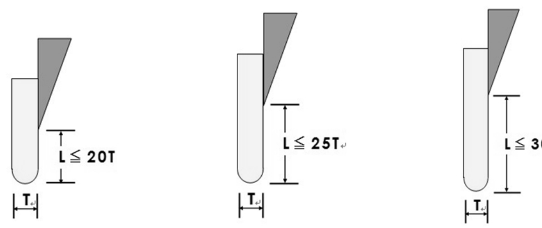
(a) No trimming (b) Trimming small fillets (c) Trimming medium fillets (d) Trimming large fillets

Fig. 8 *Cross-sectional shape of the blade of the scribing knife*

The non-trimmed blade shape is simple to manufacture, which is more practical for the occasions where the accuracy of the silicon wafer slit is not very high, but the rotating speed of the machine tool is limited, and once the speed is too high, it will increase the width of the slit and the damage of the grinding wheel; the trimming of the small rounded blade can ensure the size of the blade width, so that the slit width of the silicon wafer can be controlled, and with the small rounded blade, the chipping phenomenon will not occur in the grinding due to the machine tool and the workpiece. With a small rounded blade, the chipping phenomenon can be avoided during grinding due to the machine tool and workpiece, and the edges of the blade can be eliminated properly to reduce or eliminate the cracks around the slit of the silicon wafer [15], which can improve the accuracy of the slit width; the trimming of the middle rounded blade is a better guarantee for the improvement of the accuracy of the slit width; the trimming of a large rounded blade can greatly reduce the defects of the blade itself, and at the same time can accurately ensure the width of the slit, but it is not suitable for the depth of the grind, which is not suitable for particularly high speed. However, the depth of grinding is increased, which is not suitable for occasions with particularly high rotational speeds. In the end, we chose a small rounded grinding edge as the experimental grinding wheel.

4.2 Blade length of the scribing knife

The length of the blade of the paddle knife is shown in Fig. 9(a), (b) and (c). The greater the degree of exposure of the blade, the greater the imbalance of the force during grinding, which causes vibration and cracking of the blade; it is also related to the rotational speed of the machine tool, and is generally used in accordance with the ratio of the length of the blade to its width [16]. One of the high-speed type of blade, its length is the smallest, the economic cost is relatively small, the rigidity is better, suitable for high-speed grinding, but the depth of grinding has a certain limit; standard type of blade length, is currently the most widely used; maximum exposure type of blade, is not suitable for high-speed grinding, the blade rigidity is greatly reduced for the harder workpiece is very difficult to grind, but can be ground on the grinding depth of the workpiece requires a high degree of. In the end, we chose the standard grinding edge length as the experimental grinding wheel.

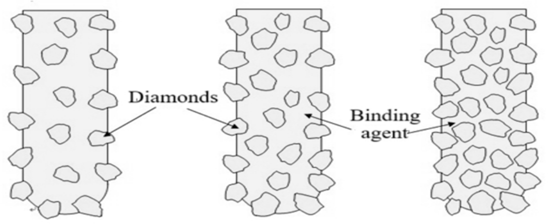


(a) High-speed type (b) Standard type (c) Maximum exposure type

Fig.9 *Schematic diagram of the length of the blade of the slicing knife*

4.3 Diamond granularity in the blade of a scribing knife

The size and concentration of diamond particles as well as the hardness and softness of the binder have a significant effect on the cutting ability and applicability of the blade [17-18]. The concentration of diamond particles in the blade of a scribing knife is divided into three main categories shown in Fig. 10(a), (b) and (c). Among them, the low concentration type of grinding wheel is mainly used for the workpiece material is not very hard, toughness is relatively high occasions, the grinding wheel wear resistance is relatively low, the diamond particles of the highest degree of difficult to fall off; standard concentration of the knife edge of the application of the largest number of occasions, its performance belongs to the low and high concentration of the knife edge of the knife edge between the high concentration of the knife edge is mainly used for grinding the cutting material of the workpiece of the hardness of the grinding wheel wear resistance is high, but the diamond particles of the difficult to fall off the lowest degree [19-20]. The degree of hardness of diamond particles is the lowest. In the end, we chose the standard concentration grinding edge as the grinding wheel for the experiment.



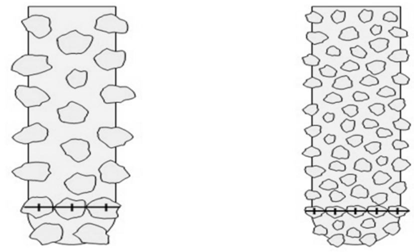
(a) Low concentration (b) Standard concentration (c) High concentration

Fig. 10 *Concentration of diamond particles on the blade of the scribing knife*

The larger the diamond grains, the stronger the grinding ability of the scribing blade, the slower the wear of the diamond grains, and the longer the service life of the scribing blade, but the larger the grains, the larger the impact on the slit of the silicon wafer during the grinding process, which is prone to mechanical stress, leading to cracks and chipping and other defects on the slit of the silicon wafer [21]. Smaller diamond grains can reduce the impact force on the slit during grinding and reduce the slit defects, but the diamond grains can not be dislodged and renewed in time, and the phenomenon of wrapping the blade will easily occur, resulting in a drastic decrease in the grinding capacity of the scribing blade, and the slit of the silicon wafer will have serious defects.

4.4 Thickness of the Scribe Blade

The thickness of the blade is shown in Fig. 11(a) and (b). The maximum recommended thickness of the blade is 3 times the diameter of the diamond particles. The thickness of the blade determines the width of the slit, the smaller the thickness, the smaller the width of the slit, and at the same time, the faster the blade wears, the shorter the life [22]. In the end, we chose the dense grain thickness grinding edge as the grinding wheel for the cutting experiment. The concentration of diamond particles in the scribing blade also significantly affects the quality of cutting silicon wafers. When the concentration of diamond particles is large, the diamond particles can be dislodged and renewed in a timely manner during the working process along with the wear and tear of the bonding agent [23-24], which can prolong the service life of the blade.



(a) Recommended thickness (b) Dense particle thickness

Fig. 11 *Thickness of the blade of the scribing knife*

Tab 1. *Data sheet of grinding experiment*

Spindle speed (r/min)	Grinding speed (mm/s)	Grinding depth (um)	Grinding times	Mean value of slit width (um)	Average cutting width on the front side of the blade (um)	Mean value of slit width on the back of the blade (um)	Total slit width (um)
50000	60	30	5	32.1	2.4	3.2	37.7
50000	70	30	5	32.3	2.8	3.3	38.4
50000	80	30	5	32.6	2.9	4.3	39.8
50000	60	50	5	33.8	4.1	4.1	42
50000	70	50	5	33.5	3.9	3.9	41.3
50000	80	50	5	33.6	4.3	4.1	42
50000	60	75	5	33.1	3	6.3	42.4
50000	70	75	5	34.1	3.4	6.6	44.1
50000	80	75	5	34.3	3	6.4	43.7

According to the above comparative analysis of the blade shape of the scribing knife and the optimisation of the grinding parameters, a reasonable blade shape and grinding parameters were finally selected for the grinding experiments. The experimental conditions are as follows: machine tool model DISCO DFD6314, scribing knife model J35DO (35mm×0.030mm×4.5mm), diamond grain size of

3500 mesh, soft binder, blade shape of dressing small rounded corners, the standard length of the grinding edge, the standard degree of concentration and the intensive particle thickness of the grinding edge, set the grinding parameters as the spindle speed 50000r/min, grinding speed of 60, 70, 80mm / s, grinding depth of 30, 50, 75um, cutting workpiece for monocrystalline silicon integrated circuit boards, each grinding workpiece length of 200mm cutting grinding times for 5 times, the experimental settings of the total slit width (slit width + knife edge front slit width + knife edge back slit width) in 0.033 -0.045mm or less is qualified, the number of tests are: grinding of monocrystalline silicon integrated circuit boards with fixed grinding parameters, respectively, after online measurement of its slit, and then through the metallurgical microscope on the slit of the workpiece to take pictures to analyse and compare, and to derive a certain amount of data and analyse it.

According to Table 1, it can be concluded that the dimensional accuracy of the workpiece slit after each grinding is within the set range between 37.7-44.1 um, i.e., the workpieces are qualified; with the increase of the grinding speed and the grinding depth, the total slit width of the workpieces is also increased sequentially.

5 Conclusion

- (1) Through the overview of the grinding model and grinding mechanism of the scribing knife, we understand the grinding principle of diamond wheel scribing knife grinding silicon wafers and the process of silicon wafer slit generation, as well as the overview of the cracks generated on the slit when the scribing knife is grinding; based on the experimental method of the optimization of the scribing knife's grinding parameters, we analyze reasonable grinding parameters through a large amount of experimental data, and prioritize to determine that the slit quality is best when the main spindle rotational speed is 50000r/min; we select two different types (blade diamond granularity) of SQ3 and JQ3 scribing knife to conduct experiments on feed speed, and conclude that the wear rate of grinding wheel and the slit quality are the best. The best slit quality is determined by the spindle speed of 50,000r/min; two different types of SQ3 and JQ3 scribing knives (diamond granularity of the blade) are selected to conduct experiments on the feed speed, and the relationship between the wheel wear rate, slit quality and feed speed is obtained, from which it is concluded that the wheel wear rate, slit quality and processing efficiency are optimised by grinding workpieces at a feed speed of 60-80mm/sec; the grinding parameters required for grinding silicon wafers are analysed based on experimental methods; the grinding parameters are optimised based on a large amount of experimental data, and it is prioritised to determine that a spindle speed of 50,000r/min is best. And the grinding parameters required for grinding silicon wafers with a scribing knife are compared and systematically elaborated.
- (2) By analysing the effects of the blade end-face shape, blade length, blade diamond granularity and blade thickness on grinding, a blade with optimised trimming of small rounded corners, standard blade length, standard concentration and dense granular thickness was finally selected for the grinding experiment;
- (3) Conduct the grinding experiment according to the optimised blade shape and grinding parameters, and compare the data from the statistics with the set data to prove that the experimental results meet the design requirements.

Acknowledgement

Jiangsu Qinglan Project; Teaching Reform Research Project, Applied Technology College of Soochow University (JG202301).

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