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Mechanism and process parameters of lapping 6H-SiC crystal substrate based on diamond particle[1]

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Abstract. In order to achieve the high quality surface with high efficiency and low damage in lapping SiC crystal substrate, the material removal mechanism must be understood and the process parameter must be optimized. By a large number of experiments and results analysis, the influences of the lapping parameters and the lapping mechanism had been studied. The results show that the material removal rate increases with the increase of the particle size and the lapping pressure significantly. At the beginning, the MRR increases with the increase of the lapping platen speed. After the MRR reaching maximum, the MRR decreases with the increase of the lapping platen speed. The change of the carrier speed has a little influence on MRR. The surface roughness increases with the increase of the particle size significantly, the influence of the platen speed, carrier speed and lapping pressure on surface roughness is no significant. Under the same conditions, the material removal rate of lapping the Si face is larger than that of the C face. By the analysis of the surface morphology and the surface flatness, the surface flatness was changed from 35.271 μm before lapping to 38.487 μm after lapping. The results show that the wafer surface has no scratch after lapping, but it cannot effectively improve the flatness of the wafer surface after the lapping with the free abrasive.

Key words. SiC crystal substrate, lapping, mechanism, material removal rate, surface morphology, surface flatness..

1. Introduction

Due to its high hardness, excellent thermal conductivity, good chemical stability, the unique wide-band-gap, high critical puncture electric intensity, high electron

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mobility, etc., the silicon carbide (SiC) single crystal substrate has been become the ideal substrate material of manufacturing the optoelectronic integrated devices in the semiconductor industry and optical components, such as the components of high-temperature, high-frequency, high power, anti-radiation, short wavelength light-emitting, etc. In recent years, SiC crystal substrate has rapidly gained interest as a substrate for the fabrication of epitaxial devices [1]–[3], such as LED (light emitting diode). LED based on SiC substrate takes the second place in LED market. Therefore, the preparation of substrate is the core technology of semiconductor lighting industry.

SiC is a compound with a strong covalent bond, its basic unit of the crystal structure is a tetrahedron with carbon atom and silicon atom. The crystal structure of the 6H-SiC is the hexagonal lattice structure and arrangement with the parallel layered structure. Its stacking order of the atoms is ABCACB ..., as shown in Fig. 1. The 6H-SiC crystal has two faces, the (0001) C face and the (0001) Si face, when cut on the wafer orientation (0001). Because of the different atomic layer of (0001) C face and the (0001) Si face, the processing performance of the (0001) C face and the (0001) Si face may be different [4].

The research shows that the device quality largely depends on surface quality. Because the substrate surface quality has a great impact on epitaxial films. The high surface quality of SiC substrates is much difficulty to obtain due to its high hardness and high chemical stability. At present, in order to achieve the surface quality required in manufacturing optoelectronic devices, the process of the traditional hard and brittle crystalline materials has been used in ultra-precision machining of SiC monocrystal substrate, this is the process, the cutting-lapping-chemical mechanical polishing [**5**]–[8]. Lapping process is mainly to remove the cutting marks and the deterioration layer produced by cutting process, to reduce the surface damage and surface roughness and to achieve a certain surface quality. Then, the required surface quality can be obtained by the chemical mechanical polishing process eventually. If the lapping process is well organized, it can greatly short the time of the chemical mechanical polishing process, improve the process efficiency and reduce production costs. Therefore, the lapping process is still essential before the chemical mechanical polishing process.

A schematic of lapping system sees Fig. 2 [**9**]. In the lapping process, the SiC wafer is mounted in a rotating carrier and pressed face down onto a rotating lapping platen at a proper pressure. Both the platen and the carrier are rotating with the same direction. The abrasive paste containing micron or submicron particles and chemical reagents is spread over the lapping platen. In this paper, a series of tests of lapping 6H-SiC (0001) C face and (0001) Si face has been conducted. The influences of the lapping parameters, such as the particle size, the lapping velocity and lapping pressure on the material removal rate (MRR) and surface roughness Ra have been studied.

2. Experimental procedure

2.1. Experimental conditions and experimental parameters

All the experiments are done in a clean room with Grade 1000 at the constant temperature of 22°C. Many SiC wafers of 2 inches in diameter are used in the lapping experiments. The lapping experiments were conducted under different parameters on a lapping machine. Samples are bonded with paraffin on the carrier of stainless steel with $\Phi\,115\,\mathrm{mm}$ in diameter. Each carrier sticks one SiC wafer. The sample surface roughness of the wafer before lapping is about $Ra\,0.3\,\mu\mathrm{m}$, which is tested by SW1510MS 3D surface profiler. The abrasive paste 50 g can be made before each test. During the lapping process, the carrier has a reciprocating motion with a stroke of 20 mm at the frequency of 10 s and the center distance between the pad and the wafer is set 80 mm, the lapping time is 15 min for each test. The DI water with the electrical resistivity $18.24\,\mathrm{M}\Omega\cdot\mathrm{cm}$ is used in the experiments. The MRR can be calculated by weighing the weight of the SiC wafer on the high precision balance with the accuracy 0.01 mg, the surface roughness Ra can be measured by SW1510MS 3D surface profiler with the resolution 0.1 nm and the flatness of the sample is detected by the FlatMaster200 Flatness Instrument with the resolution 5 nm before and after lapping [10].

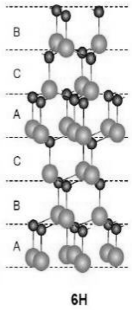


Fig. 1. The stack model of the 6H-SiC single crystal structure

2.2. The basic ingredients of abrasive paste

According to the orthogonal test results and lapping tests, the basic ingredients of abrasive paste used in all the paper had been obtained by our research group, they are as follows: lapping assistant agent 17 %, the dispersant 28 %, the thickener 19 %, the lubricant 17 %, the particle 14 % and the blending agent 5 %.

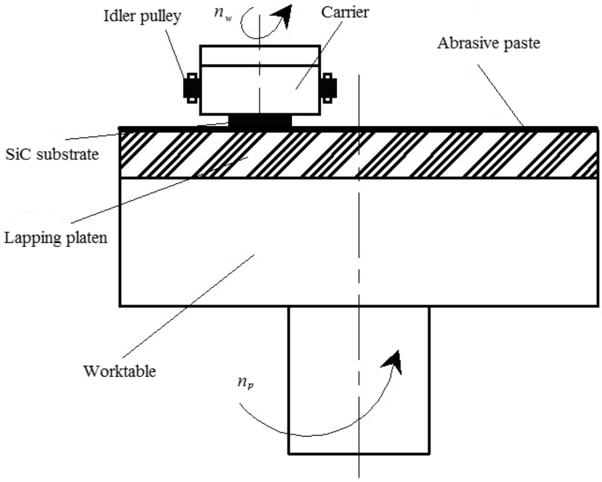


Fig. 2. The schematic of the lapping system

3. Results and discussion

3.1. *The influence of the lapping platen speed on MRR and surface roughness*

Take the diamond particle in diameter 14 μm and the basic ingredients of abrasive paste above mentioned to confect the abrasive paste used in experiment. Then, a series of lapping experiments are conducted at $n_{\mathrm{w}} = 60\,\mathrm{r/min}$, $P = 2\psi$ and different rotational velocity of lapping platen. Then, the influence of the rotational velocity of lapping platen on MRR and surface roughness can be obtained. The experiment results are shown in Fig. 3 and Fig. 4.

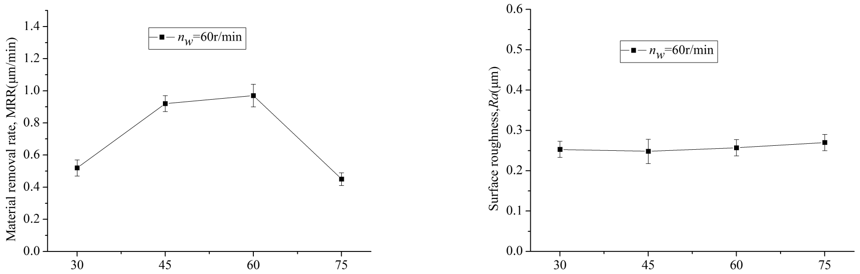


Fig. 3. The influence of n_{p} on MRR and surface roughness in lapping SiC (0001) C face: (a) The influence of n_{p} on MRR, (b) The influence of n_{p} on surface roughness, *Ra*

From Fig. 3a and Fig. 4a, at the beginning, the MRR increases with the increase of the lapping platen speed. At $n_{\mathrm{p}} = 60\,\mathrm{r/min}$, the MRR reaches maximum. Because the number of scratches on the surface produced by the particle increases with the increase of the lapping platen speed, thus increasing the MRR. But when the lapping platen speed increases to a certain value, the MRR begins to decrease. It may be because that when the platen speed is too large, the slurry flows to the edge of the lapping platen under the action of the centrifugal force and the number of abrasive participating in lapping reduces in lapping area. So the MRR increases. From Fig. 3b and Fig. 4b, the surface roughness value increases with the increase of platen speed slightly, but the increase is not too large. It is concluded that the platen speed has a little influence on surface roughness.

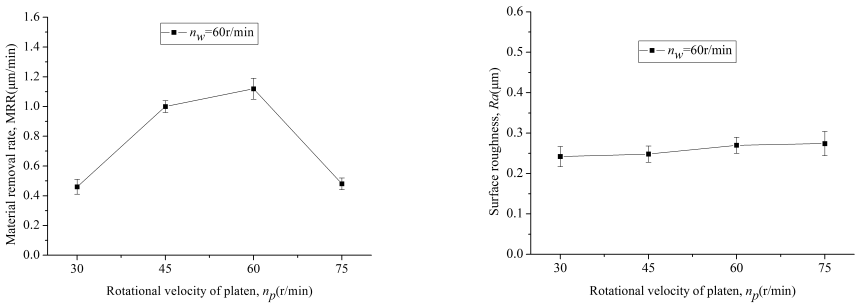


Fig. 4. The influence of n_{p} on MRR and surface roughness in lapping SiC (0001) Si face: (a) The influence of n_{p} on MRR, (b) The influence of n_{p} on surface roughness, *Ra*

Comparing the Fig. 3a with Fig. 4a, under this experimental condition, it is indicated that the MRR reaches a maximum when rotational velocity of platen, n_{p}, is $60\,\mathrm{r/min}$ in lapping Si face and C face. But in the same conditions, the MRR of lapping Si face is slightly larger than that of C face.

3.2. The influence of the carrier speed on MRR and surface roughness.

Also take the diamond particle in diameter $14\,\mu\mathrm{m}$ and the basic ingredients of abrasive paste above mentioned to confect the abrasive paste used in experiment. And then, a series of lapping experiments are conducted at $n_{\mathrm{p}} = 60\,\mathrm{r/min}$, $P = 2\psi$ and different carrier speed. Then, the influence of the carrier speed on MRR and surface roughness can be obtained. The experiment results are shown in Fig. 5 and Fig. 6.

By Fig. 5a and Fig. 6a, under different carrier speed, the MRR increases with the increase of carrier speed slightly, but the change of the MRR is not too large. Because the MRR is related to the scratch length and scratch number of the particle on wafer surface. According to the motion trajectory of the particle on wafer surface, when the platen speed is constant, the length of the motion trajectory of particle increase with the increase of the carrier speed slightly, so the MRR increases little. From Fig. 5b and Fig. 6b, when the platen speed is constant, with the increase of

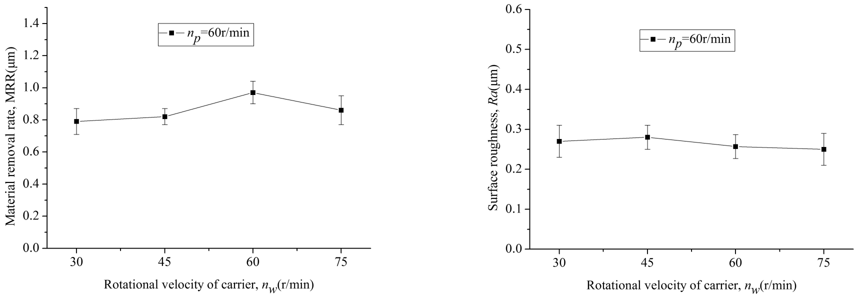


Fig. 5. The influence of n_w on MRR and surface roughness in lapping SiC (0001) C face: (a) The influence of n_w on MRR, (b) The influence of n_w on surface roughness, *Ra*

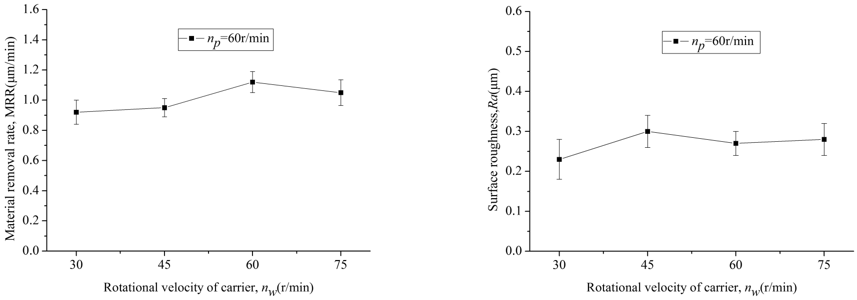


Fig. 6. The influence of n_w on MRR and surface roughness in lapping SiC (0001) Si face: (a) The influence of n_w on MRR, (b) The influence of n_w on surface roughness, *Ra*

the carrier speed, the change of the surface roughness is not large and in irregular.

Comparing the Fig. 5a with Fig. 6a, in the same conditions, the MRR of lapping Si face is slightly larger than that of C face. This result is same with section 3.1.

3.3. The influence of the lapping pressure on MRR and surface roughness

Also take the diamond particle in diameter 14 μm and the basic ingredients of abrasive paste above mentioned to confect the abrasive paste used in experiment. And then, a series of lapping experiments are conducted at $n_\mathrm{p} = 60\,\mathrm{r/min}$, $n_\mathrm{w} = 60\,\mathrm{r/min}$ and different lapping pressure. Then, the influence of the lapping pressure on MRR and surface roughness can be obtained. The experiment results are shown in Fig. 7 and Fig. 8.

By Fig. 7a and Fig. 8a, the MRR increases with the increase of lapping pressure. It is the reason that when the lapping pressure increases, the depth of particle embedding into the surface material increase, so the MRR increases. According to Fig. 7b and Fig. 8b, it showed that the increase of the surface roughness was not marked and changed slightly with the increase of the lapping pressure. It is indicated that the influence of the lapping pressure on MRR is large and the influence of the lapping pressure on surface roughness is little.

Comparing the Fig. 7a with Fig. 8a, in the same conditions, the MRR of lapping Si face is larger than that of C face. This result is same with section3.1.

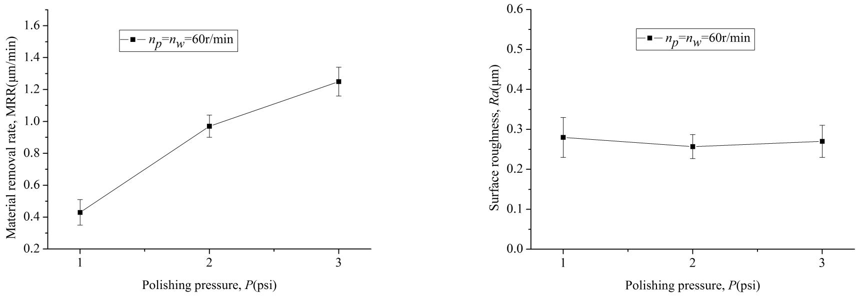


Fig. 7. The influence of lapping pressure on MRR and surface roughness in lapping SiC (0001) C face: (a) The influence of lapping pressure on MRR, (b) The influence of lapping pressure on surface roughness

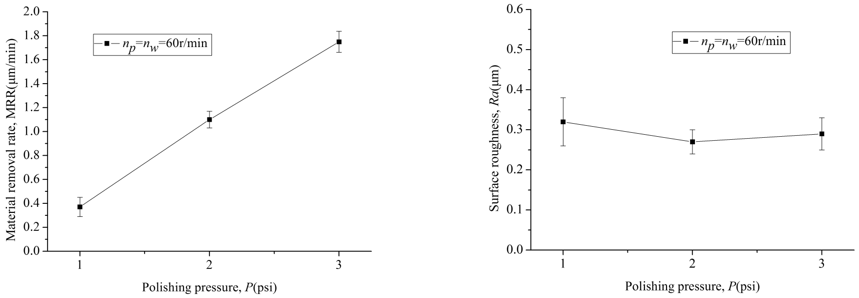


Fig. 8. The influence of lapping pressure on MRR and surface roughness in lapping SiC (0001) Si face: (a) The influence of lapping pressure on MRR, (b) The influence of lapping pressure on surface roughness

3.4. The influence of the particle size on MRR and surface roughness

Also take the diamond particle in different diameter and the basic ingredients of abrasive paste above mentioned to confect different abrasive pastes used in experiment. And then, a series of lapping experiments are conducted at $n_{\mathrm{p}} = 60\,\mathrm{r/min}$, $n_{\mathrm{w}} = 60\,\mathrm{r/min}$ and $P = 2\psi$ with different particle size. Then, the influence of the particle size on the MRR and the surface roughness can be obtained. The experiment results are shown in Fig. 9 and Fig. 10.

As shown in Fig. 9a and Fig. 10a, the MRR increases with the increase of the particle size. With the increase of the particle size, the depth and width of particle pressed into the wafer surface increase, thus the MRR also increases accordingly. From the experimental results, when the particle size is 3.5 μm in diameter, the MRR is 2.59 nm/min and the surface roughness does not change. On the one hand, the material of lapping platen is cast iron. Its surface is very rough and have many pores. The surface roughness Ra was about 1.6 μm detected by roughness tester TR200. When the particle size is very small, it may embed into the vales and pores on the surface of lapping platen, and loses the material removal action. On the other hand, because the abrasive paste is sticky, in the lapping process, the abrasive paste is full of between the wafer and the lapping platen. Therefore, in certain pressure, when the particle size is less than the thickness of abrasive paste, the particle will have little opportunity to contact with substrate surface and lose the material removal action. So when the particle size is very small, the MRR is very low.

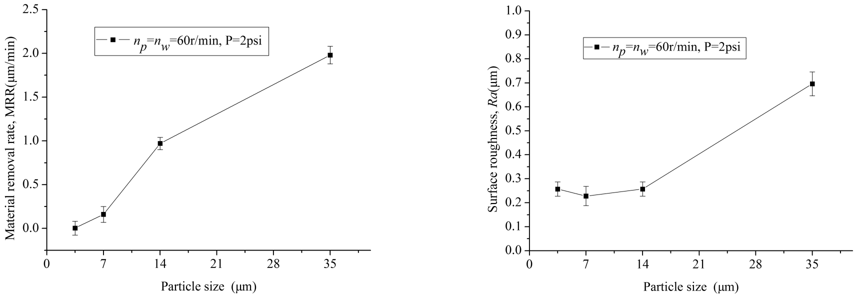


Fig. 9. The influence of particle size on MRR and surface roughness in lapping SiC (0001) C face: (a) The influence of particle size on MRR, (b) The influence of particle size on surface roughness

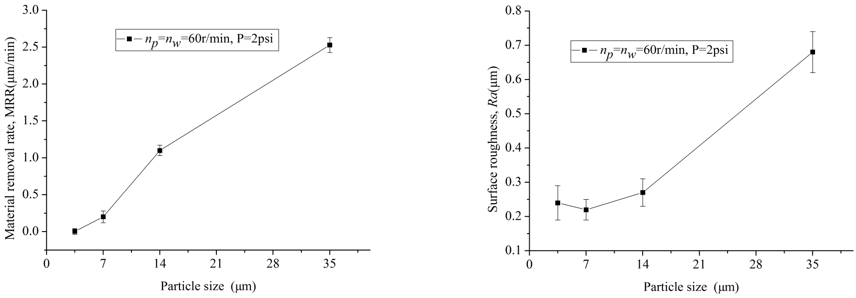


Fig. 10. The influence of particle size on MRR and surface roughness in lapping SiC (0001) Si face: (a) The influence of particle size on MRR, (b) The influence of particle size on surface roughness

It may be By Fig. 9b and Fig. 10b, except the particle size is 3.5 μm in diameter, the surface roughness reduces with the decrease of the particle size. Because the particle size reduces, the depth and width of the particle embedded into wafer surface decreases. On the other hand, when the particle size is $3.5\,\mu$m in diameter, $Ra = 0.248\,\mu$m before lapping. But after lapping, the surface roughness does not change.

When the particle size is $3.5\,\mu$m in diameter, the MRR is very low. In order to judge the smallest particle size to use for lapping SiC crystal substrate, the lapping experiments with the particle size $5\,\mu$m in diameter had been conducted. The material removal rate is about 5.62 nm/min. It shows that when the particle size is less than $7\,\mu$m in diameter, it is not suitable for lapping SiC crystal substrate. So in precision lapping process, the particle size about $7\,\mu$m in diameter can be taken by Fig. 9b and Fig. 10b.

Comparing the Fig. 9a with Fig. 10a, in the same conditions, the MRR of lapping Si face is larger than that of C face. This result is same with section 3.1. Also comparing the Fig. 9b with Fig. 10b, in the same conditions, the change trend of the surface roughness is the same with that of the particle size. It is indicated that the influence of the particle size on MRR and surface roughness is large.

3.5. The surface morphology

The surface morphology of the samples was observed with electron microscope and the white light interferometer after lapping, respectively, as shown in Fig. 11. It can be seen from the figure that there is no scratch on the wafer surface and the surface is hilly.

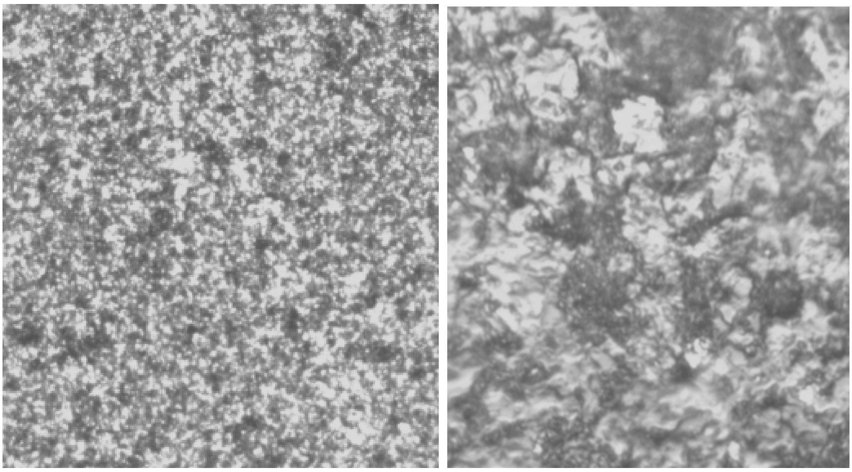
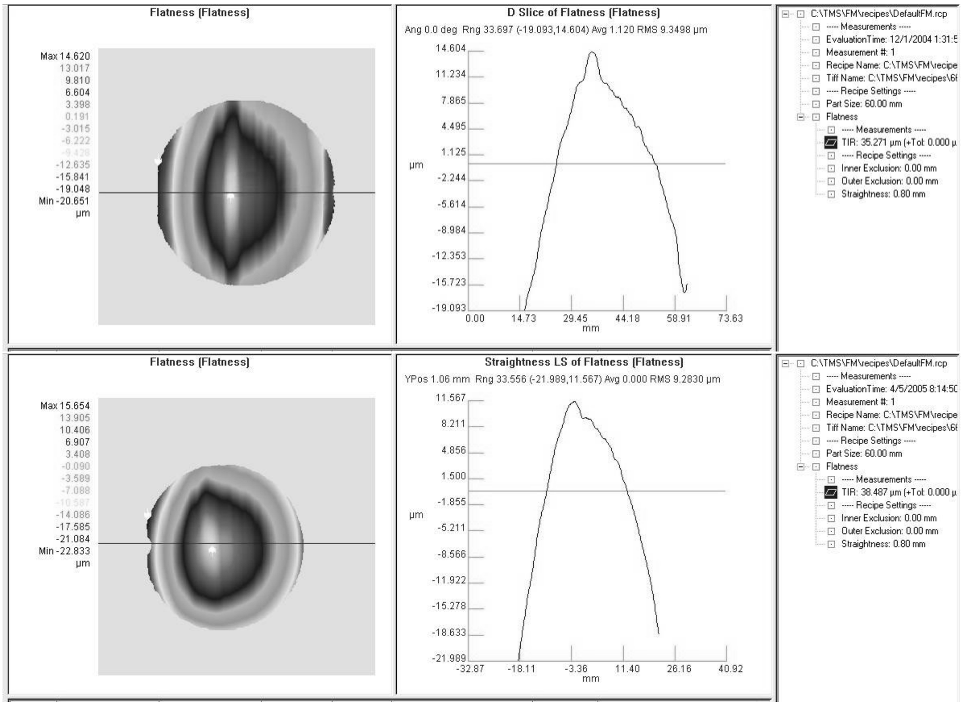


Fig. 11. The surface morphology after lapping (sample No. 70102495): (a) Amplified 100 times, (b) Amplified 800 times

3.6. Surface flatness

The surface flatness of the samples was detected by the FlatMaster200 flatness instrument before and after lapping, and the test results as shown in Fig. 12. It can be seen that the height difference was changed from 33.697 μm before lapping to 33.556 μm after lapping and the surface flatness was changed from 35.271 μm before lapping to 38.487 μm after lapping. This shows that the surface flatness cannot be improved after lapping with the free abrasive.



```
Ang 0.0 deg  Rng 33.697 (-19.093,14.604) Avg 1.120 RMS 9.3498 µm
```

```
C:\TMS\FM\recipes\DefaultFM.rcp
    ----- Measurements -----
    EvaluationTime: 12/1/2004 1:31:5
    Measurement #: 1
    Recipe Name: C:\TMS\FM\recipe
    Tiff Name: C:\TMS\FM\recipes\6
    ----- Recipe Settings -----
    Part Size: 60.00 mm
    Flatness
        ----- Measurements -----
        TIR: 35.271 µm (+Tol: 0.000 µ
        ----- Recipe Settings -----
        Inner Exclusion: 0.00 mm
        Outer Exclusion: 0.00 mm
        Straightness: 0.80 mm
```

```
YPos 1.06 mm  Rng 33.556 (-21.989,11.567) Avg 0.000 RMS 9.2830 µm
```

```
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    ----- Measurements -----
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    Measurement #: 1
    Recipe Name: C:\TMS\FM\recipe
    Tiff Name: C:\TMS\FM\recipes\6
    ----- Recipe Settings -----
    Part Size: 60.00 mm
    Flatness
        ----- Measurements -----
        TIR: 38.487 µm (+Tol: 0.000 µ
        ----- Recipe Settings -----
        Inner Exclusion: 0.00 mm
        Outer Exclusion: 0.00 mm
        Straightness: 0.80 mm
```

Fig. 12. The surface flatness before and after lapping (sample No. 70102495, C face): (a) Before lapping, (b) After lapping

3.7. Mechanism of the free abrasive lapping

According to the above research, the material removal model with the free abrasive lapping is obtained, as shown in Fig. 13. From Fig. 13, it can be seen that the lapping paste is contacted with the whole wafer surface and the surface material of the SiC crystal substrate can be removed at the same time by the free abrasives in lapping paste under the role of lapping pressure. It cannot effectively improve the flatness of the wafer surface [**?**].

4. Conclusion

According to the experiment results and the analyses above mentioned, the conclusions are as follows.

1. The particle size, lapping pressure and platen speed have a great influence on

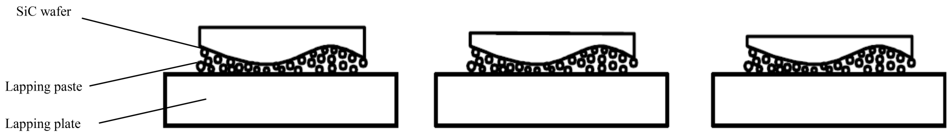

Fig. 13. The schematic of the model of the material removal process with the free abrasive lapping: (a) Before lapping, (b) In lapping, (c) After lapping

MRR, but the impact of the particle size on MRR is larger than that of the platen speed and the impact of the carrier speed on MRR is not significant.

2. With the change of the particle size, the change of the surface roughness after lapping is large, but with the change of the platen speed, the carrier speed and the lapping pressure, the change of the surface roughness after lapping is slight. It is indicated that the influence of the particle size on the surface roughness is remarkable. The influence of the platen speed, the carrier speed and the lapping pressure on surface roughness is very smaller. The larger the particle size, the higher the surface roughness is. Different abrasive size is corresponding to a different surface roughness.
3. In the same conditions, the MRR of lapping Si face is larger than that of C face. This is indicated that the physics and chemistry performance of the (0001) C face and the (0001) Si face is different.
4. In the same conditions, the change trend of the surface roughness after lapping Si face and C face is the same.
5. When the particle size is less than 7 μm in diameter, the MRR is very low and it is not suitable for lapping SiC crystal substrate.
6. Under the role of lapping pressure and lapping paste, the free abrasives not only remove these asperities of the wafer surface, but also remove the entire wafer surface material at the same time in lapping SiC crystal substrate. So the free abrasive lapping cannot effectively improve the flatness of the wafer surface. The wafer surface has no scratch after free lapping with free abrasive, but the wafer surface is hilly.

References

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