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High efficiency and high precision machining of Fresnel microstructure on silicon carbide through integrated sub-nanosecond laser ablating and ultra-precision grinding chain

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Abstract
Through this integrated sub-nanosecond laser ablating and ultra-precision grinding chain, Fresnel micro-structured surface was machined on SiC featuring high efficiency and high precision. The material removal rate of the pre-machined Fresnel microstructure by laser ablating could achieve 0.72mm^3/min, with a subsurface damage depth of about 5µm. Finally, ultra-precision grinding was conducted on the laser pre-machined mould as a finish process, generating the ultimate Fresnel micro-structured surface with removed sub-surface cracks and better surface quality. Through this integrated sub-nanosecond laser ablating and ultra-precision grinding chain, Fresnel micro-structured surface was machined on SiC featuring high efficiency and high precision.

Key words: sub-nanosecond laser machining; ultra-precision grinding; silicon carbide; Fresnel microstructure; high efficiency; high precision

1. Introduction

Fresnel micro-structured lens have been widely applied in advanced optical systems, where glass molding press has been considered as potential solution for the mass production. Silicon carbide (SiC) is one of the typical hard and brittle materials, which has been widely used as glass molding moulds. However, the tool wear problem in the diamond grinding moulds has not been well solved, resulting in the limited improvement of efficiency and accuracy.

In order to solve the rapid tool wear problem in grinding Fresnel microstructure on SiC, this study firstly utilized the sub-nanosecond laser as a pre-machining process thanks to its high material removal rate while with the form error in micrometer scale. Afterwards, the ultra-precision grinding, as a deterministic process, was applied to machine the pre-machined surface in generating the ultimate surface quality in terms of form accuracy and surface roughness with minimized tool wear volume, as shown in Fig 1.

2. Experimental facility and processing parameters

The experimental facilities used in this experiment were shown in Fig 2 and 4. During laser ablating of Fresnel microstructure on SiC, the X axis would keep static to ensure the focusing point of the laser ray stays at the same position, while the Z axis would perform reciprocating motion and provide SiC the required feeding speed. The feeding distance was increased gradually according to the shape profile need to be machined, as shown in Fig 3. The laser machining parameters in this experiment were listed as follows: laser power 16.37W, repeating frequency 3MHz, laser pulse duration 500ps, laser wavelength 1064nm. Besides, it was assumed that the depth of SiC removed by each scanning of the laser was about 1µm. In order to ensure the same material removal rate, the federate (V_f) and workpiece rotation speed (N_w) were different when processing each circle surface of the Fresnel microstructure, as follows:

3rd circle surface, N_w=2040rpm, V_f=0.2mm/min;
2nd circle surface, N_w=2460rpm, V_f=0.24mm/min;
1st circle surface, N_w=3180rpm, V_f=0.31mm/min;
center circle surface, N_w=8040rpm, V_f=0.79mm/min.

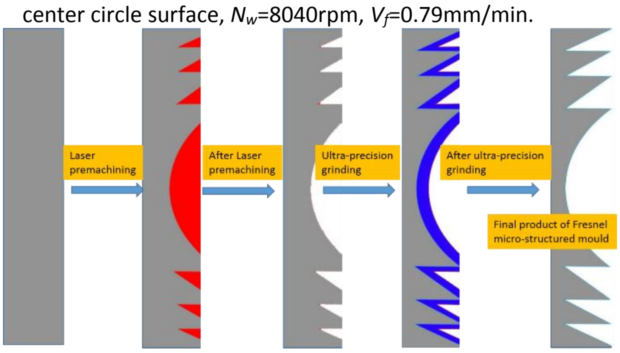

Figure 1. production chain integrating sub-nanosecond laser ablating and ultra-precision grinding

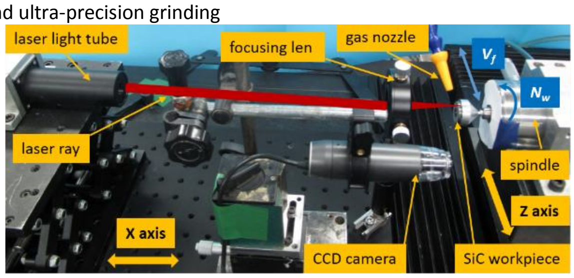

Figure 2. experiment platform for laser machining

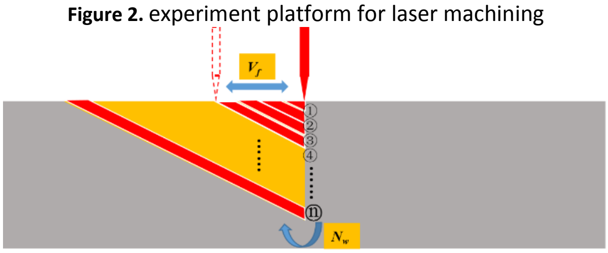

Figure 3. processing path for laser machining of Fresnel microstructure

After the laser ablation process, a three axis ultra-precision machine tool was used to finish the ultra-precision grinding of Fresnel micro-structure on SiC. The grinding parameters were as follows: D7 resin bonded diamond grinding wheels, N_g=6030rpm, N_w=500rpm, V_f=1mm/min, grinding depth 2µm.

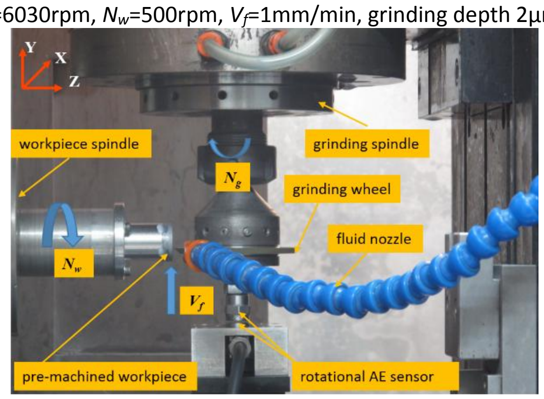

Figure 4. experiment platform for ultra-precision grinding

3. Results and discussion

Figure 5 showed that smooth Fresnel micro-structured surface could be obtained on SiC after laser pre-machining and ultra-precision grinding. As for the laser ablation procedure, it only took about 20 minutes, reaching a material removal rate of 0.72mm³/min, which is about 5 times as much as the material removal rate of rough grinding process. In order to make a further analysis of the machined workpiece, SEM was used to observe surface topography and 45° cross-sectioned polished surface of the SiC workpiece, as shown in Fig 8-11.

The form profile of the finally ground workpiece had been measured by a non-contact profilometer, in Fig 7. Except for the center area being ablated too much, most of its profile is OK. Fig 8 and 10 showed that the profile of the laser ablated surface was linear and approximated to the expected profile.

Figure 9 and 11 indicated that there don't had remarkable subsurface damage except for the bottom of the corner areas. The reason was that the federate of workpiece approximated to zero at the corner bottom and laser beam stayed here longer than the plan. Even so, the subsurface damage depth was less than 5 µm.

Figure 5. SiC fabricated by only laser ablation (left) and "laser + ultra-precision grinding chain" (right)

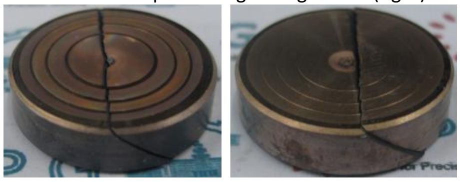

Figure 6. 45° cross-sectioned surface of SiC workpiece for subsurface damage observation

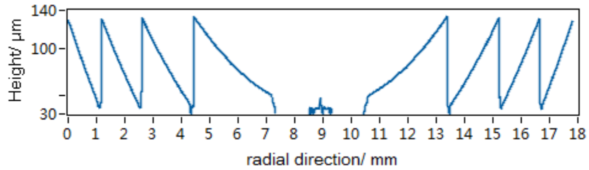

Figure 7. form profile of the finally ground Fresnel workpiece

4. Conclusion

This study has proved the feasibility of integrating laser ablation and ultra-precision grinding chain for the high efficiency and high precision machining of axis-symmetrical micro-structured surface on SiC. But there are still much further work need to be done for exploring the material removal mechanism between SiC and sub-nanosecond laser and improving the form accuracy of laser ablation.

Acknowledgements

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References

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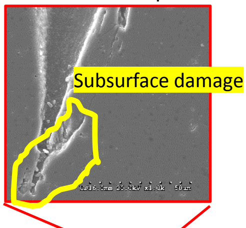


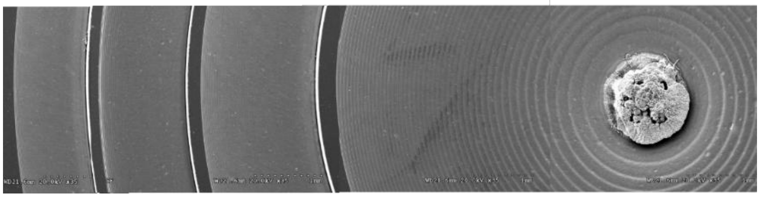


Figure 8. the surface topography of the laser machined workpiece

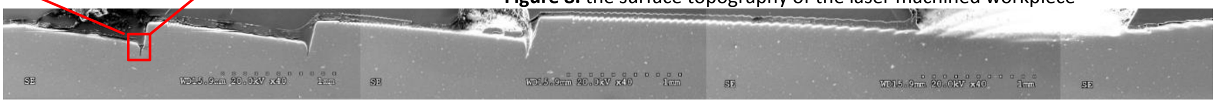
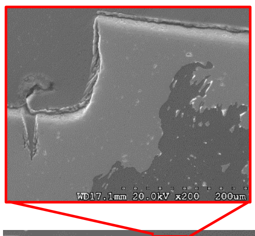


Figure 9. the subsurface topography of the laser machined workpiece



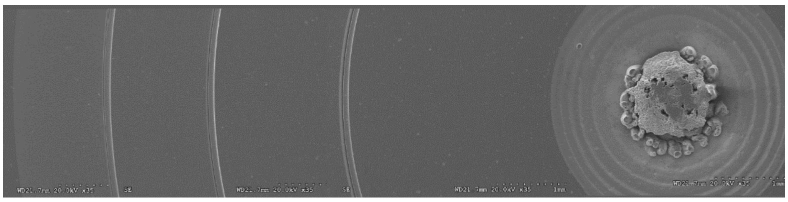


Figure 10. the surface topography of the workpiece machined by "laser + ultra-precision grinding chain"

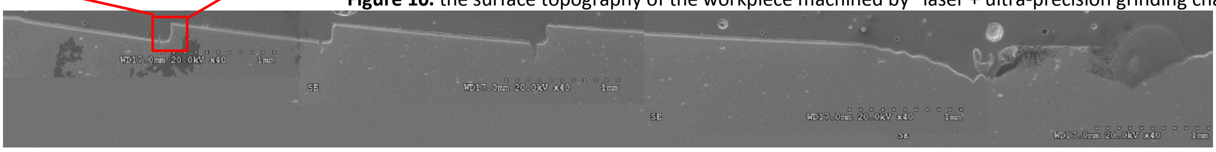


Figure 11. the subsurface topography of the workpiece machined by "laser + ultra-precision grinding chain"