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RESEARCH ARTICLE

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Dimethicone-aided laser cutting of solar rolled glass

Abstract Solar rolled glass, with one micro-structure surface and another roughness surface, can cause diffuse refraction of the focused laser spot, and this phenomenon restricts the application of laser manufacturing. In this study, laser cutting of solar rolled glass with a thickness of 2.5 mm was successfully achieved with the help of dimethicone to ensure laser focusing. Dimethicone was coated on the top surface of the rolled glass processing zone, and a *Z* bottom–up multilayer increment with the *X*–*Y* spiral line was applied to control the cutting path. Different viscosity values of dimethicone were considered. Results showed that surface quality increased as the viscosity increased until a certain threshold was reached; afterward, the surface quality decreased or directly caused the cutting to fail. The minimum surface roughness (3.26 μm) of the processed surface (chipping: Width$\leqslant$113.64 μm, area 215199 μm^2) was obtained when the dimethicone viscosity and laser pulse frequency were 1000 mm^2/s and 43 kHz (power 25.4 W), respectively. The micro-defects on the processed surface were few, and the edge chipping width and depth of the laser processed surface were small.

Keywords laser cutting, solar rolled glass, dimethicone, viscosity, surface quality

1 Introduction

Glass is transparent, hard, and brittle, and its processing has always been a research hotspot in the manufacturing field. Diamond cutters or hard metal tools are usually utilized to cut glass by creating a scratch on the glass surface and performing mechanical breaking afterward [1]. The edge strength of the glass is greatly impaired by the presence of micro-cracks and residual stress when the scribing and breaking method is utilized; as a result, subsequent polishing is required [2]. However, polishing can recover only one-third of the strength and makes the entire cutting process time consuming [3]. Rotary ultrasonic machining [4] and abrasive water jet cutting [5] can also be used in glass processing. These types of processing methods are all contact processing, which entails an uneven cutting force and easily causes vibration in the cutting process, thereby directly affecting the processing quality (chipping, roughness, and even breakage). Moreover, these methods cannot easily meet the lightness and thinness demands in glass processing. In addition, achieving complex structures, such as curves and other cambered paths, via mechanical cutting is difficult.

As a non-contact processing method, laser processing has the advantages of high processing speed and easy control and is therefore widely used in various industries [6]. Lumley [7] was the first to introduce the use of a CO_2 laser to cut glass through a controlled fracture technique. In the past few years, high-efficiency, high-quality glass cutting by laser processing has become the focus of many researchers [8–10]. Laser scribing and breaking are nearly similar to traditional mechanical scribing and breaking; the difference is that the laser beam is used to create partially penetrating holes or deep vents at depths of one-third to one-half of the material thickness [11]. This method also causes damage to the cut edge of the glass surface and requires additional processing. The laser melting and evaporation method is a cutting method performed above the glass transition temperature, and it leads to the creation of large heat-affected zones, which affect the quality of the glass surface [12]. In laser-induced thermal crack propagation, the laser beam is utilized to heat the surface of the glass, and compressive stress is generated. As the laser beam moves, the heating region cools down to generate residual stress. When the residual stress is greater than the failure stress, a crack is generated. This method of glass

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cutting can achieve high quality and high efficiency [13] and has been extensively used to cut glass [14] and other transparent materials [15]. However, cutting deviation occurs at the leading and trailing edges of the glass sheet. Several researchers have proposed multiple-laser systems [16] and dual-laser-beam methods [17,18] for cutting glass substrates to address the cutting deviation of laser-induced thermal crack propagation. Other ultrashort pulse lasers, such as picosecond and femtosecond lasers, are good tools to achieve high-quality processing and becoming increasingly widespread [19–24]. However, they are suitable only for the micro-machining of materials because of the limitation in laser power. Laser multi-focus separation technology has also been developed and successfully used to achieve the separation of thick KDP crystal; this method can improve the uniformity of temperature and thermal stress distribution by producing multiple foci along the thickness of the material [25]. Moreover, a more flexible laser multi-focus separation than the previous technology been developed to cut thick soda-lime glass successfully and with high surface quality [26].

Solar rolled glass is a low-iron soda-lime glass with a suede structure on the upper surface and an embossed structure on the lower surface, as shown in Fig. 1. The suede structure reduces the glass reflection of sunlight, and the embossed structure with a certain angle can effectively improve the transmittance of the glass. The high transmittance of solar rolled glass has made this material widely used in the photovoltaic industry, although holes need to be cut in solar rolled glass for threading. However, transparent glass with a smooth surface was the main object of existing studies on glass laser cutting, and most of them focused on glass separation. Diffuse refraction occurs when the laser passes through solar rolled glass, causing the focus spot to be distorted and resulting in failed laser cutting. Traditional glass drilling methods lack efficiency because of the high hardness and brittleness of glass, and they create serious tool wear and poor surface quality, especially severe chipping at the edge of the cut glass. The main indicator of the quality of glass drilling is the severity of the chipping that occurs at the edge of the glass cut [27]. This condition inevitably requires post-processing procedures, such as polishing, and causes high resource wastage and pollution. This study aims to perform laser cutting of solar rolled glass holes by applying transparent dimethicone on the upper surface of glass a with suede structure. The nanosecond laser beam scanning path was planned with a Z bottom–up multilayer increment with the X–Y spiral line. The effect of dimethicone viscosity on the quality of solar rolled glass cut using the proposed method was analyzed.

2 Proposed dimethicone-aided laser cutting of solar rolled glass

The basic principle of solar rolled glass laser cutting is shown in Fig. 2. The solar rolled glass is placed near the laser focus, with the suede glass surface facing up. Only the downward direction can increase the transmittance of the glass because of the unique embossed structure and pattern angle of the glass. However, when a focused laser beam passes through the glass suede surface, as shown in Fig. 3, diffuse refraction occurs and causes the focused laser spot to distort into various irregular shapes, thereby failing to achieve effective cutting. A layer of transparent dimethicone is evenly coated on the upper surface of the glass to fill the suede structure and make the laser spot regular. Dimethicone with a certain viscosity has high transmittance and small surface tension, and it can be easily attached to glass.

Solar rolled glass laser cutting makes full use of the high transmittance and absorption of the laser beam energy of glass [13]. During laser cutting, the laser energy acts on the glass, making the glass temperature rise rapidly and producing compressive stress under the high temperature. With the movement of the laser beam, the temperature of the heating area begins to decrease through air convection and heat conduction, resulting in residual tensile stress. Micro-cracks are produced in the glass heating area under the effect of residual tensile stress, and the glass is subsequently cracked into powder. As the laser beam

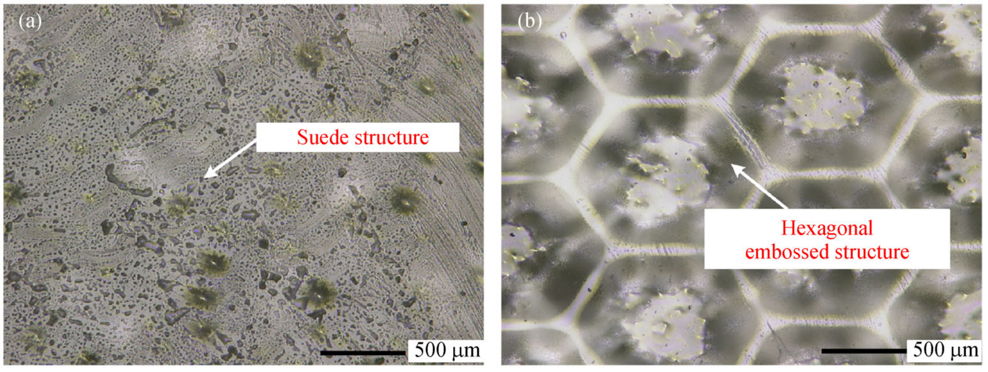

Fig. 1 Schematic of the solar rolled glass surface: (a) Suede surface of glass and (b) hexagonal embossed surface of glass.

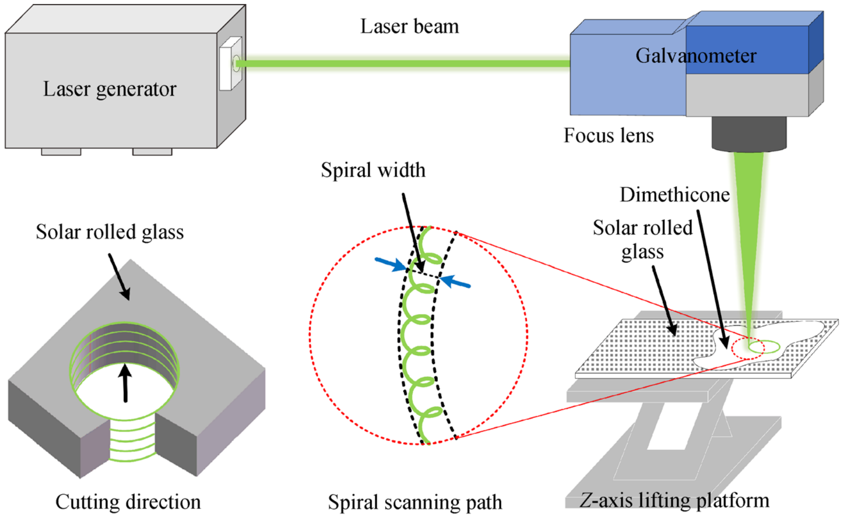

Fig. 2 Schematic of solar rolled glass laser cutting.

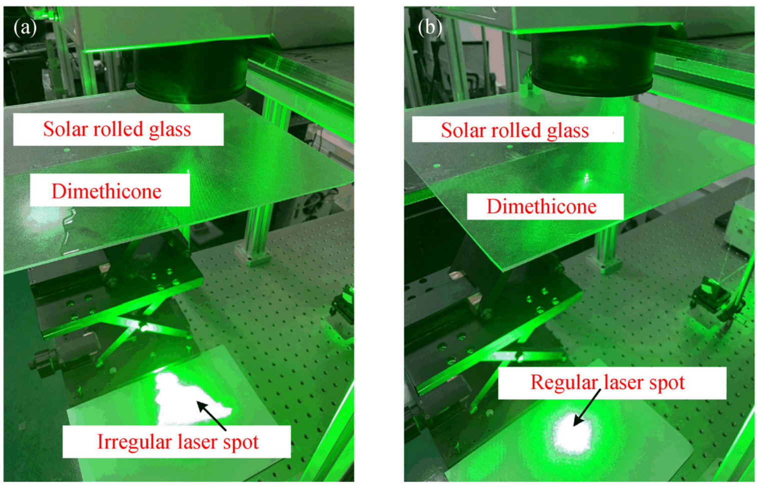

Fig. 3 Schematic of the laser spot cutting assisted by dimethicone: (a) Without auxiliary dimethicone and (b) with auxiliary dimethicone.

moves, the crack propagates along the scanning trajectory and discharges the cutting powder to form a kerf.

The Z bottom–up multilayer increment cutting method is adopted because of the high transmittance of glass, and the cutting powder can be eliminated by gravity in time. However, when the laser beam scans the hole shape in each layer, the kerf width for discharging the cutting powder smoothly cannot be achieved due to the small laser spot. The spiral scanning path can fully cut the edge of the circle to form a stable and reliable kerf width, as shown in Fig. 2. The spiral scanning trajectory is a path formed by large semicircles with a certain overlap, and the overlapping parts are smoothly connected by small semicircles. This scanning trajectory has two key parameters: Spiral width and spiral overlap ratio. Spiral width determines the kerf width, and the spiral overlap ratio represents the ratio of the adjacent large circle overlapped area to the large circle area and determines the density of the trajectory. The spiral trajectory parameters have the following relationship:

$$S_{\mathrm{w}} = 2R - \frac{D}{2}, \tag{1}$$

$$S_{\mathrm{or}} = \frac{2R^2 \arccos\frac{D}{2R} - D\sqrt{R^2 - \frac{D^2}{4}}}{\pi R^2}, \tag{2}$$

where S_{w} is the spiral width, S_{or} is the spiral overlap ratio, R is the radius of the large semicircle, and D is the center distance between two adjacent large semicircles.

After the laser focus scans a circle on any layer, its position rises by a certain distance. It continues scanning the next layer until the cutting is completed. By treating the suede surface of the solar rolled glass with dimethicone and planning the laser scanning path by adopting the Z

bottom–up multilayer increment method with the *X–Y* spiral line, high-efficiency and high-quality hole laser cutting of the solar rolled glass can be achieved.

3 Experimental procedure

3.1 Materials

Solar rolled glass (provided by CSG Holding Co., Ltd., China) was used as the workpiece because of its wide application in the photovoltaic industry. The composition of solar rolled glass is 70.8%–72.5% SiO_2, 0.94%–1.1% Al_2O_3, 0.015% Fe_2O_3, 8.2–8.9% CaO, 3.34%–4.2% MgO, 14.3% $Na_2O + K_2O$, and 0.3% SO_2. In this experiment, a solar rolled glass sheet with a common thickness of 2.5 mm and a hexagonal embossed structure was selected as a cutting target. The physical and mechanical properties of solar rolled glass are presented as below:

Density: 2480 kg/m^3;

Expansion coefficient: 9.1×10^{-6}/K;

Refractive index (25 °C): 1.51;

Specific heat capacity: 836 J/(kg·K);

Thermal conductivity: 0.8 W/(m·K);

Young's modulus: 74 GPa;

Poisson's ratio: 0.23;

Softening temperature: 993 K–1003 K;

Average bending fracture strength: 49 MPa.

Dimethicone (XIAMETER: PMX-200) was selected as the surface auxiliary liquid for the laser cutting of the solar rolled glass in this experiment. Dimethicone is transparent, odorless, non-toxic, heat resistant, and easy to clean; it can also be evenly attached to glass surfaces. The physical and chemical properties of dimethicone vary with viscosity values. The dimethicone properties at a viscosity value of 1000 mm^2/s are shown as follows:

Specific weight (25 °C): 0.97;

Refractive index (25 °C): 1.4035;

Flash point: > 326 °C;

Melting point: –25 °C;

Pour point: –50 °C;

Surface tension: 21.2 mN/m;

Dielectric strength: 15.75 kV/mm;

Volume resistivity: 1.0×10^{15} Ω·cm.

3.2 Experimental equipment

The experimental setup of the laser cutting of solar rolled glass is shown in Fig. 4. The 532 nm laser beam was emitted by a Nd:YVO_4 nanosecond solid laser generator (LOGAN: LNS-532-40 PRO) with a maximum power of 40 W (the laser beam was near Gaussian with an M^2 value less than 1.2). The laser beam was then reflected by two total reflection mirrors into the galvanometer (Anshan Precision: 3D Post-Scanning System) and finally focused by the f-theta focusing lens (CARMAN HAAS: SL-532-50-65). The galvanometer has 1.67 times optical beam expansion for reducing the focus spot size, and its 2.5 D function (a dynamic focus axis) allows the focus position to be varied within a certain height range. The field lens is a f-theta focusing lens with a scanning range of 50 mm × 50 mm and a focal length of 65 mm. A computer was needed to control the laser generator and galvanometer, and a manual precision *Z*-axis lifting optical platform was adopted to ensure that the glass was accurately placed near the laser focus. A vacuum cleaner was placed under the glass sheet to prevent the glass powder from drifting around, causing damage to the laboratory equipment, and affecting the health of the experimenters.

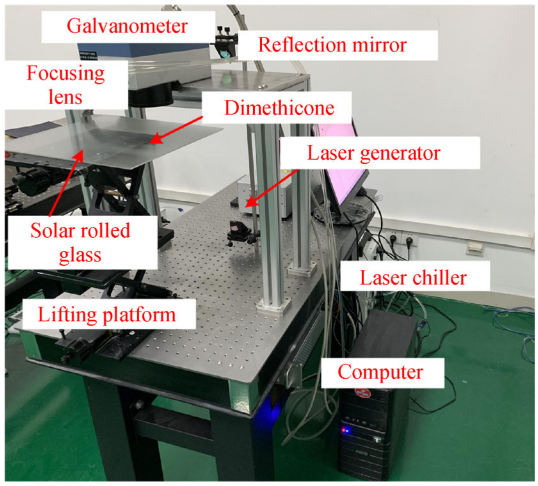

Fig. 4 Experimental setup for the laser cutting of solar rolled glass.

3.3 Experimental design

Single-factor experiments were conducted with the viscosity of dimethicone as the main parameter. Thirteen common values with unequal spacing were selected as the dimethicone viscosity parameter levels. All single-factor experiments were performed in three different laser processing conditions, and the other parameters were set to the optimal value on the basis of experience. The experimental parameters and their levels are presented in Table 1.

Table 1 Process parameters and their levels

Processing condition	Laser frequency /kHz	Power /W	Dimethicone viscosity /($mm^2 \cdot s^{-1}$)
A	34	17.6	0.65, 5, 10, 20, 50, 100, 350, 500, 1000, 2000, 3000, 5000, and 12500
B	43	25.4	
C	52	30.7	

The other conditions and parameters for the laser cutting of the solar rolled glass are listed as follows:

Shape and size of specimens: Square, 8 mm × 8 mm × 2.5 mm;

Focus spot size: 15 μm;
Scanning speed: 290 mm/s;
Spiral width: 0.5 mm;
Spiral overlap ratio: 70%;
Focus rise distance per layer: 0.02 mm;
Chiller cooling water: Deionized water;
Laser chiller constant temperature: 23 °C;
Ambient temperature: 25 °C.

The shape of the glass cutting hole in the photovoltaic industry is basically circular. This experiment used square as the shape of the cut hole to assess cutting quality in order to facilitate the detection. Each group of experiments was performed five times to reduce the random error.

3.4 Measurement

The cut square blocks of solar rolled glass were utilized as research specimens because of the similar cutting conditions. The chipping situation of the glass was evaluated by using the size of the chipping area and the maximum chipping width; both values were measured with a laser confocal micro-scope (VK-X200K, KEYENCE Corporation, Japan). One side of the embossed structure was adopted as the detection target because the side with the embossed structure is also as the side where the laser cut in (the quality is relatively poor). Then, the chipping situation on one even side of the square was measured. Each specimen was placed horizontally in the middle of the micro-scope field, and the area of the chipping and the maximum chipping width were measured using the laser confocal micro-scope analysis software over a visual field length of 2907.67 μm. The average chipping value of five specimens was used as the chipping value of each set of parameters. In addition, the laser processed surface of the solar rolled glass was observed using the laser confocal micro-scope, and the surface roughness (*Ra*) of each set of parameters was obtained with the analysis software. The micro-structures of the laser-processed surface were observed with a field emission scanning electron micro-scope (SEM: Sirion 200, FEI Company, Netherlands), and the cut square glass specimens were sprayed with gold by using an ion sputtering instrument (SBC-12, KYKY Technology Co., Ltd., China) for 90 s before observation because glass is not conductive. The glass chipping of the laser-processed surface was also observed using the SEM images. The common logarithm of the viscosity values was used in the analysis because the viscosity levels were not equally spaced.

4 Results and discussion

4.1 Effect of dimethicone viscosity on glass edge chipping

The effect of dimethicone viscosity on the chipping situation under three different laser processing conditions is shown in Fig. 5. The overall trend was that the chipping area and the maximum chipping width decreased with increasing dimethicone viscosity under the three laser processing conditions, but several differences were noted in the various laser processing conditions. For laser processing condition A, the laser cutting of the solar rolled glass was not completed when the dimethicone viscosity was greater than 500 mm^2/s. The chipping area was the smallest when the viscosity value was 50 mm^2/s, and the chipping area showed a slight increase in size when the viscosity was greater than 50 mm^2/s. However, the maximum chipping width continued to decrease. For condition B, cutting failure occurred when the viscosity value was greater than 3000 mm^2/s. The minimum chipping area and the smallest maximum chipping width were observed at a viscosity of 1000 mm^2/s, after which the chipping situation began to deteriorate. Meanwhile, all viscosity values resulted in successful laser cutting of the

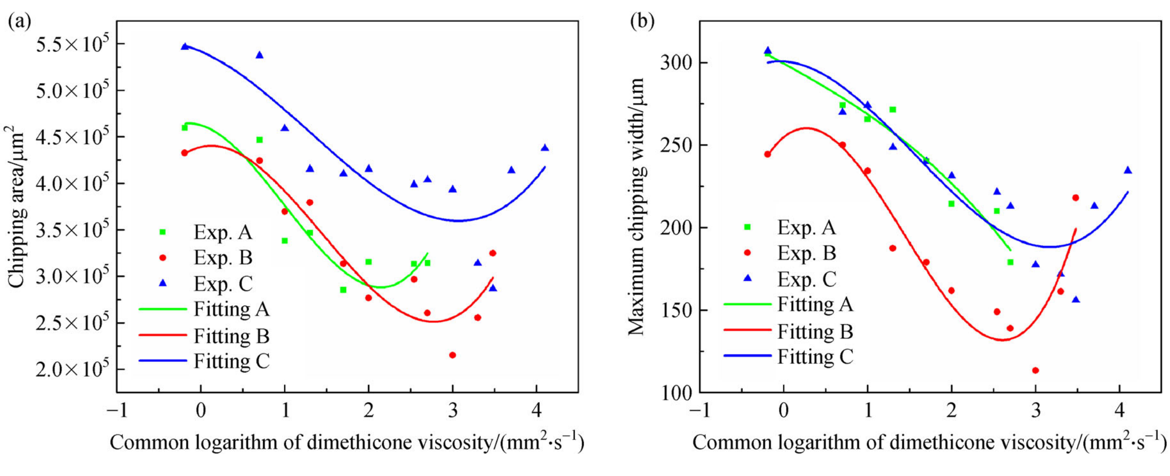

Fig. 5 Effect of dimethicone viscosity on glass edge chipping under different laser processing conditions: (a) Chipping area and (b) maximum chipping width. Exp.: Experiment.

solar rolled glass under condition C. The optimal chipping situation occurred when the viscosity was 3000 mm^2/s. Similarly, as the viscosity value continued to increase, the chipping area and width began to increase.

The phenomenon wherein the glass chipping decreased with increasing dimethicone viscosity may be due primarily to the refractive index of dimethicone becoming close to that of glass. The corresponding refractive index and surface tension at different viscosity values are shown in Fig. 6. As the viscosity value increased, the refractive index of dimethicone became close to the refractive index of the glass, thereby reducing the influence of the interface between dimethicone and glass on the focused spot, which in turn increased the uniformity of the laser energy density and reduced glass chipping. Notably, the laser beam is a focused beam, and the refracted beam generated when passing through the interface of different media may change the focus position, resulting in an error in glass cut hole dimensions. However, due to the fact that the refractive index of dimethicone is close to that of the glass, this effect is small, as confirmed by the current experiment results.

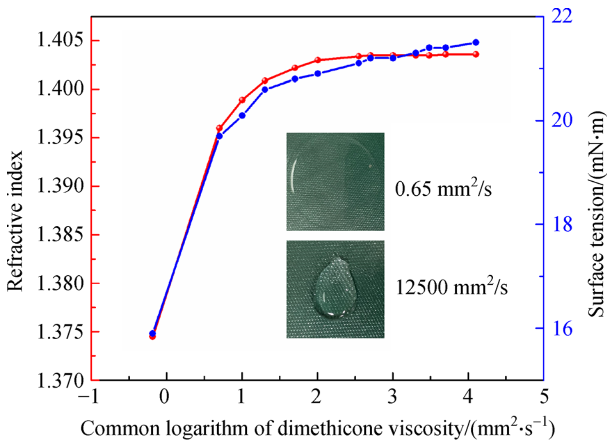

Fig. 6 Refractive index and surface tension of dimethicone under different viscosity values.

However, when the viscosity increased to a certain value, although the influence of the interface between dimethicone and glass on the focused spot decreased, the flatness of the dimethicone on the surface of the glass deteriorated because of the high viscosity and large surface tension; this situation resulted in the deterioration of laser focusing and eventually increased the glass chipping. The result of this effect differed in the various laser power conditions. The pulse energy was low (0.518 mJ) in processing condition A, and the pulse number per spot was only 1.758, which was not enough to successfully cut the glass by passing through the dimethicone when the viscosity and surface tension of the dimethicone were sufficiently large. As the laser frequency increased, the viscosity threshold of dimethicone that cannot achieve glass cutting successfully increased. For processing conditions B (pulse energy: 0.591 mJ, pulse number per spot: 2.224) and C (pulse energy: 0.59 mJ, pulse number per spot: 2.69), although the pulse energy was similar, a considerable difference was observed in the viscosity threshold for successful processing because of the difference in the pulse number per spot. Therefore, the effect of the uneven liquid surface on the uniformity of laser energy density did not reach the threshold of cutting failure in laser processing condition C. Reducing the laser scanning speed could effectively increase the pulse number per spot, thereby increasing the viscosity threshold for successful processing. However, it may also increase the pulse overlap rate, which will make the energy density too large, leading to processing failure. Figure 7 shows typical glass edge chipping under different dimethicone viscosity values and laser processing conditions.

4.2 Effect of laser power on glass edge chipping

Figure 5 also indicates that laser processing condition B had the smallest chipping area or the maximum chipping width. When the viscosity of dimethicone was 1000 mm^2/s, the glass chipping area had a minimum value of 215199 μm^2, and the maximum chipping width had a minimum value of 113.64 μm. Excessive or insufficient laser power can increase the chipping of the glass and reduce the cutting quality. Insufficient laser power does not produce enough stress to evenly crack the glass, resulting in uneven and large chipping. Meanwhile, excessive laser power can exert great thermal effects, resulting in large chipping. A laser frequency of 43 kHz and corresponding laser power of 25.4 W were determined to be the most suitable for solar rolled glass cutting. With the dimethicone viscosity value of 0.65 mm^2/s as an example, Fig. 7 shows that low or high laser power causes obvious chipping damage on the glass at the cutting edge.

4.3 Effect of process parameters on laser-processed glass surface roughness

The effect of dimethicone viscosity on laser-processed surface roughness is shown in Fig. 8. The surface roughness of the laser-processed glass surface showed basically the same trend as the chipping of the glass edge with the variation of dimethicone viscosity. Overall, surface roughness decreased as dimethicone viscosity increased. When it had decreased to a certain value, it began to increase. In addition, the laser-processed glass surface was the smoothest when the laser power was moderate. The smallest *Ra* of 3.26 μm appeared when the chipping area and width were minimal. This result indicates that when the edge chipping of the solar rolled glass was small, the surface roughness of the laser-processed glass surface was also small.

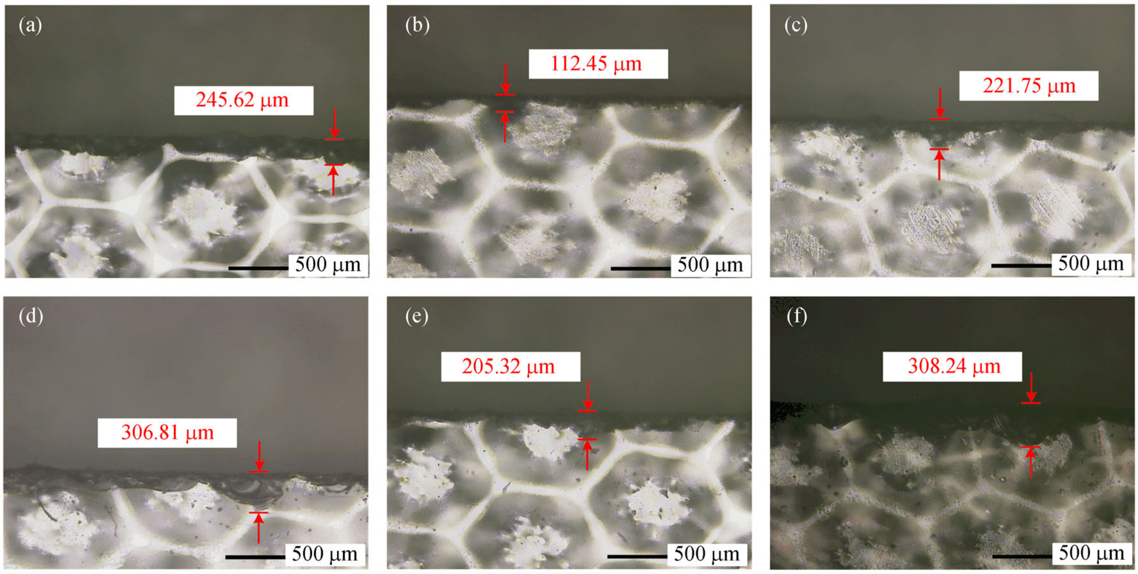

Fig. 7 Typical glass chipping under different dimethicone viscosities and cutting conditions. Processing condition B under dimethicone viscosities of (a) 0.65 mm^2/s, (b) 1000 mm^2/s, and (c) 3000 mm^2/s; 0.65 mm^2/s dimethicone viscosity under (d) processing condition A, (e) processing condition B, and (f) processing condition C.

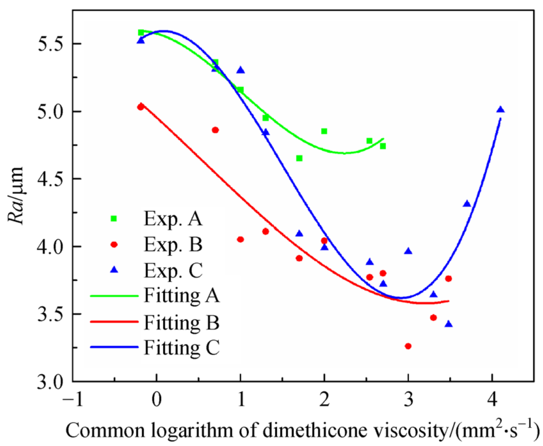

Fig. 8 Effect of dimethicone viscosity on laser-processed surface roughness under different laser processing conditions. Exp.: Experiment.

4.4 Analysis of surface topography

4.4.1 Analysis the profile of the glass chipping area

By drawing a horizontal line in the glass chipping area, the contour curve of the glass height on this line was obtained. As presented in Fig. 9, when the chipping width was small, the fluctuation range of the height of the chipping profile was also small, that is, the degree of glass breakage in the chipping area was small. Therefore, for dimethicone-aided solar rolled glass laser cutting, the appropriate laser power and dimethicone viscosity can reduce the area of glass edge chipping and the glass damage in the chipping area.

4.4.2 Analysis of the surface topography of the laser-processed surface

As shown in Fig. 10, when the laser power and dimethicone viscosity were small, the laser-processed glass surface had obvious white spots. The reason for this phenomenon is that although low laser energy can achieve glass cutting, the glass is easily affected by environmental factors, such as little dust on the surface of the glass, and the cutting power is not completely discharged smoothly, thereby causing the laser cutting energy in certain areas to be insufficient for completely breaking the glass into powder. As a result, white spots are formed. When the laser power was 25.4 W and the dimethicone viscosity was 1000 mm^2/s, no white spot was observed on the laser cutting surface. The 3D surface topography showed that the laser cutting surface was very smooth under this parameter condition. Under high laser power and large dimethicone viscosity, the laser-processed surface showed good consistency, but the surface had many dense protrusions from the 3D topography. Therefore, the glass surface was not smooth enough.

4.5 Analysis of micro-structures

The micro-structure of the laser-processed surface was studied through the images obtained from SEM, as presented in Fig. 11. Various surface defects, such as micro-voids, micro-cracks, and melted debris, were detected on the laser-processed surface. Many micro-cracks, voids, and irregular debris were observed on the surface when the laser power and dimethicone viscosity were too high or too low. By contrast, the micro-defects on

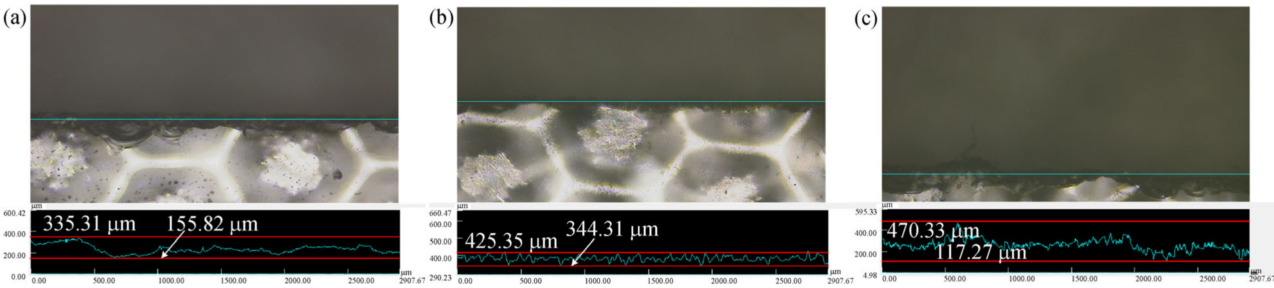

Fig. 9 Profile of the chipping area under different chipping values: (a) Processing condition A, 0.65 mm^2/s, maximum chipping width: 307.35 μm; (b) processing condition B, 1000 mm^2/s, maximum chipping width: 112.45 μm; and (c) processing condition C, 12500 mm^2/s, maximum chipping width: 234.37 μm.

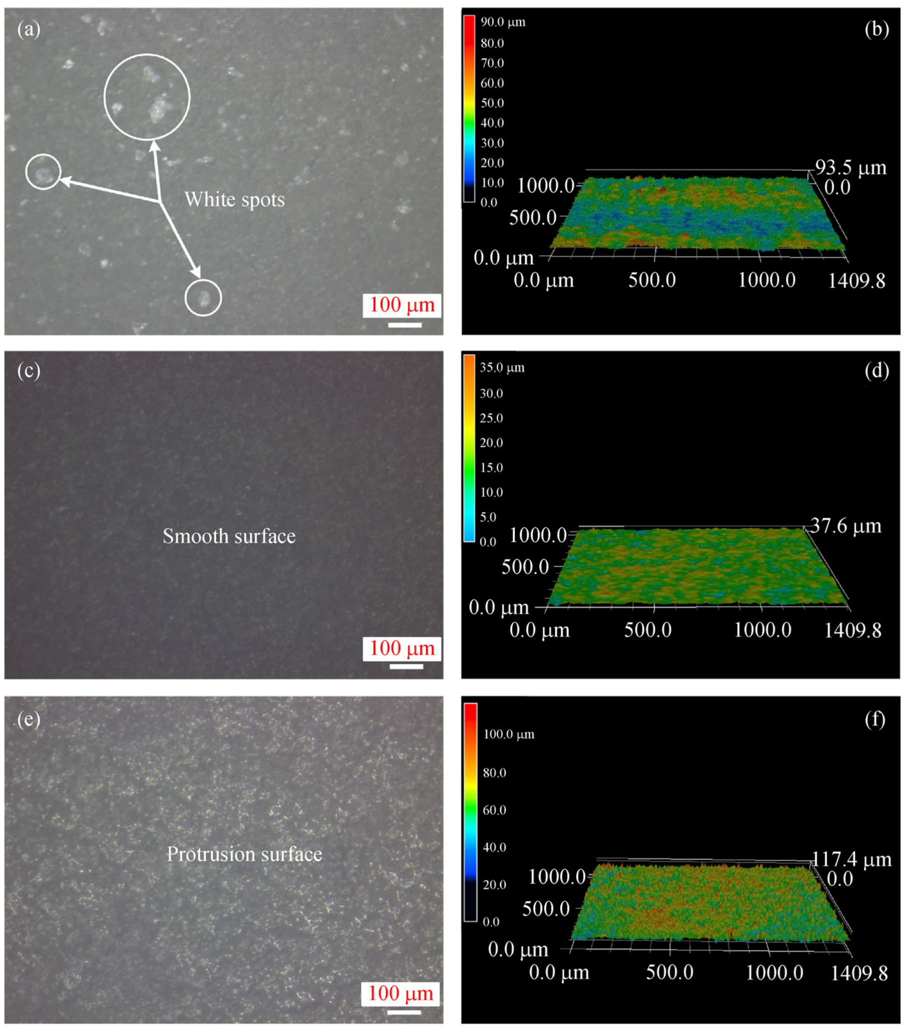

Fig. 10 Surface topography of the laser-processed surface under different parameters: (a) Processing condition A, 0.65 mm^2/s, *Ra*: 5.47 μm; (b) 3D topography corresponding to (a); (c) processing condition B, 1000 mm^2/s, *Ra*: 3.21 μm; (d) 3D topography corresponding to (c); (e) processing condition C, 12500 mm^2/s, *Ra*: 5.12 μm; and (f) 3D topography corresponding to (e).

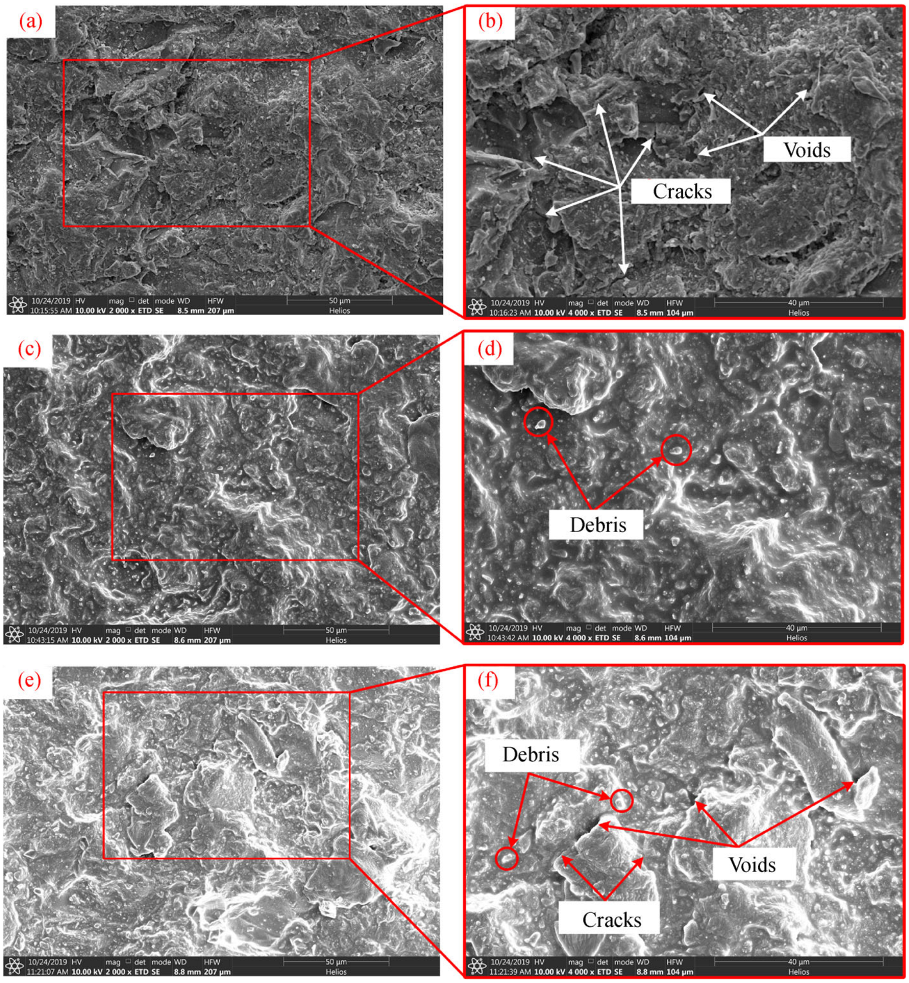

Fig. 11 SEM images of the laser-processed surface under different parameters: (a) Processing condition A, 0.65 mm^2/s; (b) enlarged SEM image corresponding to (a); (c) processing condition B, 1000 mm^2/s; (d) enlarged SEM image corresponding to (c); (e) processing condition C, 12500 mm^2/s; and (f) enlarged SEM image corresponding to (e).

the laser-processed surface were few at suitable laser power and viscosity. This result indicates that the smaller the edge chipping of the glass cuts is, the smaller the surface roughness of the cut surface is and the fewer the micro-defects of the cut surface are.

The bottom edge (embossed side) of the laser-processed glass surface is shown in Fig. 12. The trend of edge chipping was consistent with that of the edge of the vertical surface. In addition, Figs. 12(a) and 12(c) show not only a large chipping area, but also a large depth of chipping and a complicated chipping condition. The chipping condition in Fig. 12(b) with a small chipping width, smooth chipping area, and small depth of chipping is much better than that in the other sub-figures. We posit that when the laser power

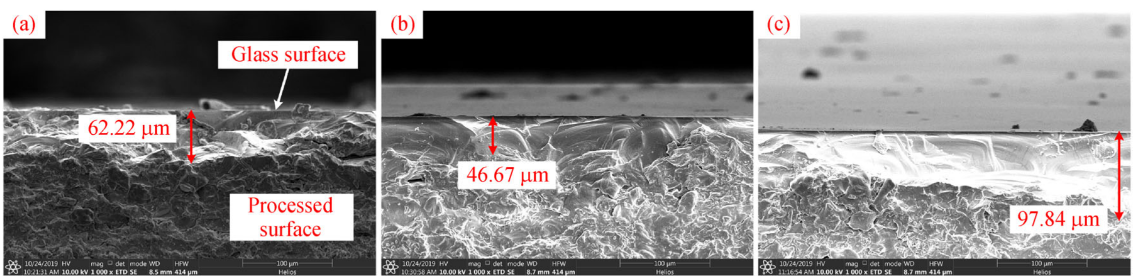

Fig. 12 SEM images of the laser-processed surface edge under different parameters: (a) Processing condition A, 0.65 mm^2/s; (b) processing condition B, 1000 mm^2/s; and (c) processing condition C, 12500 mm^2/s.

and viscosity of the auxiliary dimethicone are appropriate, the edge chipping degree of glass surfaces perpendicular to each other is small.

5 Conclusions

This study investigated the laser cutting of solar rolled glass with the aid of a transparent liquid, namely, dimethicone. The effects of dimethicone viscosity and laser power on surface quality were also determined. The following conclusions were derived from the experiments and analysis.

1) Solar rolled glass 3D hole laser cutting was successfully realized by applying the auxiliary liquid dimethicone on the upper surface of the glass and planning the scanning path of the laser beam into a *Z* bottom–up multilayer increment with an *X*–*Y* spiral line pattern. In this manner, glass hole laser cutting of any shape and size can be achieved within the scanning range of the lens without a need for any post-processing.

2) Dimethicone viscosity exerts a great influence on surface quality. In the three different laser power conditions in this study, the glass edge chipping and laser-processed glass surface roughness decreased with increasing viscosity and began to increase when a certain threshold was reached. The best surface quality in the three different laser power situations (from low to high) was obtained when the dimethicone viscosity was 50, 1000, and 3000 mm^2/s.

3) The viscosity limit of dimethicone for successfully achieving laser glass cutting increases with the increase in laser frequency because of the increased pulse energy and the pulse number per spot. High and low laser power are expected to increase the chipping degree on the edge of the glass and the roughness of the laser cutting surface. When the dimethicone viscosity was set to 1000 mm^2/s in the experiment and the laser pulse frequency was 43 kHz (corresponding to a laser power of 25.4 W), the average minimum glass edge chipping area was 215199 μm^2, the average smallest maximum chipping width was 113.64 μm, and the average minimum *Ra* of the processed surface was 3.26 μm.

4) When the glass edge chipping on the embossed side and the surface roughness of the laser-processed surface are minimized, the surface profile of the chipping area becomes increasingly uniform. The 3D topography of the laser-processed surface also becomes smoother than it was before. Furthermore, the surface micro-defects are few, and the edge chipping width and depth on the laser-processed surface are small.

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