Pre-Groove Development for Laser Cleaving of Brittle Materials by Using Micro-Lens*

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Abstract

Thermal stress cleaving is a prospective technique for separating thin plates of brittle materials such as silicon, ceramic and glass. This study, deals with a new method which provide the initial fracture on the edge of workpiece. The initial fracture such as crack, scratch and groove is the starting point of crack propagation in laser cleaving and the crack propagates along laser scanning path from the initial fracture. In previous study, the initial fracture is created by Vickers indenter. Since shape of Vickers indenter is pyramid, the unnecessary cracks propagate. In addition, lateral cracks are created at the surface. Because of cracks, the quality of thermal stress cleaving is poor. In this study, a pre-groove is used as the initial fracture. The pre-groove is formed on the workpiece surface by pulsed Nd:YAG laser irradiation through a cylindrical micro-lens. The cylindrical micro-lens is made by the irradiation of Er:YAG laser to the surface of acrylic board. Silicon wafer is used as a workpiece. Continuous Nd:YAG laser is used for laser cleaving. By using this method, there is no unnecessary cracks happen, and subsequently improve the quality of thermal stress cleaving.

Key words: Laser Cleaving, Silicon Wafer, Crack Propagation, Nd:YAG Laser, Er:YAG Laser

1. Introduction

Laser cleaving is a prospective technique for separating thin plates of brittle materials such as silicon, ceramic and glass^[1]. Diamond blade dicing is usually used for the cutting of these brittle materials. This method has disadvantages, such as a contamination by the coolant and chips. In addition to this, the microcrack is created during this process.

Laser cleaving has a lot of advantages. It is non-contact process and no allowance required for cutting, there is no contamination by coolant and chips. This method has the capability of producing an extremely smooth surface by cleaving along the cleavage plane of the workpiece. Many studies about the laser cleaving have been carried out. R.M. Lumley studied about laser cleaving of alumina and glass by CO₂ laser^[2]. Yen-Liang Kou et al. studied on numerical simulation and experiment about cleaving glass sheet by multiple laser system^[3].

In the present paper, the new method is suggested in providing the initial fracture. In the laser cleaving, the tensile stress which is generated by laser irradiation is applied to crack tip for crack propagation. The initial fracture is used as the starting point of crack propagation.

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There are various methods of creating initial fracture. The conventional method is that the pre-crack is induced by Vickers indenter in previous study. Median crack propagates from edge of indenter by inducing Vickers indenter. The pre-crack can be formed to ensure in this method. However, the shape of Vickers indenter is pyramid, and the other median cracks propagate perpendicular to the direction of cleaving and it affects the linearity of crack propagation. In addition, the processing accuracy is debased at starting point of cleaving by Vickers impression and lateral cracks.

The pre-groove is created on the surface of workpiece by laser irradiation through a cylindrical micro-lens. In this paper, the best condition of fabricating pre-groove for silicon wafer is selected and it is investigated that the pre-groove is valid for the thermal stress cleaving of silicon wafer. In this method, there are no secondary cracks and the pre-groove improves the linearity of crack propagation.

2. Micro-lens

2.1 Fabrication method of micro-lens

Micro-lens can be produced by using acrylic materials. This technology has been developed by previous researcher ^[4]. When the laser irradiates to the surface of acrylic board, the temperature rises rapidly and thermal expansion occurs at irradiation area. At this time, the hemispherical shape of a convex micro-lens is formed on the acrylic board. The cylindrical micro-lens is formed by feeding workpiece during laser irradiation.

The experimental conditions are summarized in **Table1**. Pulsed Er:YAG laser is used. Beam diameter at surface of acrylic board is 0.1mm. The laser power is 32mW and the feed rate of workpiece is 4μm/s. Acrylic board with thickness of 3mm is used as a substrate of micro-lens. The frequency of pulsed laser is 4Hz, the laser irradiation time is 500s and the length of micro-lens is 2mm.

Table1 Experimental conditions of micro-lens fabrication

Er:YAG laser		
Wavelength	λ_E	2940 nm
Irradiation mode		Pulse
Beam diameter		0.1 mm
Defocus	df	0 mm
Frequency	f_E	4 Hz
Pulse width	τ_E	0.2 ms
Feed rate	v_E	4 μm/s
Laser power	Q_E	32 mW
Workpiece		Acrylic board
Size		50 × 50 × 3 mm

2.2 Shape of micro-lens

Figure 1 shows the 3-D profile of micro-lens and **Figure 2** shows the 2-D profile. **Table2** shows evaluation parameters of micro-lens. Lens height is defined as the distance from surface of acrylic board to top of micro-lens. Lens width is defined as the width of part of thermal expansion affected. Curvature radius is the radius of circle which is approximated the convex obtained by the thermal expansion. Focal length is determined from the curvature radius, the refractive index of acrylic of substrate and the refractive index of water.

Fig.1 3-D profile of micro-lens

Fig.2 2-D profile of micro-lens (A-A')

Table2 Evaluation parameters of micro-lens

Micro-lens		Acrylic board
Curvature radius	r	150 μm
Focal length	F	1.25 mm
Lens height	h	25 μm
Lens width	w	200 μm

3. Pre-Groove

3.1 Experimental method of inducing pre-groove

Pre-groove is created at edge of workpiece of (100) face silicon wafer. Pulsed second harmonic Nd:YAG laser is used. The laser beam is focused on the surface of the workpiece through the micro-lens. The workpiece is irradiated with laser beam of high energy density and only the laser beam irradiated zone is removed. **Figure 3** shows the experimental set up.

The workpiece is located in the water to inhibit the debris from attaching to the workpiece surface. The experimental conditions are summarized in **Table 3**. The wavelength of laser beam is 532nm and the irradiation mode is pulse irradiation. Beam diameter at surface of acrylic board is 4mm. The laser power used is 100~350mW and 100-pulses laser beam are irradiated.

Fig.3 Experimental set up of inducing pre-groove

Table3 Experimental conditions of inducing pre-groove

Nd:YAG laser		
Wavelength	λ_{NI}	532 nm
Irradiation mode		Pulse
Beam diameter		4 mm
Defocus	df	0 mm
Frequency	f_{NI}	10 Hz
Pulse width	τ_{NI}	5 nsec
Laser power	Q_{NI}	100-350 mW
Pulse number		100 pulses
Workpiece	(100) face silicon wafer	
Size	$10 \times 20 \times 0.5$ mm	

3.2 Shape of pre-groove

Figure 4 shows schematic illustration and micrographs of pre-groove formed on workpiece which is irradiated with the 200mW laser beam. The groove width t_g and the groove depth l_g is measured. **Figure 5 (a)** shows the relationship between the laser power and the groove width. With increasing laser power, the groove width tends to increase. **Figure 5 (b)** shows the relationship between the laser power and the groove depth. The groove depth was measured about $45\mu\text{m}$ at each laser power. It shows that increasing laser power did not affect the groove depth.

Fig.4 Schematic illustration and micrographs of pre-groove

(a) Relationship between Q_{NI} and t_g

(b) Relationship between Q_{NI} and l_g

Fig.5 Measurement results of pre-groove

4. Laser cleaving

4.1 Phenomenon of laser cleaving

The principle of laser cleaving is shown in **Fig.6**. When a laser beam is irradiated to a small area on the material surface, the compressive stress is occurred at the focus area and the tensile stress is occurred at the outside of the focus area by the temperature gradient. By the circumferential tensile stress, the crack propagates toward the center of the laser spot. The crack propagates along the path of the laser beam and the workpiece is separated.

Fig.6 Phenomenon of laser cleaving

4.2 Experimental method of laser cleaving

The experimental conditions are summarized in **Table 4**. In this experiment, continuous Nd:YAG laser is used. The laser spot is ellipse, and the long axis is 0.2mm and the short axis is 0.1mm at the just focus position. **Figure 7** shows the schematic of workpiece used in laser cleaving. The laser power is 46W and the feed rate is 2mm/s. The pre-groove is induced to the direction of cleaving by pulsed second harmonic Nd:YAG laser with 200mW laser power. As feeding the workpiece with irradiating laser, the crack starts to propagate from the pre-groove. The crack propagates along the laser irradiated path and the workpiece is separated.

Table4 Experimental conditions of laser cleaving

Nd:YAG laser		
Wavelength	λ_{N2}	1.064 μm
Irradiation mode		Continuous wave
Beam diameter		0.2 $\times$ 0.1 mm
Defocus	df	0 mm
Feed rate	v_{N2}	2 mm/s
Power	Q_{N2}	46 W

Fig.7 Experimental set up of laser cleaving

4.3 Experimental results and discussions

Micrographs of initial fracture and crack propagation after laser cleaving by pre-groove and pre-crack by Vickers indenter are shown in Fig.8. Figure 8 (a) (i) shows micrograph of the pre-crack. The pre-crack is induced by loading a Vickers indenter with a microhardness testing machine. This process is the conventional method. The Vickers indenter is loaded at 5 points and the load is 9.8N. The width of unnecessary crack is about 160~200 μ m. The time required to induce the pre-crack is about 50s. Fig.8 (a) (ii) shows micrograph of the pre-groove. The width of groove is 9~10 μ m. The time required to induce the pre-groove is about 10s. Figure 8 (b) (i) shows the starting point of the workpiece cleaved with pre-crack, and Fig.8 (b) (ii) shows the starting point of the workpiece cleaved with pre-groove. From these figures, it is found that the processing accuracy is improved by using the pre-groove for initial fracture.

Fig.8 Micrographs of initial fracture and starting point after laser cleaving

5. Conclusions

In thermal stress cleaving of silicon wafer, the method of providing the initial fracture of cleaving is investigated. The main results obtained are as follows.

- (1) The pre-groove can be formed by laser beam irradiation through the micro-lens. The width of groove increases in proportion to the laser power, but the depth of groove is almost constant at each laser power.
- (2) Laser cleaving is possible by using pre-groove for the starting point of the cleaving.
- (3) By using the pre-groove, the processing accuracy is improved and the time of providing the initial fracture for the cleaving is only 10s.

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