Optical Waveguide Fabricating on Lithium Niobate with UV Laser

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Abstract:

This paper presents fabrication of an optical waveguide on a lithium niobate plate using UV pulse laser of 355 nm in wavelength. The optical waveguide is composed of smooth bottom grooves with 300 μm in width and 10 μm in depth. The grooves are made by repeating a fabrication of small uniform groove. Therefore, geometry of small groove should be controllable. Some experiments were conducted to find out control methods of the geometry of a small groove. As a result, it is clarified that the width of a groove can be controlled by changing a focal position. Furthermore, it is found that there are three methods to control the depth of a groove. Finally, we tried to fabricate a smooth bottom groove with 300 μm in width and 10 μm in depth. As a result, the groove which had 300 μm in width, 9.92 μm in depth, and the bottom of 0.932 μm Rmax or 0.130 μm Ra was obtained by means of UV laser.

1.Introduction

It is required for optical components to have precise optical waveguides fabricated on a material surface. The waveguide has linear ridges as shown in Figure 1. At present they are fabricated by dicing technology while chipping may be occurred on their edges. This paper presents fabrication of an optical waveguide by means of UV laser instead of dicing. Compared with dicing technology, laser fabrication provides variety of ridge shape as well as cost and proceeding time reduction [1]. Key issues to be investigated are repeatability of fabricated geometry, control of width and depth of a groove in terms of machining conditions. The present paper provides experimental results from the viewpoint in detail.

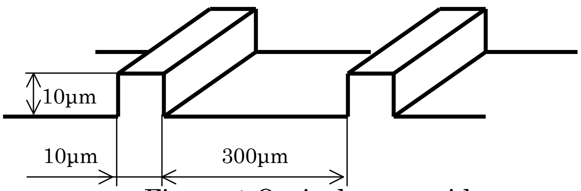


Figure 1 Optical waveguide

2.How to Make an Optical Waveguide

An optical waveguide is fabricated on a lithium niobate plate using UV pulse laser. The optical waveguide is composed of smooth bottom grooves of 300 μm in width and 10 μm in depth, called a waveguide's groove. The grooves are made by repeating a fabrication of a small uniform groove.

3.UV Laser Machining System

Small grooves are fabricated by means of pulsed UV laser of 355 nm in wavelength. The laser beam is focused to a spot with 9.02 μm in diameter by a lens. The small grooves are fabricated on a lithium niobate plate which was placed on a XY stage. The overview of the laser machining system is shown in Figure 2. Specifications of the system are shown in Table 1.

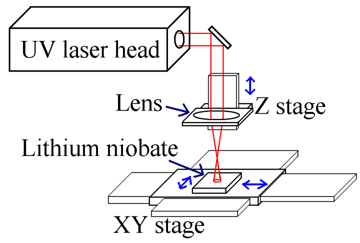


Figure 2 The overview of the laser machining system

Table 1 Specifications of the laser machining system

Wavelength	355 nm
Spot Diameter	9.02 μm
Focal Distance of Laser	42.09 mm for 355 nm wavelength
Pulse length	40 nsec
Polarization	Horizontal
Pulse Mode	Tem_{00} (M^2<1.3)

4.Geometry definitions of a small groove

In order to evaluate a small groove geometry, following factors were defined as shown in Figure 3; D(Depth of groove), W(Width of groove), H(Height of groove), and A(Area of groove). The factors were investigated using a surface profile measurement instrument (SURFCOM 570A, TOKYO SEIMITSU).

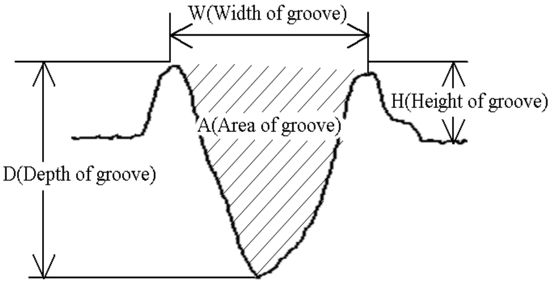


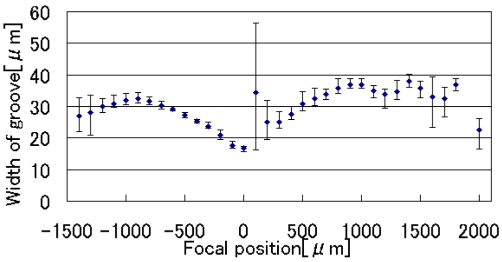
Figure 3 Geometry definitions of a small groove

5.Repeatability of geometry

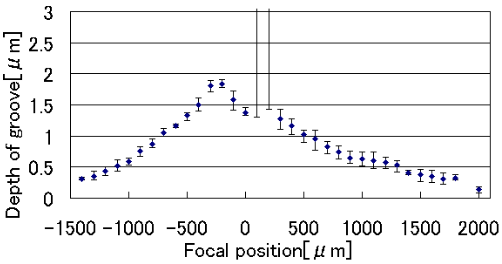
Repeatability of the geometry of a small groove is very important, when an optical waveguide is fabricated. Therefore, experiments ware conducted to make relationships between focal position and the geometry of a small groove clear. Machining conditions in this experiment are shown in Table 2. The results of relationships between focal position and geometry are shown in Figure 4.

Table 2 Machining conditions

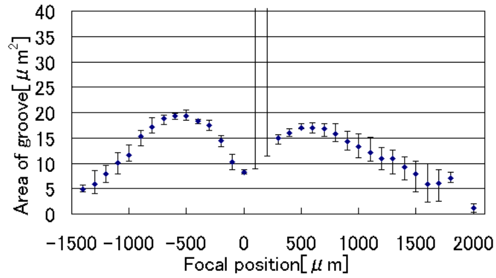
Laser energy	30 μJ/pulse
Pulse frequency	10 kHz
Feed speed	30 mm/sec
Focal position	-1400 μm～2000 μm



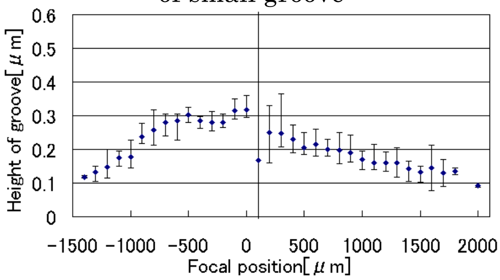
(a) Relationships between focal position and width of small groove



(b) Relationships between focal position and depth of small groove



(c) Relationships between focal position and area of small groove



(d) Relationships between focal position and height of small groove

Figure 4 Relationships between focal position and geometry of small groove

In the results, it was found that geometrical repeatability was not good because of the crack occurrence, if the focal position from workpiece surface was less than 200 μm. It is considered that cracks are caused by high power density. Therefore, it is necessary to set the focal position to be more than 200 μm to obtain a small uniform groove.

6.Controllabirity of groove geometry

The geometry of the waveguide's groove is composed of small grooves. Therefore, it is required that a depth and width of small uniform groove should be controlled for an optical waveguide.

Machining conditions, i.e. pulse energy, pulse frequency, feed speed and focal position, which affect a geometry of a groove should be determined appropriately. Therefore, experiments were conducted to find out the relationship between the geometry of a groove and machining conditions mentioned above. Another propose of these experiments were to determine machining conditions for stable machining of a small groove that has required depth and width.

6.1 Control of the width of a small groove

From the experimental results, it is found that the width of a small groove can be easily controlled by a focal position. It means that the range of focal position from –800 µm to 0 µm is available to control the width of a groove as shown in Figure 4(a). However, the depth of a groove is also changed as the focal position is changed as shown in Figure 4(b). Therefore, other machining conditions should be controlled to keep the depth controlled. Section 6.2 provides the control methods.

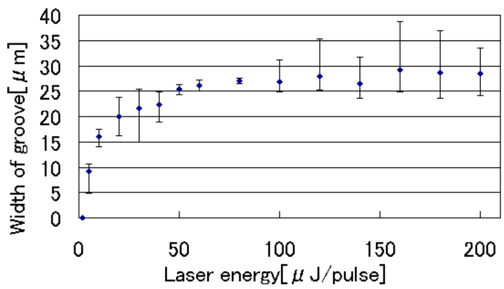
6.2 Control of the depth of a small groove

From the experimental results, we find out that there are three methods to control the depth of a small groove without changing its width.

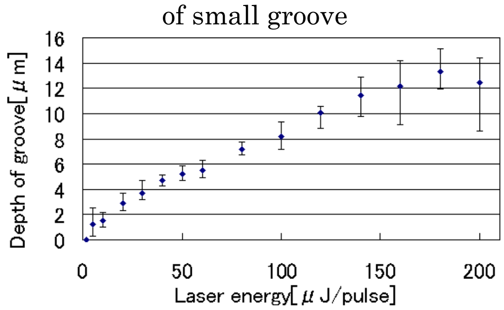
The first method is to determine laser energy appropriately. Figure 5 shows the results of the depth and width of a groove in changing the laser energy.

Table 3 Machining conditions for the first method

Laser energy	1～200 µJ/pulse
Pulse frequency	10 kHz
Feed speed	30 mm/sec
Focal position	-600 µm



(a) Relationships between focal position and width of small groove



(b) Relationships between focal position and depth of small groove

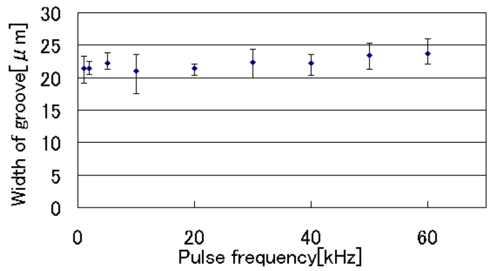
Figure 5 Relationships between energy and geometry of small groove

A constant width of a groove can be obtained by the laser energy greater than 50 µJ, keeping other machining conditions constant. It means that the depth of a groove can be controlled by the laser energy greater than 50 µJ.

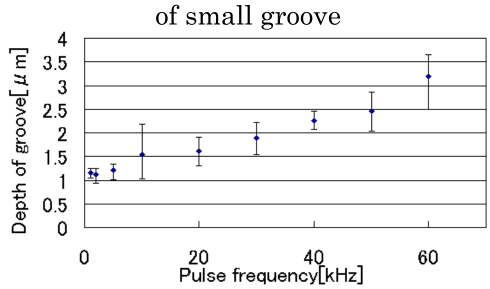
The second method to control the depth is to determine pulse frequency and feed speed appropriately. Figure 6 shows the results of the depth and width of a groove in changing the pulse frequency with keeping shot distance constant.

Table 4 Machining conditions for the second method

Laser energy	20 µJ/pulse
Pulse frequency	1～60 kHz
Feed speed	1～60 mm/sec
Focal position	-600 µm
Shot distance	1 µm



(a) Relationships between focal position and width of small groove



(b) Relationships between focal position and depth of small groove

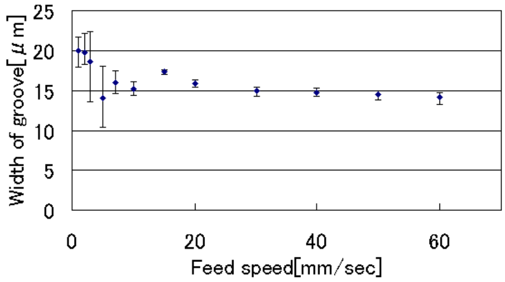
Figure 6 Relationships between pulse frequency and geometry of small groove

It is observed that a constant width of a groove can be obtained when the pulse frequency and the feed speed are adjusted to realize a constant shot distance. In the case, the depth of a groove increased as the pulse frequency increased. It means that the depth of a groove can be controlled by pulse frequency and feed under the constant condition of shot distance.

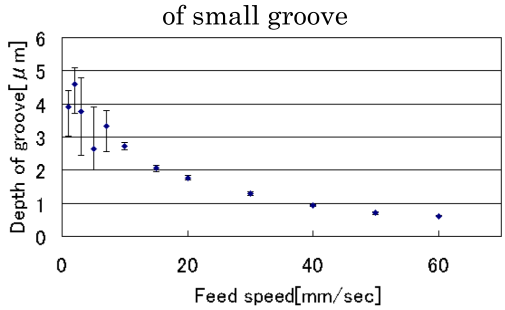
The third method to control the depth is to adjust the feed speed. Figure 7 shows the results of the depth and width of a groove in changing the feed speed.

Table 5 Machining conditions for the third method

Laser energy	30 µJ/pulse
Pulse frequency	10 kHz
Feed speed	1～60 mm/sec
Focal position	-600 µm



(a) Relationships between focal position and width of small groove



(b) Relationships between focal position and depth of small groove

Figure 7 Relationships between feed speed and geometry of small groove

It is found that the width of a groove does not change when the feed speed is changed if it is greater than 20 μm/sec. It means that the depth of a groove can be controlled by the feed speed greater than 20 μm/sec.

7.Optical Waveguide Fabrication

Finally, applying the results clarified above, we tried to fabricate an optical waveguide's groove of 300 μm in width and 10 μm in depth with a smooth bottom. In this fabrication, the machining conditions were determined as shown in Table 6, which gave the best geometry of a small groove for the optical waveguide's groove fabricating.

The fabricated optical waveguide's groove had 300 μm in width, 9.92 μm in depth, and the bottom of 0.932 μm Rmax or 0.130 μm Ra as shown in Figures 8 and 9.

Table 6 Machining conditions for an optical waveguide' groove

Laser energy	17 μJ/pulse
Pulse frequency	10 kHz
Feed speed	30 mm/sec
Focal position	-600 μm
Distance of pick-feed	6 μm
Number of small grooves	50
Number of wide grooves	5

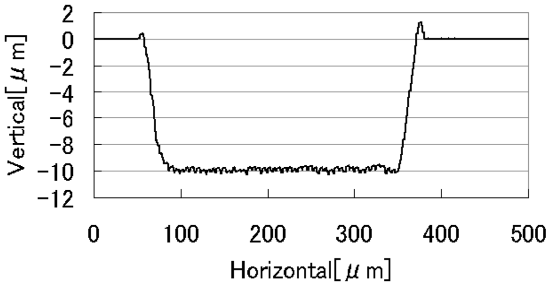


Figure 8 Cross section profile of a waveguide's groove measured by a surface roughness profile instrument

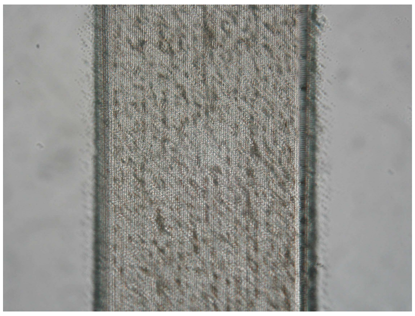


Figure 9 A top view of photograph of waveguide's groove

8.Conclusion

This paper presents fabrication of an optical waveguide on a lithium niobate plate using UV pulse laser. For the purpose, some experiments were conducted to clarify the relationships between machining conditions and a small groove geometry. As the results, it is made clear that groove geometry can be controlled by adjusting machining conditions. The details are following:

(1)The width of a small groove can be controlled by a focal position from –800 μm to 0 μm.

(2) The depth of a groove can be controlled by the laser energy greater than 50 μJ without changing its width.

(3) The depth of a groove can be controlled by pulse frequency and feed with keeping shot distance constant without changing its width.

(4) The depth of a groove can be controlled by the feed speed greater than 20 μm/sec without changing its width.

Finally, we fabricated the optical waveguide's groove, which had 300 μm in width, 9.92 μm in depth, and the bottom of 0.932 μm Rmax or 0.130 μm Ra, using the UV laser.

Reference:

1.J.Meijer,K.Do,A.Gillner,D.Hoffmann,V.S.Kovalenko,T.Masuzawa,A.Ostendorf:Laser Machining by Short and Ultrashort Pulses, State of the Art, Annals of the CIRP,51,2,pp.1-20,2002.