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Study of Surface Integrity in Micro-groove Cutting of Anisotropic Material

Hiroyuki Kodama[1], Koichi Okuda[1], Yuji Kishi[1]

[1]*University of Hyogo, Graduate School of Engineering, Japan*
kodama@eng.u-hyogo.ac.jp

Abstract
This study examines how change in the direction of the crystal structure of lithium niobate and change in rake angle affects surface roughness. Since crystallographic orientation of anisotropic material differs according to cutting direction, the integrity of the finished surface will also differ. We performed an experiment assuming that a cutting direction conducive to a good finished surface could be obtained by matching the angle formed between the rake plane and slip plane with conditions that suit a good surface. We found that the rake angle and slip plane are factors affecting the roughness of the finished surface. It was also found that changing the rake angle to bring the angle formed between the slip plane and rake plane (crossing angle) near 30 and -25° tends to reduce the roughness of the bottom surface and the amount of cracks.

Keywords: lithium niobate, crystallographic orientation, planer-type cutting, surface integrity

1. Introduction

Lithium niobate ($LiNbO_3$) is used as substrate material in microelectro-mechanical systems (MEMS), micro total analysis systems (µTAS), and other applications. While lithography technology has so far been used to process $LiNbO_3$, the development of cutting processes with greater degrees of freedom can help reduce costs and enable the manufacturing of diverse products in short periods of time. However, $LiNbO_3$ is a brittle material, which makes it easy for cracks to form in grooves formed by cutting, and the occurrence of cracks makes $LiNbO_3$ unsuitable as substrate material. On the other hand, performing $LiNbO_3$ cutting at depths of cut less than a critical value results in the generation of no brittle fractures enabling cutting similar to that of ordinary ductile materials. Using the characteristics of this ductile mode enables the generation of good finished surfaces that can be used as substrate material [1]. Furthermore, even under conditions that facilitate ductile mode cutting, ductile cutting of $LiNbO_3$ tends to be favored in certain cutting directions reflecting the crystal dependency of this material. In this study, we make us of this crystal dependency to experimentally clarify how changing both the slide direction between the tool and work material and the tool's rake plane affects the integrity of the finished surface.

2. Experimental method

In this study, we performed planar-type linear cutting using the UVM-450C High Precision Vertical Machine (Toshiba Machine Co., Ltd.). The tool was a single-crystal diamond bit (A.L.M.T. Corp. NWD-CL308) having a tip radius of 0.8 mm and an edge radius from the tool's rake plane to flank plane of 30 µm. Table feed was 500 mm/min. A depth of cut of 0 – 25 µm in the axial direction was linearly obtained by feeding the tool diagonally for a feed distance of 10 mm. A schematic diagram of the cutting process and definition of cutting direction are shown in Figure 1. For this experiment, we used a tool with a rake angle of 0°. In addition, we performed the cutting after fixing the work material to a fixture having a 30° inclined plane to which a tilting

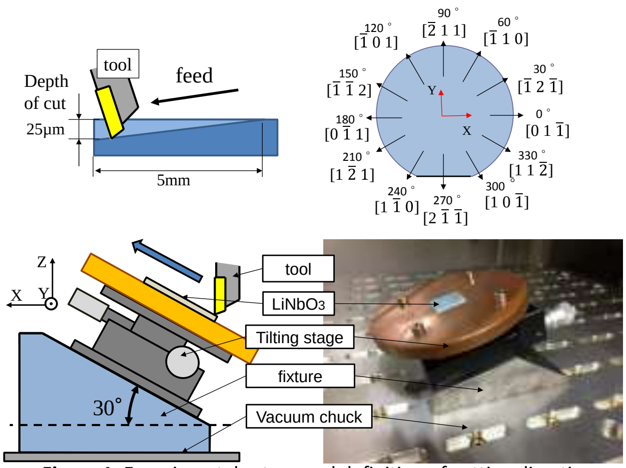

Figure 1. Experimental set-up and definition of cutting direction.

stage was attached. In this way, we could cut on the $LiNbO_3$ plane with a rake angle of -30°, that is, with an angle the same as that of the above inclination. The $LiNbO_3$ used in the experiment was obtained by cutting into an ingot at an angle of 128° and forming a wafer with a thickness of 0.5 mm and a diameter of 4.0 inches (128° Y-cut). In the experiment, we observed the shape of the grooves formed by cutting using a 3D optical surface profiler (Zygo NewView 7300).

3. Crystal slip direction and cutting mechanism

The crystal lattice structure of anisotropic material results in the existence of slip directions, each of which features weak crystal binding that makes it easy for cleavage to occur. Slip direction differs according to cutting direction, so the amount of cracks and fractures will likewise differ by cutting direction. The fact that the position of the slip plane differs according to cutting direction has been verified by visualization of the $LiNbO_3$ crystal structure using Visualization for Electronic and

Structure Analysis (VESTA) software [2]. Crystal structure of $LiNbO_3$ for a cutting direction of 0° and definition of the crossing angle are

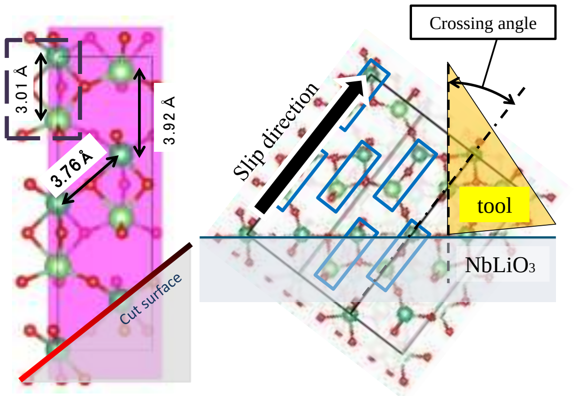

Figure 2. LiNbO3 crystal lattice and definition of crossing angle.

shown in Figure 2 [3]. The numerical values in the figure indicate the inter-atomic distance between L_i and N_b. Binding force is strongest at a distance of 3.01Å, the smallest of the distances shown, but becomes weaker as the inter-atomic distance increases. It can be considered that a relationship exists between the angle formed between the rake plane and slip plane (referred to below as "crossing angle") and the integrity of the finished surface, so the possibility arises of cutting LiNbO3 in a direction in which cleavage can easily occur if the crossing angle is small. In other words, it should be possible to obtain a good finished surface with few cracks.

4. Comparison of surface roughness for different rake angles

Graph example of average roughness (*Ra*) of the bottom surface are shown in Figure 3 for depths of cut of 0 – 5 µm. In the graphs, the tail and tip of each arrow signify the results at rake angles of 0° and -30°. For a depth of cut of 0 – 5 µm, bottom-surface roughness increased by changing the tool's rake angle from 0° to -30° for most conditions although it decreased for a cutting direction of 270°. Therefore, the roughness of the bottom surface could be decreased especially for a cutting direction of 270°. We compared results for a cutting direction of 270° when varying crossing angles in the range of 5 – -25° with those for a cutting direction of 30° corresponding to larger crossing angles (36 – 8°) and those for a cutting direction of 150° corresponding to smaller crossing angles (-34 – -64°). Examining the results for a cutting direction of 270° in Figure 4 and focusing on the cutting end planes indicated by dotted lines, no large cracks could be observed in the shallow portion of the groove for a rake angle of -30° in contrast to those that could be seen in the groove for a rake angle of 0°. In addition, a groove shape with little unevenness on the side surfaces could be obtained. However, cracks could be observed in the bottom surface of the groove as depth of cut increased. Bottom-surface shapes for a cutting direction of 270° are shown in Figure 5. Ductile mode cutting changed to brittle mode cutting at depths of cut greater than 6 µm. Moreover, for cutting directions of 30° and 150° Surface roughness increased when changing to a rake angle of -30°. Therefore, the finished surface becomes rough by increasing depth of cut for crossing angles in the vicinity of 30 – 0° and -30 – -60°.

5. Conclusion

This study examined the effects of rake angle on the finished surface when performing micro-groove processing on lithium niobate using a single-crystal diamond tool. Rake angle and slip plane are factors affecting the roughness of the finished surface. Changing the rake angle to bring the angle formed between the slip plane and rake plane angle near 30° tends to reduce the roughness of the bottom surface and the amount of cracks.

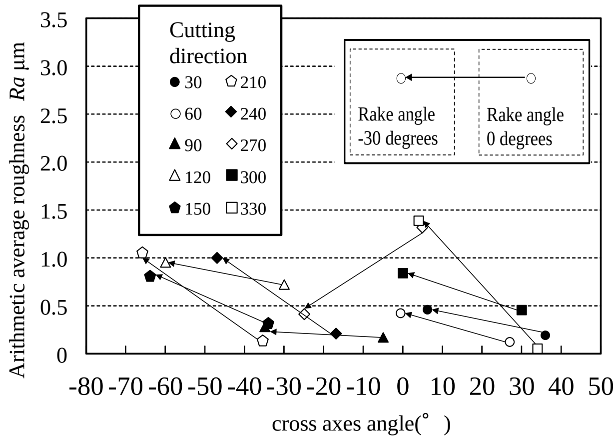

Figure 3. Measurement results of bottom-surface roughness.

Cutting direction: 30° 1mm	Crossing angle
	36° Rake angle: 0°
	8° Rake angle: -30°
Cutting direction: 150°	Crossing angle
	-34° Rake angle: 0°
	-64° Rake angle: -30°
Cutting direction: 270°	Crossing angle
	5° Rake angle: 0°
	-25° Rake angle: -30°

Figure 4. Comparison of groove shapes by cutting direction.

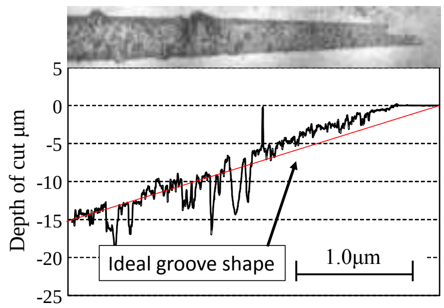

Figure 5. Bottom-surface shapes for a cutting direction of 270° (-30°)

References

[1] Okuda K, Harada M, Shizuka H, Saiki T, Hamaguchi K and Utsumi Y 2014 Machining of micro groove of lithium niobate by planer-type cutting with diamond tool for fabrication of SAW device Proc. of the 14th Euspen Int. Conf.

[2] Kodama H, Okuda K, Harada M, Saiki T and Hamaguti K 2015, Experimental Verification of Lithium Niobate Cutting Phenomena from the View point of Crystallographic Orientation, Proc. of the 15th Euspen Int. Conf., pp323-324

[3] Korecki P, Tolkiehn M, Dąbrowski KM, Novikov DV 2011 J Synchrotron Radiat, **18**, 851-861.