Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 45 (2016) 139 – 142

www.elsevier.com/locate/procedia

3rd CIRP Conference on Surface Integrity (CIRP CSI)

Influence of nose radius on surface integrity in ultra-precision cylindrical turning of single-crystal calcium fluoride

Yuta Mizumoto[a]*, Hiroi Kangawa[a], Yosuke Nakagawa[b], Hiroki Itobe[b], Takasumi Tanabe[b] and Yasuhiro Kakinuma[a]

Department of System Design Engineering, Faculty of Science and Technology, Keio University,
3-14-1 Hiyoshi, Kohoku-ku, Yokohama 223-8522, Japan
Department of Electronics and Electrical Engineering, Faculty of Science and Technology, Keio University,
3-14-1 Hiyoshi, Kohoku-ku, Yokohama 223-8522, Japan

* Corresponding author. Tel.: +81-45-566-1721; fax: +81-45-566-1721. *E-mail address:* mizumoto@ams.sd.keio.ac.jp

---

Abstract

Optical micro-resonators attract interests as essential components to develop optical signal processing circuits which can reduce energy loss. Single-crystal calcium fluoride (CaF_2) could be the most suitable material from a viewpoint of optical property. To satisfy high form accuracy and surface roughness, ultra-precision cylindrical turning (UPCT) is a feasible fabrication process. In previous research, it was indicated that the tool with sharper nose radius could make UPCT more stable and reduce subsurface damage. In this study, the tool with much smaller nose radius 0.01 mm was applied, then, the influence on surface integrity was investigated by TEM observation.

Peer-review under responsibility of the scientific committee of the 3rd CIRP Conference on Surface Integrity (CIRP CSI)

Keywords: Single crystal; Surface integrity; Optical micro-resonator

---

1. Introduction

For reducing the energy loss caused by Joule heating in electronic signal circuits, all-optical signal processing circuits are required. As components of the new circuits, optical micro-resonators, which can store light at a certain spot, are necessary. Although various materials such as Silica or $SiNb_3$ are conventionally used [1], single-crystal materials especially CaF_2 could be the most suitable from the perspective of optical properties [2]. For the production of CaF_2 optical micro-resonators, etching is inadequate to obtain bulge-shaped resonators because of crystal anisotropy [3]. To satisfy the requirements of a high form accuracy and a smooth surface, ultra-precision cylindrical turning (UPCT) is the most feasible fabrication process for optical micro-resonators [4]. However, micro-cracks in UPCT of CaF_2, which propagate due to brittleness, deteriorate performance of resonator. Moreover, subsurface damage resulting from UPCT can cause a loss in light absorption and performance degradation. In a previous study, the UPCT performance of CaF_2 has been experimentally investigated to determine the most appropriate cutting condition. When the end face was set as the (100) plane, a smooth surface was obtained [5]. In addition, it was indicated that a tool with a sharper nose radius could make UPCT more stable and reduce subsurface damage [6]. In this study, a tool with a much smaller nose radius was used, and the influence on the subsurface damage was further investigated in terms of nose radius and crystal anisotropy.

Nomenclature

f	feed per revolution [μm/rev]
R	nose radius [mm]
a_p	depth of cut [nm]
γ_0	rake angle [°]
l	tool contact length [μm]

Peer-review under responsibility of the scientific committee of the 3rd CIRP Conference on Surface Integrity (CIRP CSI)
doi:10.1016/j.procir.2016.02.075

2. Experimental setup and procedure

UPCT of CaF_2 was performed by the ultra-precision aspheric surface machine tool (ULG-100E, Toshiba Machine Co., Ltd.). Conical CaF_2 workpieces with small cylindrical tips, 1 mm in diameter and 1 mm in length, with an end face orientation of (100), were prepared by rough cutting the initial workpiece from 6mm in diameter to 1mm. Under the cutting condition shown in Table 1, finish cutting was carried out. The total depth of cut was set as 6 μm to prevent the tilting of workpiece and keep 50 nm actual depth of cut as much as possible. This procedure can prevent influence of rough cutting damage on finish machined surface, too. Fig. 1 and Table 2 show the experimental setup for the UPCT and the specifications for the round nose diamond tools. In a previous work, the cutting performance of tool #1 and tool #2 were investigated. In this study, the cutting performance of Tool #3 was investigated, and the difference in the surface quality was compared. The geometries of these tools were measured by optical microscope and scanning electron microscope (SEM).

In order to investigate the surface roughness with regard to the crystal anisotropy, the entire cylindrical surface after UPCT was observed at 15° intervals. The surface roughness was measured by scanning white light interferometry microscopy. In addition, the cylindrical surface at the end face of (100) corresponds to 90° from the cycle of crystal structure (Fig. 2). The sub-surface damage at 15° intervals was analyzed by field emission transmission electron microscopy (FE-TEM) from point a to point f.

Fig. 1. Experimental setup for ultra-precision cylindrical turning (UPCT) of single-crystal CaF_2

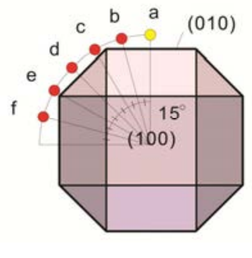

Fig. 2. Observation points on cylindrical turning with end face orientation (100) of CaF_2

Table 1. Finish cutting condition

Cutting speed [m/min]	3.14
Rotational speed [min^{-1}]	1000
Feed per revolution [μm/rev]	0.1
Depth of cut [nm]	50

Table 2. Specification of cutting tool

Diamond tool geometry	Tool #1	Tool #2	Tool #3
Nose radius [mm]	0.2	0.05	0.01
Rake angle [°]	-20	0	0
Cutting edge angle on rake face [°]	90	40	40

3. Results and discussion

3.1. Surface roughness

Figure 3 shows the result of surface roughness Sa on the entire cylindrical surface turned with end face (100). All of the tools showed a surface roughness Sa of less than 3 nm at 15° intervals, and it did not change significantly. In a previous study, where UPCT of CaF_2 with the end face (100) was performed, it was indicated that the surface roughness did not change significantly because the symmetric crystal structure, along with the cutting direction, advantageously distributes the cutting force towards the cleavage plane, which usually causes crack initiation [6]. Even though the sharper tool #3 was used, cleavage was prevented because of the same principle, and there was not such a big difference among the three tools. Here, after UPCT, no wear on the tools was observed by SEM.

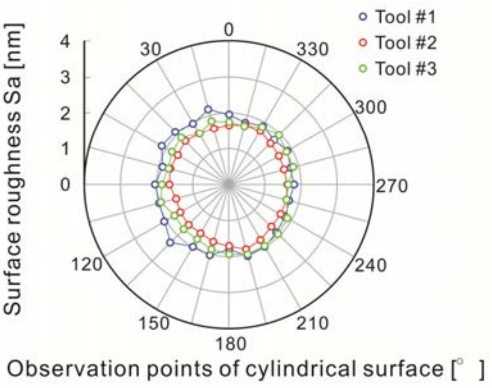

Fig. 3. Surface roughness Sa on the turned surface with end face (100)

3.2. Subsurface damage

Figure 4 (a) shows the TEM micrograph of the machined surface at point (c). To analyze the subsurface damage, fast Fourier transform (FFT) analyses of the TEM images were performed, as shown in Fig. 4 (b). FFT images show that 2 types of material layers exist beneath the machined surface.