euspen's 21st International Conference & Exhibition, Copenhagen, DK, June 2021
www.euspen.eu

# Control of straight laser induced periodic surface structures on aluminium alloy by ultraprecision cutting

Kosuke Oike [1], Shuhei Kodama [1], Keiichi Nakamoto [1], Yoshimi Takeuchi [2]

[1] *Tokyo University of Agriculture and Technology, Japan*
[2] *Chubu University, Japan*

*nakamoto@cc.tuat.ac.jp*

**Abstract**

Laser induced periodic surface structure (LIPSS) is one of surface nanostructures fabricated by irradiating laser to the material surface. LIPSS can produce functionalities such as reduction of friction, anti-reflection, wettability and biocompatibility. However, there are some problems in terms of the fabrication caused by low repeatability and difficult shape control. A surface unevenness divides the incident light of laser into the scattered light and plasma wave. Therefore, the material surface shape before laser irradiation is an important factor for the fabrication of LIPSS. Additionally, it has been reported that the control of original surface shape is effective to control the fabricated LIPSS on nickel-phosphorus. Thus, this study aims at the fabrication of LIPSS with high straightness based on the use of V microgrooves by ultraprecision cutting at material surface before laser irradiation. In the proposed method, it is required to reveal the suitable groove pitch and depth to fabricate the straight LIPSS by creating several microgrooves with different pitches and depths. By assuming that the phenomenon changes depending on materials, the fabricated LIPSS on aluminium alloy is compared to the LIPSS on nickel-phosphorus in the previous study. In the conducted experiments, straight LIPSS is fabricated on the aluminium alloy surface with V microgrooves of 2 µm depth and 10 µm pitch. Since straight LIPSS is fabricated on the nickel-phosphorus surface with V microgrooves of 1 µm depth and 10 µm pitch, it is found that deep V microgrooves are required to fabricate straight LIPSS on the aluminium alloy surface.

Laser induced periodic surface structures, Ultraprecision cutting, V grooves, Surface functionality

## 1. Introduction

In recent years, the demands to reduce energy consumption and to improve functionalities have been increased for mechanical parts. Fine structures on material surfaces have been studied because they perform various functionalities such as reduction in friction, anti-reflection, control of wettability, and improvement of biocompatibility. laser induced periodic surface structure (LIPSS) is surface nanostructures fabricated by a short-pulsed laser on a material surface. Fabrication of nanostructures with a short-pulsed laser has some advantages. For example, a short-pulsed laser can machine metals in the single process, applying to a large area and three-dimensional shapes. However, it is difficult to control fine structures with a short-pulsed laser, because the principles and the phenomena have not been completely clarified.

There are a few reports that the surface shape before irradiating laser would have possibility to control the fabricated LIPSS. Straight LIPSS is fabricated on the nickel-phosphorus surface with straight V microgrooves created by ultraprecision cutting in the previous study [1]. However, the suitable groove pitch and depth are not investigated to fabricate LIPSS with high straightness and high aspect ratio (the height of LIPSS divided by the pitch length of those), and material effects have not been clarified. Thus, in this study, straight V microgrooves are created by changing the pitch and the depth on the aluminium alloy surface to investigate the effects of V microgroove specifications. By assuming that the phenomena depend on materials, the fabricated LIPSS on the aluminium alloy surface is compared to the LIPSS on the nickel-phosphorus surface.

## 2. Experimental setup

Figure 1 illustrates a 5-axis control ultraprecision machining center ROBONANO α-0iB (FANUC corp.) used to create straight V microgrooves. The machining center consists of three translational axes (X, Y and Z) and two rotational axes (B and C). The resolution of the translational and the rotational axes are 1 nm and 0.00001 degrees, respectively. Straight V microgrooves are created by using a single crystalline diamond tool with the nose angle of 90° shown in Fig. 2. In this study, the cutting tool is set up on the B table and a workpiece is located on the C table.

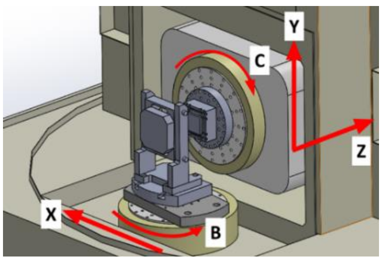



**Figure 1.** Machine structure of ultraprecision machining center

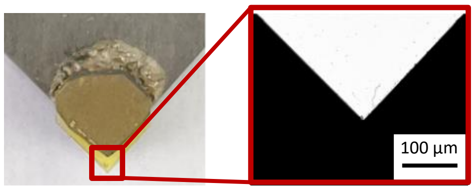



**Figure 2.** Single crystal diamond tool with the nose angle of 90°

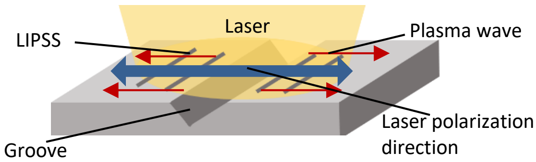



**Figure 3.** Schematic of fabrication of straight LIPSS

**Table 1** Cutting conditions

| | |
|---|---|
| Tool material | Single crystal diamond |
| Nose angle | 90° |
| Workpiece material | Aluminium alloy (A5052) |
| Depth of cut | 1, 2 µm |
| Cutting speed | 40 mm/min |

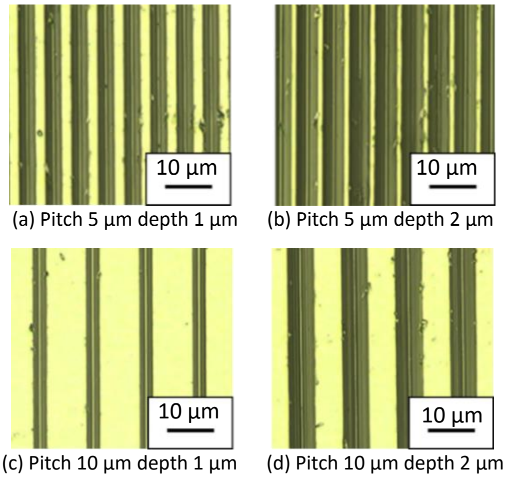
## 3. Surface shape before Laser irradiation

LIPSS is fabricated through the surface plasmons, induced by interference between incident light of laser and surface plasma waves [2]. Surface roughness divides incident light into the scattered light and plasma waves which are propagated parallel to the laser polarization direction. Therefore, the surface shape before laser irradiation is a key factor to control the fabricated LIPSS. In order to control LIPSS, ultraprecision cutting is employed to create an optional surface shape before irradiating a short-pulsed laser because ultraprecision cutting can create microshapes with high accuracy. Figure 3 illustrates the schematic of the fabrication of straight LIPSS. The Laser polarization direction is perpendicular to straight V microgrooves in this study. Therefore, surface plasma waves are generated perpendicular to the straight V microgrooves. As a result, the LIPSS is fabricated parallel to the created straight V microgrooves. Straight V microgrooves induce and propagate surface plasma waves periodically and linearly. The LIPSS would be distorted at the area far from microgrooves due to the attenuation of surface plasma waves. Therefore, straight V microgrooves are created by changing the pitch and the depth to investigate the effect of V microgroove specifications.

## 4. Machining experiment and result

Cutting conditions for creating straight V microgrooves are listed in Table 1. The depth of cut is set to 1 and 2 µm that are equal to the groove depths. The groove pitch is also set to 5 and 10 µm to investigate the differences in the fabricated LIPSS. Figure 4 shows laser microscope images of the created straight V microgrooves on a flat plate of aluminium alloy. Then, the laser with the number of irradiation 10-500 and the energy density 0.05-0.30 J/cm$^2$ is irradiated on the flat surface and the surface with the V microgrooves to fabricate LIPSS.

Table2 summarizes the average of groove pitch and depth and measured by the three-dimensional measurement of a confocal laser microscope. From the results, groove pitch and depth are realized precisely. SEM images of the fabricated LIPSS on the surface with the created microgrooves are shown in Fig. 5. Figure 5(a) shows the fabricated LIPSS on the flat surface. From this figure, it is found that LIPSS fabricated on the flat surface is curved and distorted in different directions. On the other hand, LIPSS is fabricated parallel to straight V microgrooves in Fig. 5(e), that is, the V microgrooves created with 2 µm depth and 10 µm pitch can fabricate straight LIPSS in the same direction. In case the groove depth is 1 µm or the pitch is 10 µm, straight LIPSS is not fabricated. Since straight LIPSS is fabricated on the nickel-phosphorus surface with V microgrooves of 1 µm depth and 10 µm pitch, it is found that deep V microgrooves are required to fabricate straight LIPSS on the aluminium alloy surface. Additionally, from the experimental results, it is recognized that the short-pitch V microgrooves might disturb the fabrication of straight LIPSS.



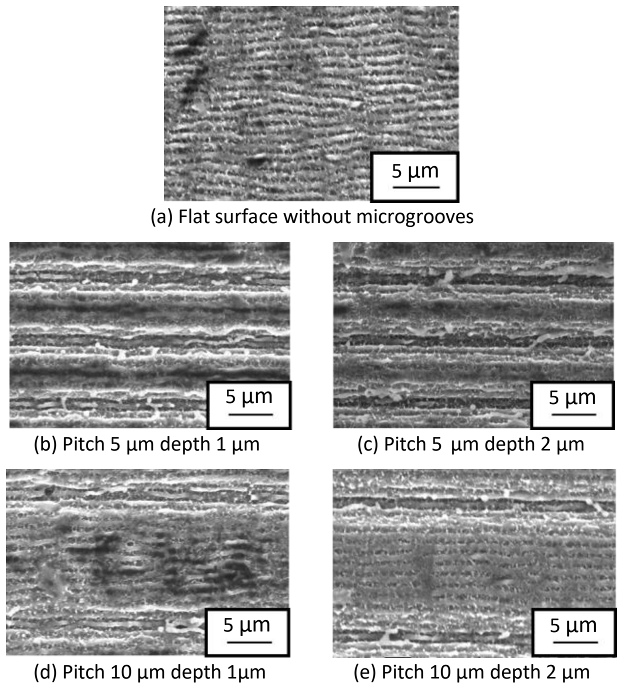

(a) Pitch 5 µm depth 1 µm (b) Pitch 5 µm depth 2 µm

(c) Pitch 10 µm depth 1 µm (d) Pitch 10 µm depth 2 µm

**Figure 4.** Microscopic images of created straight V microgrooves

**Table 2** Measurement results of created straight V microgrooves

| | Measured | Standard deviation | Targeted |
|---|---|---|---|
| Groove pitch | 5.005 µm | 0.029 µm | 5.000 µm |
| | 9.997 µm | 0.016 µm | 10.000 µm |
| Groove depth | 1.044 µm | 0.133 µm | 1.000 µm |
| | 1.923 µm | 0.026 µm | 2.000 µm |




(a) Flat surface without microgrooves

(b) Pitch 5 µm depth 1 µm (c) Pitch 5 µm depth 2 µm

(d) Pitch 10 µm depth 1µm (e) Pitch 10 µm depth 2 µm

**Figure 5.** LIPSS fabricated on Aluminium alloy with microgrooves

## 5. Conclusion

Straight LIPSS is fabricated on the aluminium alloy surface with V microgrooves of 2 µm depth and 10 µm pitch. From the experimental results, the deep straight V microgrooves with long pitch is effective to fabricate straight LIPSS on the aluminium alloy surface.

## References

[1] Kodama S, Suzuki S, Hayashibe K, Shimada K, Mizutani M and Kuriyagawa T 2019 Control of Short-Pulsed Laser Induced Periodic Surface Structures with Machining -Picosecond Laser Micro/Nanotexturing with Ultraprecision Cutting-, *Precision Engineering,* **55** 433-438

[2] Sakabe S, Hashida M, Tokita S, Namba S and Okamuro K 2009 Mechanism for self-formation of periodic grating structures on a metal surface by a femtosecond laser pulse, *Physical Review B,* **79** 1-4