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Fabrication process of slicing mirror for hyperspectral imaging and its performance evaluation

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Abstract
In this study, we fabricated a 5-channel slicing mirror for hyperspectral imaging and evaluated its optical performance. The mirror consists of 5 mirror facets with width of 520 µm and 0.4 degree tilt angle from the neighbour channel facet. The facets are manufactured by a shaper cutting process with a single crystal diamond tool using an ultraprecision machine tool. This method is suitable for manufacturing increasing number of channels in a short processing time. An electroless-plated amorphous nickel phosphorus layer deposited on an aluminium alloy substrate is used for the fabrication experiment. After a flat turning process by R-shape diamond tool, the 5ch mirror facet is formed by shaper cut process using a trapezoid single crystal diamond cutting tool with width of 120 µm, angles of both cutting edges 45 degree and rake angle of 0 degree. Feed rate of shaper cutting tool was 100 mm/min with depth of cut of 2 µm. Surface roughness measured by scanning white-light interferometry reach 6.2 nm Rq. and 32.5 nm Rz. The flatness of the facet in the longitudinal direction measured is 19.5 nm r.m.s. and 117 nm P-V. Spatial resolution of acquired images has been measured and its error factors affected edge eating by tool interference and diffraction effect of cutting tool marks has been discussed.

Keywords: Ultraprecision cutting, hyperspectral imaging, slicing mirror

1. Introduction

Hyperspectral imaging techniques is a technology for obtaining both spatial and spectral information from objects. It is utilized in many application fields such as remote sensing, food inspection, clinical diagnosis and astronomy. A snapshot hyperspectral imaging enables a real time observation of dynamic phenomena in high frame rate. In our previous study [1], an optical system for snapshot hyperspectral imaging was proposed and demonstrated, which is called spectral slicer (SS). The SS is a very simple optical component which consists of a slicing mirror and 4f-relaying lens system. Using the optical design, the number of spectral channels can be increased by simply increasing the number of facets of the slice mirror.

In this study we describe a fabrication process of the 5-channel slicing mirror we manufactured for snapshot hyperspectral imaging and discuss the configuration of fabrication error and its effect to image quality.

2.Experiment

2.1. Fabrication process

Figure 1 depicts a design of the 5-facet slicing mirror and its fabrication process. The slicing mirror consists of a series of consecutive rectangular mirror facets which size is 2 mm long and 520 µm wide respectively. Each facet is allocated in 0.4 degree different tilt angle from the neighbour facet. To attain surface roughness suitable for visible light use, ultraprecision cutting process has been adopted using an ultraprecision machine tool ULG-100A (Toshiba machine Co., Ltd) which is equipped with double V roller guides and 1 nm laser scales. A shaper cutting is applied to form the slicing mirror facets using a trapezoid-shaped single point diamond tool with 120 µm nose tip width, 45 degree cutting edge angle on both sides and 0 degree rake angle. This method is suitable for manufacturing increasing number of channels in a short processing time.

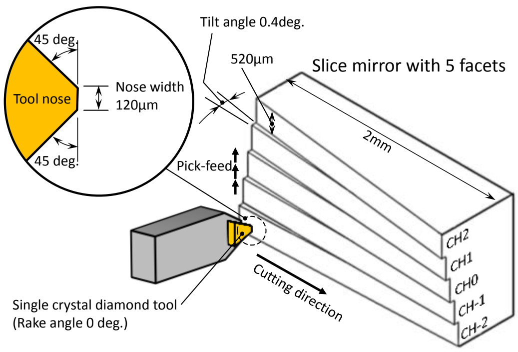
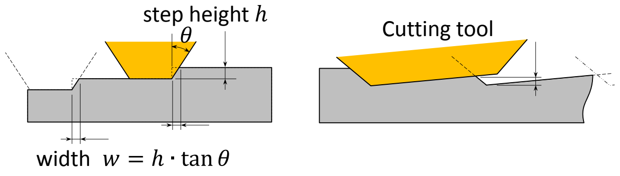


Figure 1. Dimensions and ultraprecision cutting configuration of a 5-channel slicing mirror.

Since a design of the tool is not ideal, two type of form error are caused by geometry of a cutting tool (Figure 2). One is tool interference and the other is cutting tool marks. Tool interference is generated on the edge between 2 neighbour facets. The interfered area depends on cutting edge angle of the tool and step height between facets. In the configuration, the 6.98 µm step height h and 45 degree cutting edge angle θ leads the maximum interfered width is 6.98 µm. Affected area is rather small, approximately 1.4% of each facets. On the other hand, amplitude of tool marks is depends on tool setting and machining conditions. It is discussed quantitatively in next subsection.



(a) Interference between facets (b) Tool mark between cutting path

Figure 2. Form errors caused by geometry of a cutting tool.

2.2. Ultraprecision cutting and measurement

Ultraprecision cutting experiment has been performed (Figure 3). An electroless-plated amorphous nickel phosphorus layer deposited on aluminium substrate is used for a workpiece. The depth of cut is 2 µm. The feed speed of shaper cutting is 100 mm/min. 5 cutting paths with 100 µm pick feed length are applied for generation of each facet. A result of profile measurement by a laser point autofocus sensor show that 5 facets of slicing mirror have been formed successfully (Figure 4). Flatness in cutting direction of a centre facet (Ch0) is 117.47nm P-V, 19.53nm r.m.s.

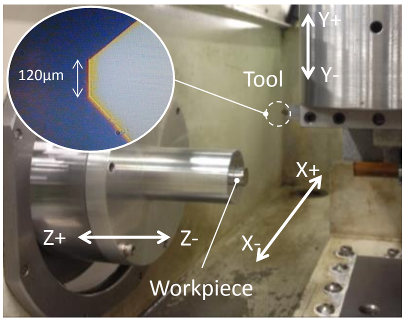


Figure 3. Setup of an ultraprecision machine tool.

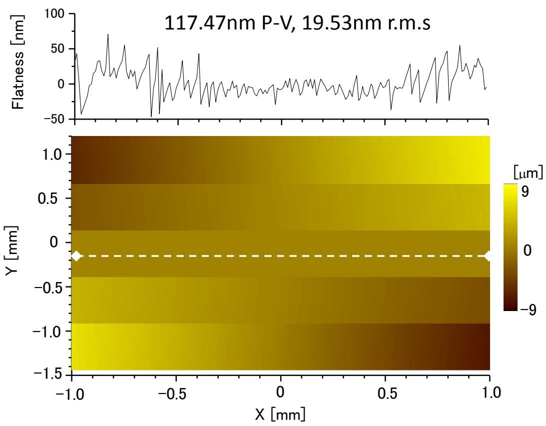


Figure 4. Measured surface shape and its longitudinal profile.

Surface roughness is measured by scanning white light interferometer. Areal roughness is 50.7 nm Sz, 6.57 nm Sq and profile roughness is 32.5nm Rz, 6.21 nm Rq (Figure 5). Figure 6 shows the photo of fabricated workpiece and transversal profile. Although step heights between each facet proved coincident with the designed shape, a sawtooth profile with 0.3 µm high has been observed in every facet. The sawtooth profile is caused by tool mark depicted in Figure 2(b). Angle of tool misalignment calculated from the result is supposed to be 0.17 degree. A height of the tool mark can be diminished by correction cutting using a result of a prior cutting and measurement procedure.

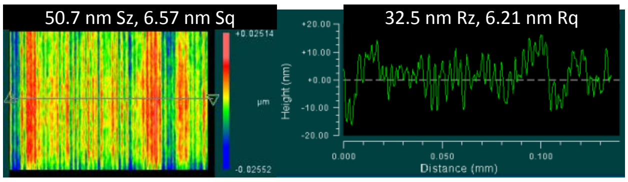


Figure 5. Surface roughness measured by scanning white light interferometer.

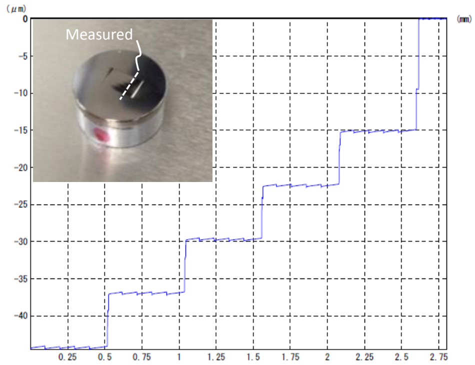


Figure 6. Photograph and transversal profile of the fabricated mirror.

3. Optical evaluation

An optical evaluation experiment of fabricated mirror is carried out (Figure 7). Figure 7 (right) shows images of crosshair target located on position of sample sliced from each facet of slicing mirror facets. The result reveals the image resolution is 25.4 pixels. It attains enough acceptable image quality for hyper spectral imaging observation. A diffraction effect derived from 100 µm pitch tool marks affect negligibly small to the image quality in the optical system.

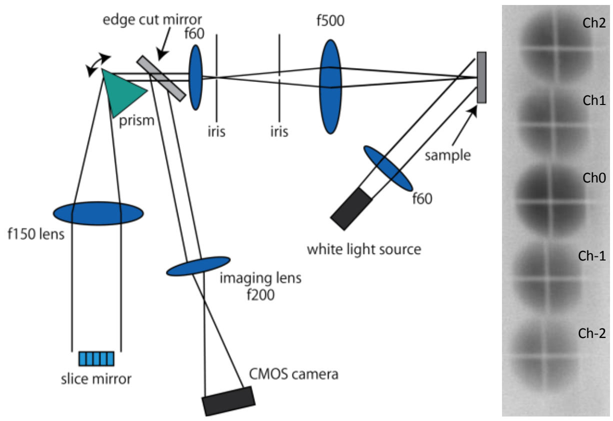


Figure 7. Layout (left) and acquired images (right) for optical evaluation.

4. Conclusion

A fabrication process of the 5-channel slicing mirror for snapshot hyperspectral imaging using ultraprecision cutting has been developed. Fabrication error and its effect to image quality have been measured and discussed.

References

[1] Tamamitsu M, Kitagawa Y, Nakagawa K, Horisaki R, Oishi Y, Morita S, Yamagata Y, Motohara K and Goda K 2015 *Opt. Eng.* **54** (12) 123115