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Tool wear monitoring in single-point diamond turning using laser scattering from machined workpiece

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ABSTRACT

In ultra-precision machining, diamond turning is widely applied for optical components and die cores. When operating diamond turning, the tool wear is among the most significant concerns, which causes the deterioration of machining quality and the waste of material and time. The tool wear is unable to be assessed by naked eyes, a tedious off line measurement is employed for evaluating the tool wear. In this paper, an optical method using laser-light scattering to evaluate the tool wear is proposed for maintaining the machining quality and determining the appropriate timing for tool change while manufacturing light guide plate. In this optical method, the progress of the tool wear of nose radius is monitored by the scattered light beams from the machined surface. The incident angle between 20 and 30 degrees is found to provide the best results for monitoring the tool wear.
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Introduction

In modern industry, diamond tools for ultra-precision machining produce high-quality optical components. To implement the automated processes and to meet the quality requirements, the diamond tool wear is in serious need to be properly assessed. The tool wears condition-monitoring technique by using laser light attracted both the academic and industrial attention since years. The light beam of laser can be described as a Bessel beam [1], and Mcgloin and Dholakia further provided the characteristics of the Bessel beam [2]. The laser could be used to judge tool wear by reconstructing the actual tool geometry. Giusti et al. [3] introduced a sensor-based TV image analysis method of a worn tool and showed that laser could be used to monitoring tool wear. Also, Jurkovic et al. [4] proposed a measuring procedure by CCD image processing. Their research confirmed that laser can also be used to detect the profile of diamond tool surface. Later, Khajornrungruang et al. [5] monitored the cutting-edge by far-field laser diffraction, showing that tool wear could be measured by analyzing laser signal. Alternatively, laser light can also be used to evaluate a surface. Whitley et al. [6] established the relationship between specular reflection and the surface roughness. Shahabi and Ratnam [7,8] proposed an in-cycle surface roughness monitoring method in use of CCD camera, which showed that the information about the machined surface of the workpiece was obtained and related to the tool image of CCD. Fan and Huyna adopted Beckmann scalar model to study scattering light [9]. A modified reflection theory of rough surface was proposed [10] and the scatter light was used to monitor surface roughness [11]. Scientists tried to use a sensor to detect the scattering light from rough surface [12]. Moreover, various models were discussed to examine the relation between the surface roughness and the scattering light [13]. In this paper, a new laser monitoring method was proposed to monitor the tool wear while manufacturing the die of light guide plate. The die is electroless nickel-plated steel and the surface structure is manufactured on the coating. Since the surface structure of the die is a series of V-cuts machined by a V-shape single crystal diamond tool as shown in Figs. 1 and 2, the tool wear will cause the shape of V-cut changes. The author made a series of workpieces represent the dies machined by a tool with different nose radius and used a laser to irradiate those workpieces. By detecting the intensity of scattering light from the workpiece and measuring the nose radius of the diamond tool, a correlation between scattering intensity and nose radius was found. The scattering intensity varies with the rounded corner of the V-cut on workpiece resulted from the dulled nose of

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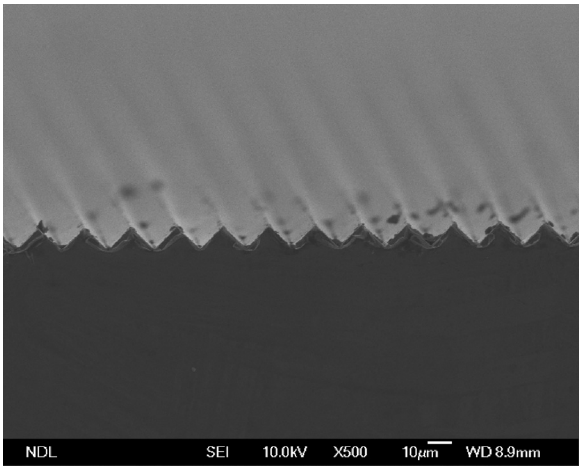

Fig. 1. Surface structure of the die.

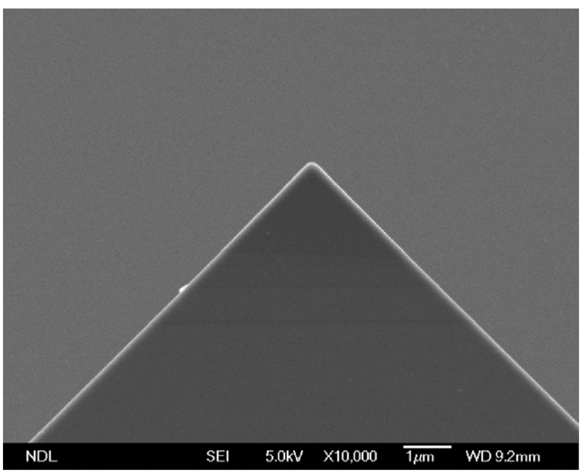

Fig. 2. Diamond tool.

the diamond tool. The tool life in machining of the precise V-shaped microstructure on the workpiece can be told.

Theoretical analysis

In this study, the authors apply the laser-light scattering to monitor the tool wear. In industrial practice, the geometric shape of the workpiece features is varied as the tool wear happens. Moreover, while using single crystal diamond turning, the workpiece will copy the tool's tip profile. In the current study, the V-shape microstructure of the workpiece is formed by the diamond tool with a sharp nose of 90-degree angle. As Figs. 3–8 shown, a series of the workpieces and the tool tip with progressively increased nose radius along with the machining length.

The surface roughness of mold of the light guide plane, an ultra-precision optical component, must be less than $R_a = 20$. Since the wavelength of He-Ne laser is 630 nm, the laser can be considered as specular reflection on the surface. As Fig. 9 shown, the incident light from the right reflected by the perfect 90°s v-cut will exit toward the right. When tool wear happened, the nose radius increased and the tip of the V-cut will became a quarter round. As Fig. 10 shown, being reflected several times at the round corner, the laser will exit from different direction and become stray light. While tool nose radius increase, more beams became stray light. A sensor located in appropriate place can gather the stray light and the radius of tool nose can be calculated. As Fig. 11 shown, for incident angle

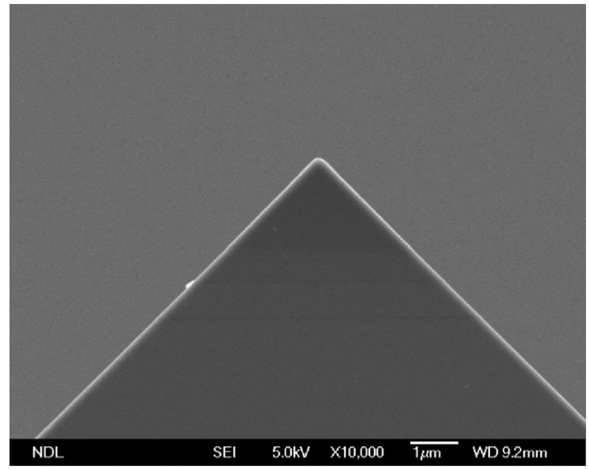

Fig. 3. New tool.

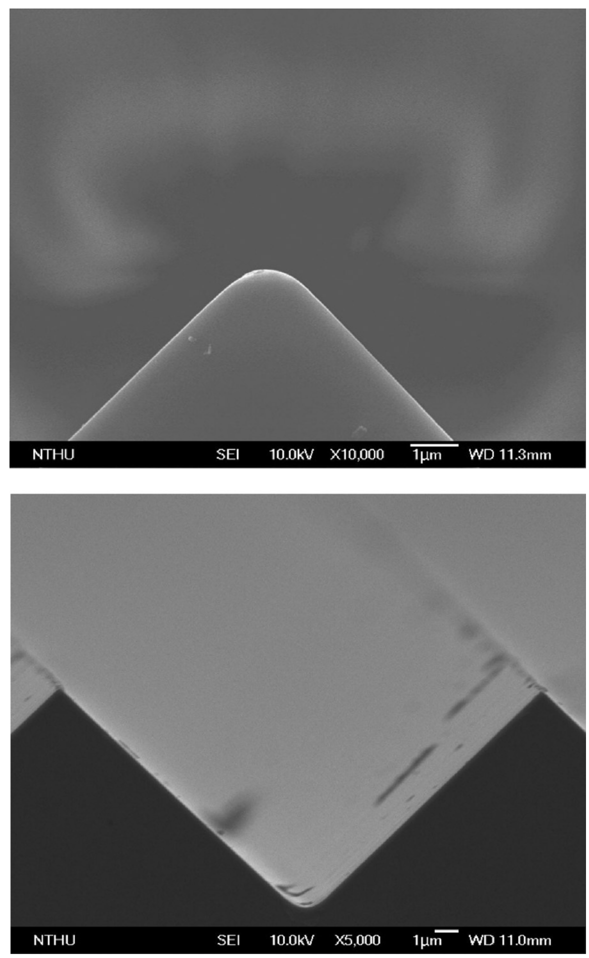

Fig. 4. Tool nose at 6km cutting length and machined workpiece at 6km cutting length.

larger than 45 degrees, the laser beam cannot reach the valley and shadow occurs. Consequently, the tool wear will not cause stray light and cannot be detected. Since the size of V-cut does not affect the reflection pattern, it will not affect the monitoring method. However, the angle of V-cut will change the reflection pattern. Reconsidering the reflection mode is needed once the angle of V-cut is changed. Moreover, the proposed principle of analysis lies in the geometrical relationship between the scattered light inten-

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