



Study on the double-sided grinding of sapphire substrates with the trajectory method

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ABSTRACT

Trajectory distributions on the workpiece surface, which are decided by the relative movement between workpiece and abrasive grit in the double-sided planetary grinding process, play an important role in workpiece surface quality, especially uniformity. To improve the uniformity of the workpiece surface during double-sided planetary grinding, the relative movement between workpiece and abrasive grit was analyzed, and a mathematical model was established on the basis of the double-sided planetary grinding machine. Then, the trajectories left on the workpiece surface by abrasive grits were simulated with the help of MATLAB software. The workpiece surface was divided into many equal areas, and trajectory dots in each area were counted; then, its variation coefficient of standard deviation (VCSD) was calculated to indicate the surface uniformity directly. Simulation results showed that the grinding wheel speed had a significant influence on the uniformity of the workpiece surface. Some experiments were performed on the double-sided planetary grinding machine with sapphire wafers. The uniformity of the sapphire wafer surface was indirectly represented by the non-uniformity coefficient of surface roughness (Ra) and total thickness variation (TTV). The experimental results have good consistency with simulation results, validating the reliability of the simulation results.

1. Introduction

Double-sided planetary grinding is well known as the popular precision technology for metal slice parts such as the tool and bearing industry because of its high efficiency and stability. At present, with the rapid development of the optoelectronic industry, the demand for hard and brittle material slices for Light Emitting Diode (LED) substrates and mobile phone screens has been sharply increasing [1], and with the increase in workpiece diameter, there is a much higher requirement for planarization, uniformity and controllability during processing. Traditionally, the free abrasive lapping was used for substrate lapping to remove wire cut marks that were left in the wire cutting process, increasing surface accuracy and decreasing surface flatness. Due to the random distribution and uncontrollable trajectory of the grits in free abrasive lapping in addition to low efficiency and environmental pollution problems, fixed abrasive lapping was suggested instead of free abrasive lapping. Currently, fixed abrasive pads are being widely studied for fixed abrasive tools that were difficult to dress and reuse. On this basis, we try to use a large size for grinding wheels that could easily be dressed for abrasive tools. In addition, several pieces of large

sapphire substrates could be lapped simultaneously in a short processing time when double-sided planetary grinding is used instead of traditional lapping. Double-sided planetary grinding can perfectly match the needs of industrial development. Therefore, we attempt to put double-sided planetary grinding into substrate grinding [2]. The uniformity of abrasive trajectories left on the substrate surface has a strong impact on substrate surface qualities such as TTV and roughness because of a short processing [3].

Kinematics and trajectory analysis based on the relative movement between workpiece and abrasive grit were widely used to analyze workpiece surface uniformity, and many valuable results were obtained. Hocheng [4] attempted to investigate the effect of kinematics on uniformity in chemical mechanical planarization and found that the relative velocity was not constant. Kim [5] further revealed that the non-uniformity of the substrate was greatly influenced by the basic kinematic parameters. However, the results above were obtained during free abrasive lapping. As the obvious disadvantage of the free abrasive lapping, Uhimann [6] started to investigate fixed abrasive trajectory, which indicated that the workpiece surface flatness and roughness were heavily influenced by the abrasive trajectory. Research

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on fixed abrasive lapping was carried out according to abrasive trajectory analysis to obtain a more uniform trajectory distribution in single-sided lapping, mainly for two purposes: one for designing abrasive tools and another for optimizing the machining parameters [7–13]. From the aspect of machine parameter optimization, the research results demonstrate that the speed ratio has an important effect on the uniformity of the workpiece surface. However, current research studies were mainly carried out during one-sided lapping and with one workpiece [14–16]. However, double-sided planetary lapping has more multidirectional movement than one-sided lapping. Yang [17–23] established a trajectory equation to make the trajectory distribution uniform by optimizing machining parameters during double-sided planetary lapping. Ku [24] developed the velocity and acceleration equations and then developed a curvature equation to discuss the influence of parameters with the size of the curvature during double-sided planetary polishing. Jin [25] used the moment balance principle to study the effect of parameters on the trajectory by force analysis. However, these studies were also focused on free abrasive lapping or polishing, and mainly established the motion model based on single abrasive grit rather than multi-grits. Some experimental research studies on double-sided lapping with fixed abrasive pads were carried out in recent years. John [26] achieved a sapphire surface of low stress and R_a by using fixed abrasive pads, which were produced by 3 M, USA. Kim [27] studied the sapphire removal rate using the same fixed abrasive pads and determined the influence factor for the material removal rate. The experimental results cited above were not explained on the theoretical level, and the internal relationship between trajectory distribution and workpiece surface quality had not been revealed in previous studies. However, a relatively accurate calculation result can be obtained from fixed abrasive double-sided planetary lapping because of the controllability of the fixed abrasive, which can guide the improvement of the uniformity of the workpiece surface.

Based on the above analysis, in this paper, the relative movement between workpiece and abrasive grits was analyzed, and a mathematical model was established based on the Peter Wolters AC700 grinding machine. The abrasive trajectories at different wheel speeds were simulated with MATLAB software to evaluate the uniformity of the workpiece surface, and the differences in the trajectory distribution on both sides of the workpiece were revealed. Some experiments were carried out with a sapphire substrate to verify the simulation results.

2. Kinematic model of abrasive trajectories left on the workpiece surface

A kinematic model was established on the basis of the double-sided

planetary grinding movement. The double-sided planetary grinding equipment structure is shown in Fig. 1, which consists mainly of an upper and lower plate as well as the sun wheel that rotates around the respective axis. The workpieces are placed in planetary wheels that are driven by the sun wheel and the fixed gear ring. Therefore, according to the orbit around the sun wheel center and revolution around its own center, the workpieces obtained synthesis rotation. The kinematic diagram is shown in Fig. 2. System processing pressure is obtained from the upper plate by air cylinder.

A fixed coordinate system $X_1O_1Y_1$ is located at the center of the lower plate, and a workpiece coordinate system $X_2O_2Y_2$ is fixed at the center of the planetary wheel. Point P is regarded as a fixed grit on the lower plate. The distance from point P to the center of the sun wheel is R_p , and the initial angle of point P is ϕ . L is the distance from O_1 to O_2 . The sun wheel rotates at speed ω_1 . The lower plate rotates at a speed of ω_2 . The planetary wheel revolves around its own center at a speed of ω_3 and orbits around the center of the sun wheel at a speed of ω_H . After t seconds, the fixed grit P is moved from P to P' . At the same time, the sun wheel rotates at an angle of θ_1 , the lower wheel rotates at an angle of θ_2 , and the planetary wheel rotates at an angle of θ_3 around its own center and orbits at an angle of θ_H around the center of the sun wheel. Z_1 , Z_2 , and Z_3 are used to represent the number of teeth of the sun wheel, the planetary wheel and the fixed ring, respectively, which are fixed values for the grinding machine.

The coordinate of point P' in the coordinate system $X_1O_1Y_1$ could be described as follows:

$$\begin{cases} x_{p'} = R_p \cos(\theta_2 + \phi) \\ y_{p'} = R_p \sin(\theta_2 + \phi) \end{cases} \quad (1)$$

To obtain the abrasive trajectory on the workpiece, the planetary wheel is regarded as stationary. According to the relative movement between the lower plate and the planetary wheel, the lower plate should first be rotated at an angle of $-\theta_H$ and then rotated at an angle of $-\theta_3$ around O_2 .

A bivector (x, y) can be represented by a three-dimensional vector $(x, y, 1)$ by homogeneous coordinate representation. Geometry can be interpreted as meaning a point on the plane, and the third dimension of the plane is 1. The coordinate of point P' in the coordinate system $X_2O_2Y_2$ could be obtained by homogeneous coordinate transformation, which can be written as follows:

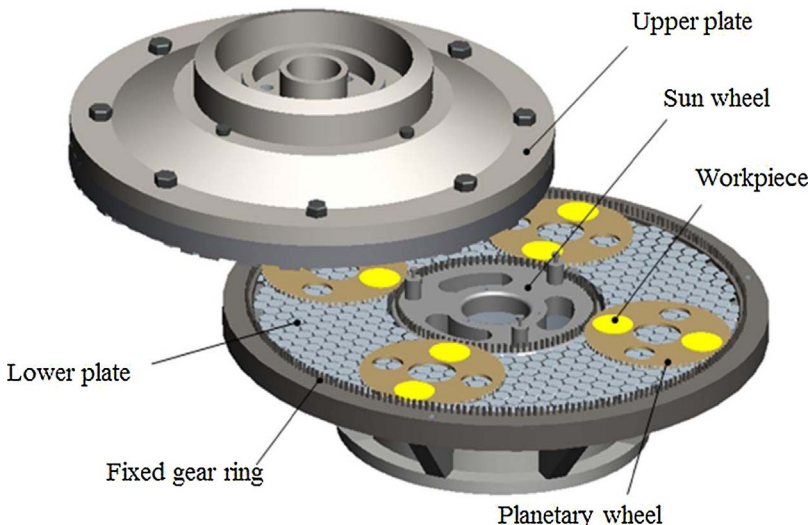


Fig. 1. The schematic diagram of double-sided planetary grinding.

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