A Novel Method for the Design and Ultra-precision Machining of the Hybrid Optical Surface of Single BD/CBHD Compatible Objective Lens

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Abstract

A novel design and production of hybrid optical surface used in single BD/CBHD compatible objective lens is presented. The hybrid surface contains both diffractive and aspherical optical structures which are generated by single point diamond turning of optical grade plastics. From optical path analysis, the aberration of the focal spot generated by the objective lens is evaluated. The results are used to revise the aspherical coefficient of the hybrid surface so as to compensate for the optical deviation caused by stringent requirement on the radius and angle of the diamond tools used in diamond turning to produce an optical surface with nanometric accuracy.

1 Instruction

The diffractive-refractive hybrid optical surface has been used to realize the compatibility issue for multi disc formats [1-4] such as Blu-ray Disc (BD) and China Blue High-Definition Disc (CBHD) based on the diffractive optics [5]. In this paper, single objective lens in the optical pick-up was designed with hybrid optical surface which was machined by single point diamond tool. The hybrid optical surface which includes both aspherical surface and diffractive phase structure determines the quality of the focal spot and is used to generate the radio frequency (RF) signal to reproduce the information from the optical disc. Although the optical surface can be designed accurately with powerful optical software, the machining of such surface with nanometric accuracy and the required optical properties is still problematic. The surface relief pattern [6] of the hybrid surface can be evaluated by dimensional measurement. However these findings only reflect the difference between the design profile and the manufactured profile alone and cannot guarantee that the objective lens will work well for both the BD and CBHD format. The data from the optical testing of the focal spot is needed to compensate for the error caused by the stringent requirement in the tool geometry of the diamond tools to reproduce the accuracy and surface finish of the diffractive surfaces to be required in the ideal design.

2 The Design and Manufacture of the Hybrid Surface

A BD/CBHD compatible objective lens which had a diffractive-refractive hybrid optical surface is designed to realize the compatibility, as shown in Figure 1.

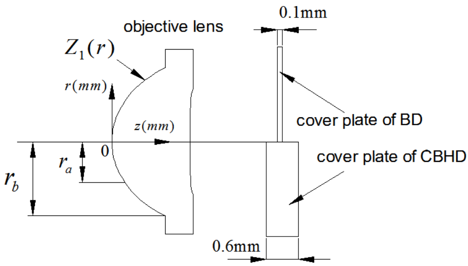


Figure 1: Schematic diagram

In Figure 1, $Z_1(r)$ represents the profile of the hybrid surface along with the distance r from the optical axis z . r_a , r_b stand for the radius of the inner and outer area respectively. $Z_1(r)$ can be described by the Eq. (1) while the other surface of the objective lens is a standard even aspherical surface.

$$\begin{aligned} Z_1(r) = \operatorname{circ}(r-r_a)\Bigg\{ & \frac{c_1 r^2}{1+\sqrt{1-(1+k_1)c_1^2 r^2}} + \sum_{i=1}^{9} a_i r^{2i} \\ & + \frac{\delta\lambda}{n-1}\left[\sum_{j=1}^{5} A_j (r/r_a)^{2j}/2\pi - \operatorname{Int}\left(\sum_{j=1}^{5} A_j (r/r_a)^{2j}/2\pi\right)\right]\Bigg\} \\ & + \left[1-\operatorname{circ}(r-r_a)\right]\operatorname{circ}(r-r_b)\left[\frac{c_2 r^2}{1+\sqrt{1-(1+k_2)c_2^2 r^2}} + \sum_{i=1}^{9} b_i r^{2i}\right] \end{aligned} \quad (1)$$

In Eq. (1), the circle functions [7] $\operatorname{circ}(r-r_a)$ and $\operatorname{circ}(r-r_b)$ are used to define the different radius of the inner and outer area. δ is the coefficient of manufacture depth; c_1, c_2 are the curvatures; k_1, k_2 are the conic coefficients; a_i, b_i, A_j are the sag coefficients of the aspherical surface and phase structure; λ is the wavelength of incident laser beam and n is the refractive index of the objective lens material at λ . After optimization of the parameters in Eq. (1) by using the optical software Zemax

[8], a prototype of the objective lens (Figure 2) was machined by using the 2-axis Ultra-precision Machine (Nanoform 200).

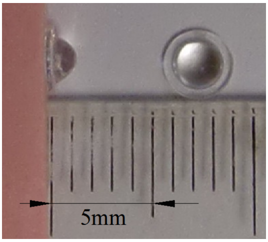


Figure 2: Prototype of objective lens

3 Evaluation and Compensation

As the diamond tool has special radius and angle, the manufactured profile of the hybrid surface has a deviation from the design one, as shown in Figure 3.

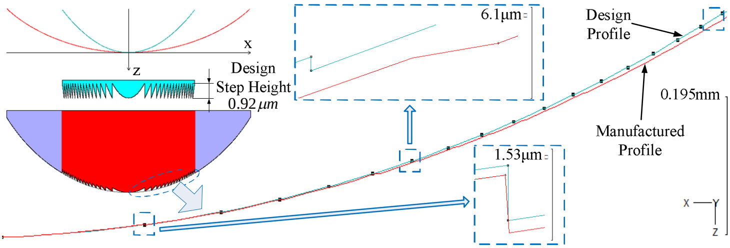


Figure 3: The manufactured and design profiles of the hybrid surface

In Figure 3 the design step height of the diffractive structure is 0.92 microns and the left hand flatted diamond tool with 68 microns radius and 70 degrees included angle is used to machine the objective lens. The objective lens reflects little light and it is difficult to measure the deviation of the manufactured profile by traditional optical profiling instrument. The relationship between manufactured profile and the sag coefficients in Eq. (1) cannot be easily established. Therefore in this paper the aberration of the focal spot generated by objective lens is evaluated, and then the evaluation results of aberrations were used to revise the aspherical coefficient of the optical equations the hybrid surface in order to compensate the manufacture deviation caused by the stringent requirement of radius and angle of the diamond tools.

The implementation procedure of evaluation and compensation of ultra-precision manufacturing is as follows. Firstly, a precision experiment platform is set up to simulate the work environment of objective lens by assembling a blue laser diode of

405nm wavelength and the collimator lens into the mechanical basement of the optical pick-up, while the diverging laser diode beam being transformed into one parallel beam with the collimator lens, the related components are shown in Figure 4.

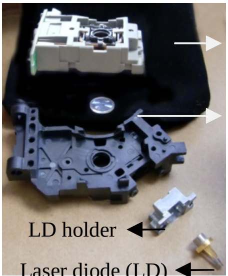


Figure 4: Experiment platform

Secondly, the optical spot analysis instrument (PT-AMS) shown in Figure 5 is used to measure the aberration of the optical read-out spot generated by the objective lens which works in the parallel beam.

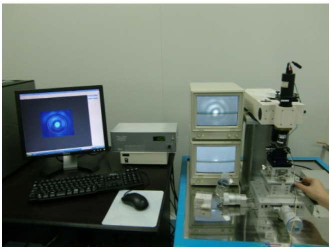
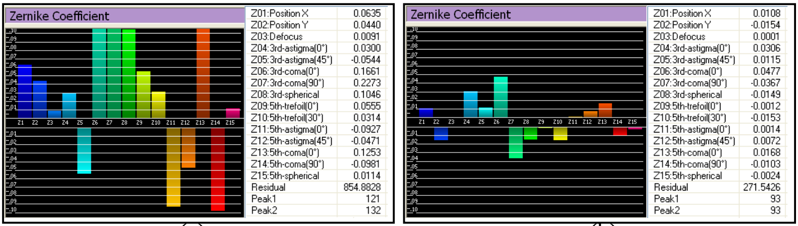


Figure 5: Optical spot analysis instrument

Thirdly, the aspherical surface of hybrid surface is revised with the help of a new added Zernike surface, which brings the measured aberration of focal spot into the focusing beam between the objective lens and optical disk, without changing the parameters of the phase structure. Finally, the objective lens is remachined based on the revised design data, thus the profile deviation can be compensated within the same manufacturing condition that the left hand flatted diamond tool with 68 microns radius and 70 degrees included angle is used to machine the objective lens. The aberration measurement results of the focal spot generated by the original and revised objective lens are shown in Figure 6(a) and 6(b) respectively. It is clear that the aberration caused by the machining error in the revised objective lens has been compensated.



(a) (b)

Figure 6: (a) The Zernike coefficient of the aberration of the focal spot generated by the original objective lens and (b) revised objective lens respectively

4 Conclusion

Based on the analysis of the aberration of the focal spot of the objective lens, a method has been proposed to compensate for the machining error caused by the stringent requirement of the radius and angle of the diamond tools in the profiling of a hybrid optical surface. The method has two advantages. The first one is that it evaluates the effect of manufacturing deviation on the aberration of the focal spot of the objective lens. The second one is that it gives a compensation solution without changing the manufacturing situation, that is to say that the machining error caused by the tool radius and angle could be eliminated at the development stage of the objective lens.

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