Enabling the Production of Aspheric Glass Lenses with Diffractive Structures

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Abstract

The demand for complex-shaped optical components is rising rapidly, driven by their significant advantages over traditional optics. A great example are lenses that combine aspherical surfaces and diffraction gratings. These can eliminate spherical as well as chromatic aberrations in imaging optics and can therefore replace multi-lens optical systems. Although glass aspheric lenses or lenses with diffraction gratings can be manufactured by various production technologies, the production of glass lenses that combine both was not possible until now. In this paper, the development of a production method of such lenses using precision glass moulding is presented.

1 Introduction

Precision glass moulding is a replicative technology, where a glass blank is heated and isothermally pressed to the desired shape between ultra-precision moulds. After the moulding process, no further processing is necessary [1]. Usually, binderless cemented tungsten carbide is precision ground to form the moulding tools, which are then coated with noble metal coatings in order to reduce the chemical interactions with the glass and increase their lifetime [2-3].

In order to manufacture diffractive structures on an aspheric surface, diamond turning must be used, since only this technology enables the production of the very fine and sharp structures required. The problem is that not all materials can be diamond turned. The binderless tungsten carbide usually used is so brittle and hard that the diamond is damaged before the entire mould can be machined. On the other hand, the usual materials that can be diamond turned (Al, NiP, Cr etc.) have insufficient mechanical properties at moulding temperatures of 450°C – 650°C. So, the first challenge was to find a material that has acceptable mechanical properties at pressing temperatures, but is also able to be diamond turned. After testing several materials, the 715 Cu/Ni alloy (Farmer's Copper Ltd.) was selected, as it has enough strength up to 600°C while maintaining its structure with no recrystallisation.

2 Experimetal details

The moulds were machined on a Moore Nanotech 350FG machine. The coatings were deposited using a modified CemeCon CC800/9 sputter coating machine with two DC pulsed cathodes. The moulding was performed on a Toshiba GMP-211V machine. The results were analysed by optical microscopy, white light interferometry using a Veeko NT1100, tactile profilometry using a Taylor Hobson Form Talysurf PGI 1250A, and SEM and EDX measurements using a Zeiss Neon 40 ESD.

3 Coating development

First, the interactions between the mould material and the glass were tested by heating a sample of the material in combination with glass for 24h at 585°C, which is the moulding temperature for the P-SK56 glass. As can be seen in Figure 1, during the stress test the mould material changed colour from metallic silver to grey and the surface roughness deteriorated from 10nm Ra to 830nm Ra, which prohibits its use in optical applications. This change could be attributed to the oxidation of the material, which was verified by EDX. To prevent this oxidation, the mould was coated with a state of the art noble metal coating which is also used for the standard tungsten carbide moulds with a composition of 45% Pt and 55% Ir [4]. The chosen coating thickness was 200nm so that the shape of the diffractive structures would not be significantly affected. A 20nm nickel layer was used to improve the adhesion to the substrate. The glass contact test was repeated, and the results are shown in Figure 1.

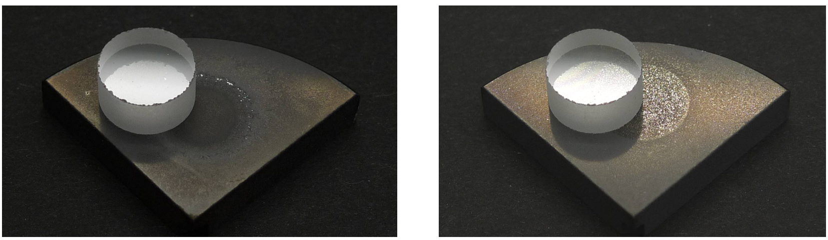
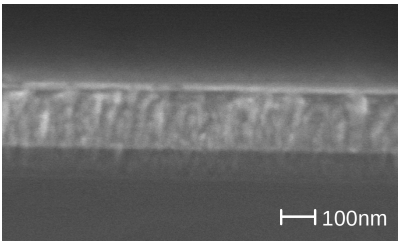


Figure 1: Uncoated (left) and coated mold material after glass contact test

It was verified by EDX that the surface of the mould was still oxidized, despite the noble metal coating, due to the diffusion of metal atoms from the substrate through the coating. The roughness increased as a result to 145nm Ra. To prevent these phenomena, the coating structure was modified to incorporate a diffusion barrier between the substrate and the Pt-Ir top layer. TiAlN was chosen as it is a very dense and stable ceramic material. A 100nm TiAlN layer and suitable thin adhesion layers both to the substrate and to the top coating were co-deposited beneath the same 200nm noble metal top coating (Figure 2). The glass contact test was repeated, with the results shown in Figure 2. This time, neither discoloration nor oxides could be detected on the surface, which also maintained its original 10nm Ra roughness, thus verifying the effectiveness of the TiAlN layer as a diffusion barrier.



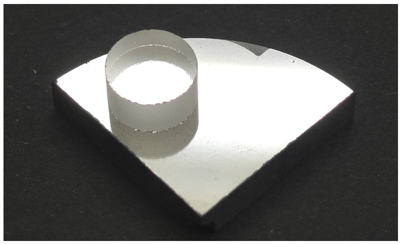
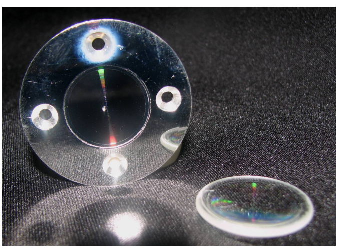


Figure 2: SEM of coating structure (left) and surface after glass contact test (right)

4 Moulding experiments

In order to verify the process under production conditions, a plano-convex, aspheric-diffractive lens with a diameter of 18mm and a thickness of 3mm for use in optical imaging applications was designed. The mould for the lens was produced by diamond turning. The diffractive structure height is about 800nm and is shown in Figure 4.



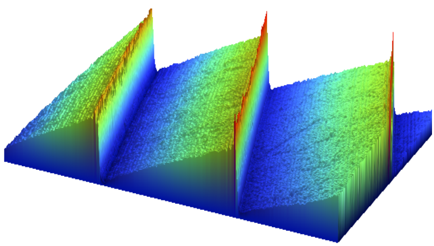


Figure 4: Mould and lens (left); surface topography of lens (right)

In the topographic profile of the lens itself (Figure 4 right), the fine diamond turning topography of the mould is still visible, despite the intermediate multilayer coating and moulding processes. This indicates that the coating does not alter the form of the mould, and that the moulding process is capable of reproducing the original form extremely faithfully. This can also be seen in the tactile profiles of the mould and the lens in Figure 5. It can be seen that their maximum deviation from the designed aspheric form is less than 300nm, while the diffractive structures are fully replicated across the entire diameter of the lens. After 20 moulding cycles, the surface of the mould remained in perfect condition without glass adhesions or discolorations, verifying the effectiveness of the developed coating system.

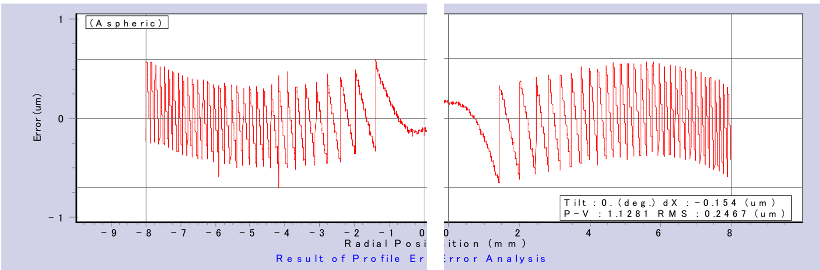


Figure 5: Profile of moulding tool (left) and moulded lens (right)

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