Case Study Applications in Numerical Simulation for Precision Glass Molding Process

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Abstract

In the last few years, a flexible and reliable simulation tool was developed in Fraunhofer IPT for glass molding process. In this work, case study applications are introduced to demonstrate the capabilities of this simulation tool in glass shrinkage prediction and mold design optimization. Most challenging simulation tasks including ultra thin asperical lens, wafer level lens arrays and cylinder lens arrays are introduced and followed with detailed process analysis result. The simulation results present an effective and reliable functionality of the simulation tool which has potential capacity also for diverse industrial applications.

1 Molding process and simulation

In the precision glass molding process, raw glass material is firstly heated to a temperature above its transition temperature (e.g., P-SK57, T_g = 493 °C, forming temperature 550 °C) and subsequently pressed into a lens shape (Fig. 1).

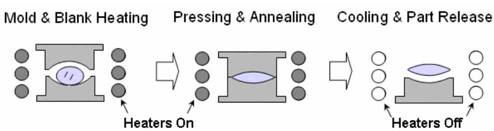

Figure1: Illustration of a molding cycle

In order to achieve preliminary understanding of the molding process, a numerical process simulation was developed at Fraunhofer IPT using commercial Finite Element Method (FEM) software packages like ANSYS™ and ABAQUS™ to predict the form filling behavior and form error on the molded glass lenses even before the initial mold manufacturing. The developed process simulation consists of a thermal model predicting the actual temperature distribution and a mechanical model to predict the viscoelastic deformation and thermal shrinkage of the molded glass lens[1].

Previous results based on specific molding experiments proved that the developed process simulation is capable of predicting the form error and possesses a prediction accuracy of 2 μm[2]. To demonstrate the capabilities of this simulation tool in mold design optimization and glass shrinkage prediction, several case study applications from the actual molding tasks are introduced in detail in the following sections.

2 Process simulation for molding of extra thin aspherical lens

The integrating of the commercial imaging products is surprisingly rapid nowadays, and one of the clear market trends is to integrate both ultra-wide-angle and high zoom ratio into portable cameras. Following this trend, extra thin aspherical lens with high thickness ratio (up to 10:1, see Figure 2) is invented to realize multiple functions in a more compact optical design, together with a faster optical image stabilization system.

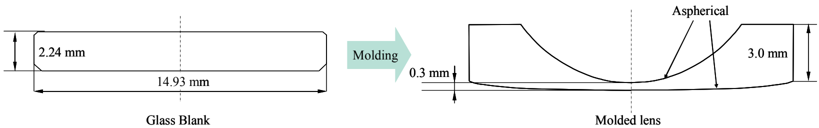

Figure 2: Molding of extra thin aspherical lens with high deformation ratio

The molding of extra thin aspherical lens is a great challenge, due to the large material flow (deformation ratio up to 7.5:1) and the high fracture risk during the molding process, in respect to its special shape with minimum central thickness and both surfaces in aspherical form.

To reduce the experimental effort by developing a suitable molding strategy, FEM simulation in ABAQUS™ was carried out to gain primary understanding on the molding behavior of such lens design. With the help of "ALE adaptive mesh" function supported by ABAQUS™, the form filling process was successfully simulated to identify the glass blank dimension, including chamfer modification to achieve a simultaneous filling at all the corners. A possible solution provided by the simulation is to control the temperature difference between upper and lower molds. Simulation result showed that a slight temperature graduation inside lens (shown in Figure 3) is enough to produces an opposite bending motion against the natural bending behaviour of lens during the cooling phase. Moreover, it offers excellent lens-mold separation, which reduces the risk of clamping at the end of cooling.

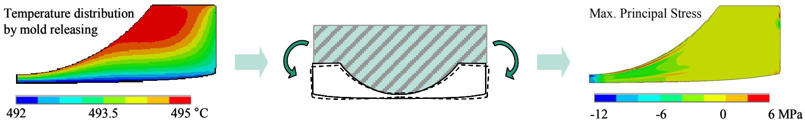

Figure 3: Control of glass deformation by temperature distribution

The reason of clamping (Figure 4) is the mismatch of CTE between glass and mold. It can be avoid by mold opening method. From Table 1, the clamping pressure appears at 270 °C, and significantly increases when the system becomes cooler. Thus the opening mold above 270 °C is recommended.

Figure 4: Clamping at the top circle of lens at the end of cooling

Table 1: Contact pressure at the top circle of lens

Temperature	Contact pressure for shrinkage
>270 °C	0 MPa
270 °C	0.1 Mpa
210 °C	132 Mpa

3 Process simulation for molding of wafer level lens array

Stacking of wafer level lens arrays to build up integrated optical systems is a new and effective approach for mass production of ultra compact image sensor packages. The molding of such lens arrays is a very challenge task due to the extreme expenditure by molding manufacturing and process development. As an effective virtual tool, process simulation was applied to investigate the material flow behavior and thus an optimized mold design for one of such molding task. System concept with wafer level glass lens array and a comparison of simulation results with and without mold design optimization is shown in Figure 5. The first try-out molding based on this result was very successful and a 3 dimensional model for all sections is under construction.

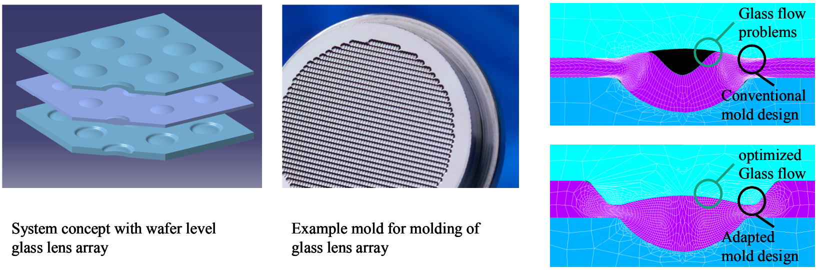

Figure 5: Mold design optimization for molding of wafer level lens array

4 Process simulation for molding of cylinder lens array

A 3D 1/2 mirror model (5×4×1mm) is built for analyzing lens array molding, where 5 pitchs are defined to evaluate the form error (Figure 6).

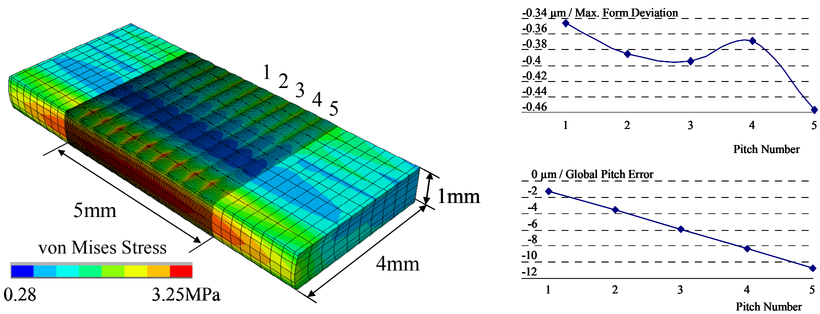

Figure 6: Form error prediction for molding of cylinder lens array

The form error of the cylinder lens array can be described in individual form error of each section and global pitch error in lateral direction. Figure 6 shows that the maximum individual form error slightly varies around an average value of 0.39µm, and the global pitch error is linear proportion towards outside and up to 20 µm for the whole array.

References:

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