Validation of Alternative Tooling Process Chains for Nickel Based Glass Moulding Moulds

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1 Introduction

Large volume production of low-cost glass lenses can be obtained by precision glass moulding, where a glass preform of suitable geometry is pressed between two optical quality mould surfaces in precisely controlled conditions. As moulding occurs at temperatures above the glass transition temperature of the glass, the process is extremely demanding for the moulds. Furthermore the long moulding cycle time poses a strong limitation to the process productivity.

Wafer based glass moulding [1] allows moulding of hundreds of lenses on a flat polished glass wafer in a single pressing step, thereby enhancing the productivity of the glass moulding process. In order to effectively implement wafer based moulding of glass lenses, suitable moulds must be developed.

2 Nickel moulds for wafer based glass moulding

Determination of a suitable temperature for pressing is an essential issue for glass moulding [2]. Processing temperatures can be as high as 700°C for high Tg glasses and average pressures can reach up to 20 MPa. Due to the high moulding temperatures and pressures, as well as the high required accuracy and the optical surface quality, the process is extremely demanding for the mould (and the associated carriers and aligning system), which must be characterized by high temperature resistance, tight tolerances and high surface quality maintained over a large number of loading cycles. Thermal shrinkage of the glass during the cooling process must be taken into account when designing the moulds in order to avoid form errors and damages to the moulded components. One important requirement is that the mould material must have a large thermal expansion coefficient in order to accommodate for the displacements of the peripheral glass lenses during cooling. Moreover, moulds containing hundreds of cavities require a long machining time when obtained by grinding. Use of diamond milling is preferable as it reduces drastically the machining time and cost. Conventional glass moulding mould solutions are based on the use of either steel or tungsten carbide as mould materials which do not exhibit large thermal expansion coefficient nor they are diamond machinable. Owing to the large thermal expansion coefficient when compared to conventional tungsten carbide moulds ($4.7*10^{-6}$ °C^{-1}), nickel moulds ($13.1*10^{-6}$ °C^{-1} at 20°C) can be considered as a candidate solution for precision glass moulding. Such moulds can be obtained by electroplating of a negative master made of a suitable material. Nickel electroplating can be optimized to reach a hardness of 450 HV. The master material can be selected so that it is diamond machinable, thereby largely reducing the mould manufacturing time and cost. The obvious drawback is the reduced hardness at high temperatures, which limit the maximum processing temperature and the overall mould life. Furthermore, the indirect tooling process chain might affect the achievable mould surface quality.

3 Alternative indirect tooling process chains

Three alternative indirect tooling process chains for the production of glass moulding moulds were explored. The basic concept of indirect tooling is shown in figure 1. In the first process chain, a classic indirect tooling solution was pursued. A master containing optical features was generated by diamond machining on an aluminium substrate. Aluminium oxide was removed from the surface of the master by wet etching, followed by wet deposition of a thin layer of zinc and then copper in order to prevent further oxidation. The substrate was then electroplated with a 2 mm thick nickel layer. Finally the aluminium master was removed by dissolution in an alkaline solution. A critical step with respect to the conservation of the surface quality of the master was expected to be the removal of the aluminium

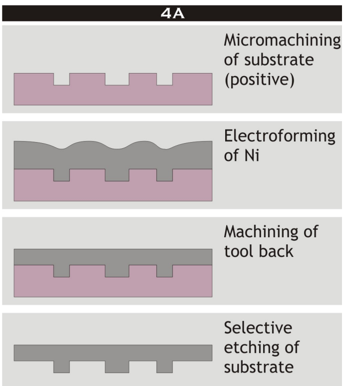
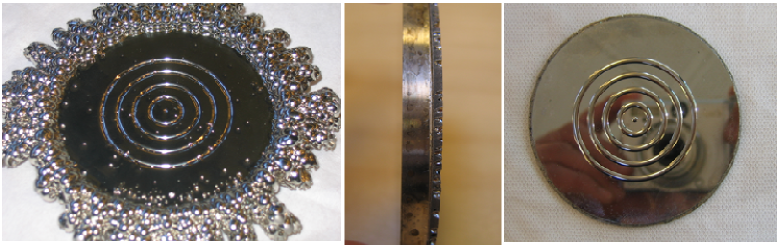


Figure 1: Indirect tooling concept.

oxide layer from the aluminium masters prior to electroplating. Thus in the second process chain, an attempt was made at removing such process step, thus an aluminium master was machined, but nickel plating took place without prior removal of the aluminium oxide. In the third process chain, a master was generated in UBAC copper (400 µm thick electrodeposited copper on a brass substrate) by diamond machining, cleaned and plated with nickel. Figure 2 shows the master/mould after the main steps of the third process chain.



After electroplating | Master and mould after preparation | Released Nickel mould

Figure 2: Process chain N° 3.

4 Moulds characterization

For the process chains N° 1 and N° 3, the topography of the optical surfaces was characterized by means of a white light interferometer in selected and well identified locations after each process step. Process chain N° 2 was unsuccessful as the aluminium oxide layer prevented good replication of the master surface. The comparison of the surface roughness measurements of masters and moulds is summarized in figure 3 for the other two process chains. In process chain N° 1 an appreciable increase of the arithmetic roughness amplitude Sa is observed as a consequence of the wet etching step, from 3.7 nm to 6.1 nm, while the Sz parameter increases from 230 nm to 270 nm. The electroplating step produces a negligible increase of Sa, indicating good replication. Sz instead is largely reduced. While it is possible that surface valleys were not completely filled during electroplating, it should be noticed that Sz is strongly dependent on the sampling area and, even though special care was taken in locating exactly the same areas on master and mould, minor variations of the sampling area could explain the observed variation. In process chain N° 3 instead an appreciable reduction of the Sa parameter, from 2.6 nm to 1.8 nm, is observed as a result of the electroplating process, while Sz increases from 52 nm to 64 nm. For both process chains the achieved mould surface quality is within the requirements for the moulding of high precision glass optics, although the wet plating step reduces the achievable quality on the optical surfaces.

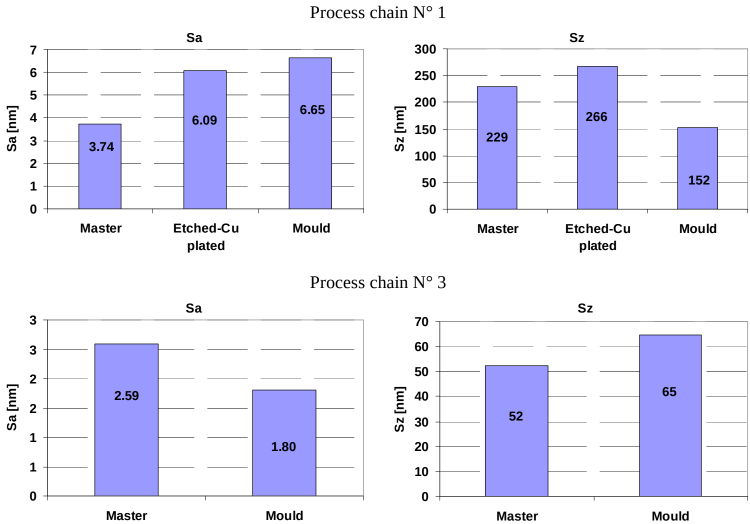


Figure 3: Surface characterization results for masters and moulds.

5 Conclusions

Three alternative indirect tooling process chains for the production of glass moulding moulds were explored. Removal of the oxide layer on the aluminium masters by means of wet etching and subsequent wet plating of Zn and Cu was found to be necessary, at the cost of a reduction of the surface quality of the functional surfaces. However such effect was found not to be critical for the application. The use of UBAC copper masters yielded superior results, maintaining the surface roughness within Sa 2 nm. Two of the explored process chains were found to be consistent with the surface quality requirements for the moulding of high precision glass optics.

References:

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