Optimised Glass Rod Drawing Process for Gradient-Index Microlenses

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In this work, we present technological and material-scientific studies on the manufacture of gradient-index microlenses. The investigations were directed to the optimisation of the glass rod drawing process to provide lens blanks in the required quality and quantity.

1 Introduction

Gradient-index (GRIN) microlenses (Fig. 1 inset) are important components for example in high-resolution optical sensors, optical communication and in technical as well as in medical endoscopy [1, 2]. The ability of GRIN lenses to have plane optical surfaces offers great qualitative advantages in the mounting and miniaturisation of microoptical systems. Instead of the conventional spherical lens surfaces, a radially decreasing refractive index gradient is used which can be achieved by a rotationally symmetrical variation of the glass composition [3].

In the present cooperation project the manufacture of the GRIN-lenses took place in a multi-stage process, beginning with the fusion casting of sodium-rich special glasses (VITRON GmbH), the shaping to cylindrical preforms (Fig. 1), the rod drawing to near-net-shape lens blanks (Ø=0,2 mm-3 mm; l=10 cm-100 cm – IPHT Jena) and finally the ion exchange [2] for profiling of the refractive index gradient (GRINTECH GmbH). Deviations from the desired parabolic refractive index profile can be caused during the entire production by inhomogeneities in the glass material and affect the performance of the gradient-index optics. The investigations were directed to the optimisation of the rod lens drawing process to provide lens blanks in the required quality and quantity. Here the activities were focused on the localisation of preform defects, the suppression of glass phase separations and the avoidance of thermal cooling asymmetries.

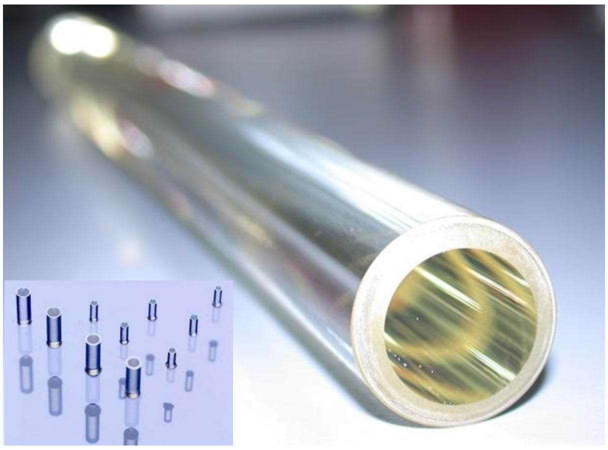

Fig. 1 *Rounded fused glass preform (Ø=2,5 cm; l=30 cm) for rod drawing to lens blanks and finished GRIN microlenses (Ø=0,2 mm-2 mm; l=0,5 cm-1,0 cm – inset).*

2 Macroanalysis - Preform defects

Material defects in the preform in the form of gas bubbles, striae and shape deviations may arise during the fusion casting and the mechanical shaping of the glass preforms. Such defects, even a single bubble affect adversely the dimensional stability of the lens blanks diameter during the rod drawing process (Fig. 2) and could disturb the imaging quality of the gradient-index optics. The detected diameter variations correspond to the preform defects, so that affected glass rod sections can be sorted out even before the silver/sodium-ion exchange process [2] will take place.

Characterised by polarimetric measurements, states of mechanical internal stress at striae containing preform glasses were confirmed. The thermo-chemically induced glass striae have an undesirable influence on the refractive index profile of the microlenses and result in a distortion of the

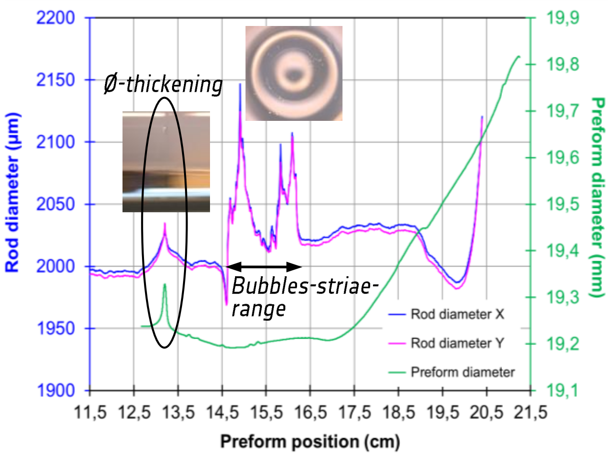

Fig. 2 *Preform defects correspond to the diameter variations of the drawn lens blanks, so that affected glass rod sections can be sorted out.*

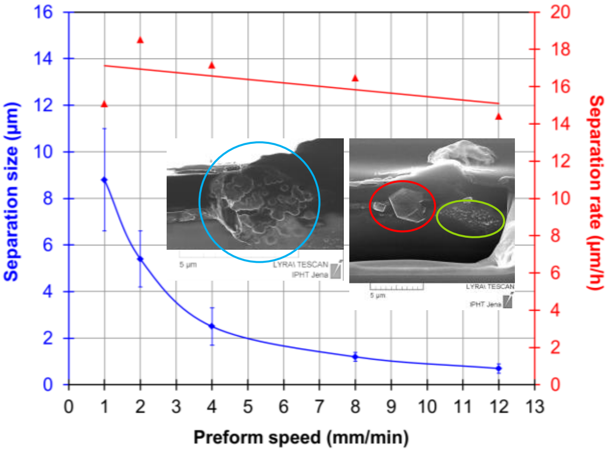

Fig. 3 Size and growth rate of the glass phase separation as a function of preform feed rate. Separation-related formation of different microphases (insets).

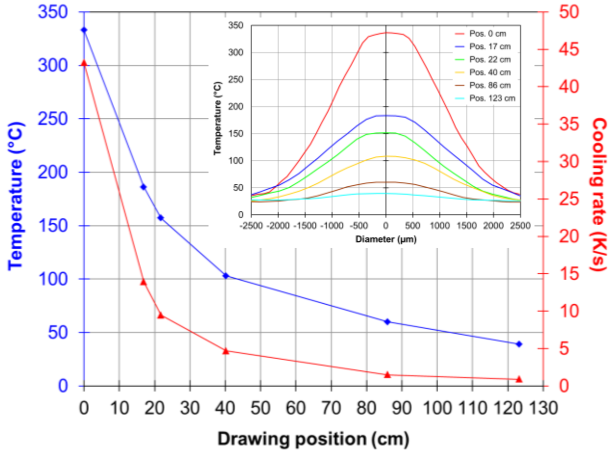

Fig. 5 Axial cooling function and cooling rate as well radially symmetrical temperature distribution of the glass rods at corresponding drawing line positions (inset).

wavefront which was demonstrated by optical tests using a Shack-Hartmann sensor.

3 Microanalysis - Glass phase separations

Signs of segregation in the form of globular glass phase separations occur in the lateral area of the rod materials which were microscopically inspected. The heat input (T≈810 °C) during the rod drawing process might cause a diffusion-based concentration shift as a consequence of evaporating of slightly mobile components. As a result of such separation the formation of different microphases could be observed depending on the interfacial tension of the participating phases. As seen in Fig. 3 (insets) an interpenetration structure (blue circle), an amorphous droplet phase (green circle) and a crystalline sodium-aluminium-silicate (red circle) exist simultaneously in the separation area.

From a draw technological point of view the appearance of the separation phenomena is dependent on the dwell time of the preform (neck-down region) in the heating zone which differed form 3 min to 35 min. It was found that at nearly constant separation growth rate, the size and frequency of glass phase separations increase significantly with a decreasing glass rod diameter and reduced preform feed rates (Fig. 3). A suppression of the phase separations could therefore achieved at high preform feed rates.

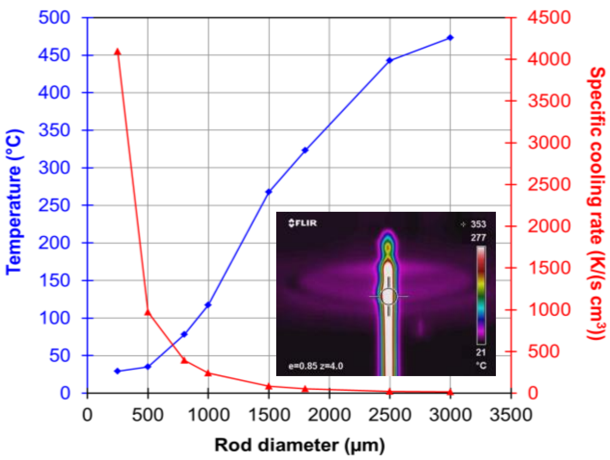

Fig. 4 Temperature change and cooling rate of the rods at the furnace outlet in relation to the rod diameter as well its symmetrical temperature distribution (inset).

4 Thermography - Cooling characteristics

Thermal investigations were performed to clarify the cooling behaviour of the glass rods and to avoid thermal asymmetries which can affect the refractive index profile of the microlenses. It was shown that the rod temperature after leaving the drawing furnace increases with the rod diameter whereby the specific cooling rate of the lens blanks decreases (Fig. 4). Here, a homogeneous thermal relaxation during cooling of the glass rods was observed (Fig. 4 inset). Fig. 5 illustrates the axial cooling function and cooling rate along the rod drawing line at a drawing rate of 1 m/min as well the radially symmetrical temperature distribution of the glass rods at corresponding drawing line positions (inset). It was further found that the temperature of the glass rods at the furnace outlet and the capstan inlet increases significantly with increasing drawing speed limited by technologically critical conditions.

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