All VLT Primary Mirror Blanks Delivered

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The last of the four VLT primary mirror blanks was formally delivered by SCHOTT Glaswerke on September 30, thereby closing eight years of a very fruitful collaboration between SCHOTT and ESO.

On ESO's part, the preparation of the contract, signed in September 1988, is the work of D. Enard and R. Fischer. The SCHOTT contract was set on a fixed-price basis, whereby the production of the 8-m blanks has probably been the highest risk area for the entire VLT programme. The collaboration went on fairly smoothly – at least for ESO. The formidable difficulty of producing a usable 8-m Zerodur casting should however not be underestimated.

Zerodur is a glass ceramic with approximately 70% of crystalline phase (quartz mixed crystal) and 30% of residual glass phase. The crystalline phase has a negative coefficient of thermal expansion (CTE), while the coefficient of the glass phase is positive; the final properties are adjusted by means of a thermal cycle (ceramisation) with the aim to reach near-zero overall expansion coefficient. Typical values of the CTE for large Zerodur mirrors are lower than 0.05×10^{-6} °K^{-1} (-0.003×10^{-6} for the NTT blank, -0.017×10^{-6} to -0.043×10^{-6} for the VLT blanks), with homogeneities in the range of $0.02–0.01 \times 10^{-6}$.

The fabrication process starts with a casting at 1400 °C. After cooling down to room temperature, the result is a glassy substrate which is machined to the approximate size, then ceramised and thereafter machined to final shape.

To execute the contract, SCHOTT built a dedicated 50,000 m^2 facility, with a 70-ton melting tank, 3 annealing and ceramisation furnaces, a spinning table, a grinding machine. Essential handling and storage equipment included a handling tool with 18 suction cups, an impressive mirror turning device, a mirror "shelf" and a dedicated support system for quality control measurements.

The melting tank entered into operation in 1991 and all castings, including, but not limited to, the 4 VLT blanks, were produced between 1991 and 1993. During these two years, the melting tank was permanently kept at a temperature (with 20 to 60 tons of glass) in excess of 1400 °C. The countdown for casting started 3 to 4 weeks prior to the casting itself, a most spectacular process in every respect; the most visible part is the process itself (Dante would have loved it), but the most important one is the flawless training, co-ordination and operation of the casting team. There, in addition to the technological dimension, enters the human one.

The spin-casting process (Figs. 1 and 2) was successfully validated on a series of 1–4-m-class castings. The first attempts at producing the VLT mirror blanks were, however, unsuccessful: the mirror blanks broke during the annealing process, as a result of internal stresses

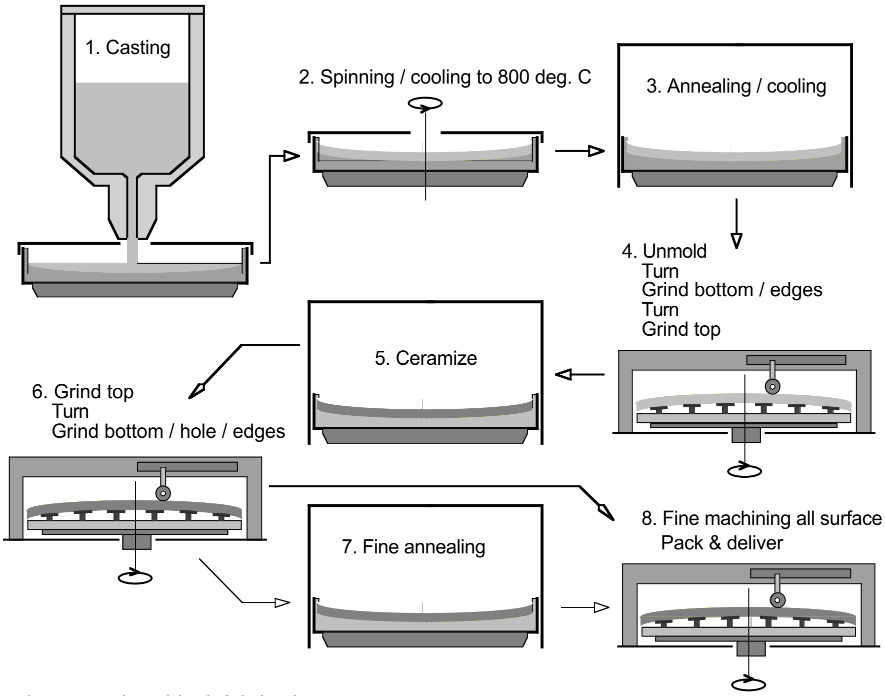

Figure 1: Mirror blank fabrication process.

Figure 2: 8-m blank being spun.

Figure 3: Turning the blank convex side up.

generated over the cooling cycle. The culprit: a sub-millimetre thin crystalline layer building up at the contact area between the bulk of the substrate and the mold. This layer, having a coefficient of thermal expansion different from the one of the glassy Zerodur, would eventually lead to breakage during cooling at temperatures in the range of 200 to 300 °C.

A major effort was made by the manufacturer in modelling and controlling the cooling cycle – a tremendous task since the properties of the material change with temperature. The blanks were actively supported, and particular attention was paid to the homogeneity of the temperature distribution during cooling. The challenge is to bring a melt of about 50 tons of glass from 950 °C to room temperature in a fully-controlled and homogeneous way.

Eventually, the molds were modified as well, and a particular separation agent (SCHOTT proprietary information) had to be used at the interface between the mold and the glass. The last produced blanks had crystalline layers of about 0.3 mm thickness, small enough in order not to generate inadmissible tensile stresses in the substrates.

Producing large mirror blanks requires more than controlling melting, casting and annealing processes. Substantial engineering effort had to be put in the areas of handling, machining and, of course, human safety. In spite of all precautions taken to limit internal stresses upon cooling down, residual stresses in the blank coming out of the annealing and cooling furnace are still dangerously high. In addition, inclusions which had fallen from the melting tank or risen from the mold into the substrate, together with possible damages such as surface cracks, require complex tooling and careful preparation of unmolding and handling. The blank is brought from the furnace onto a turning device, which turns the convex surface up (Fig. 3). The blank is brought onto the grinding machine and surface damages as well as critical inclusions are promptly machined out.

The enumeration of the difficulties could lead to the conclusion that, would the blanks indeed be feasible, the level of quality (residual stresses, homogeneity) at the very end of the process would not likely meet the highest standard. The credit for demonstrating that this assumption is wrong must be attributed to the team of SCHOTT Glaswerke.

Indeed, the homogeneity, inclusion content and dimensional accuracy fully meet the specifications – and in many

TABLE 1. Data for the four VLT primary mirror blanks.

Characteristic	Specified	Blank 1	Blank 2	Blank 3	Blank 4	
Geometrical dimensions						
Diameter	8200±2	8201.52	8201.74	8201.72	8201.74	mm
Dia. centre hole	1000±0.5	999.81	999.93	999.87	999.72	mm
Concentricity	±1	0.01	0.01	0.01	0.01	mm
Thickness	177+2–0	177.9	177.7	177.5	177.7	mm
Concave surface						
Curvature	28975	28975	28975	28975	28975	mm
Profile tolerance	2	0.12	0.08	0.08	0.06	mm
Convex surface						
Curvature	28977	28977	28977	28977	28977	mm
Profile tolerance	2	0.05	0.07	0.06	0.07	mm
Material properties						
Density	2.53	2.534	2.534	2.534	2.535	
CTE	$0\pm0.15\ 10^{-6}$	$-0.043\ 10^{-6}$	$-0.032\ 10^{-6}$	$-0.040\ 10^{-6}$	$-0.017\ 10^{-6}$	K^{-1}
Homogeneity	$<0.05\ 10^{-6}$	$0.009\ 10^{-6}$	$0.011\ 10^{-6}$	$0.024\ 10^{-6}$	$0.028\ 10^{-6}$	K^{-1}
Young's modulus	91000	90000	90000	90400	90300	Mpa
Poisson's ratio	0.24	0.243	0.243	0.243	0.24	
Internal quality						
Inclusions in critical volume						
Mean size	< 5	< 0.5	< 0.5	< 0.6	< 0.6	mm
Maximum size	< 8	2.3	3.5	1.1	1.6	mm
Average number	< 0.5	< 0.01	< 0.01	< 0.01	< 0.01	cm^{-3}
Maximum in 10 cm^3	≤ 8	< 4	< 4	< 4	≤ 4	
Stress birefringence caused by inclusions						
in critical volume	≤ 25	≤ 21	<12	0	0	nm
outside critical volume	≤ 50	≤ 30	<12	≤ 27	0	nm
Permanent stress at outer edge (compressive)						
Mean value	≥ –10	–6.2	–9.3	–6.5	–8.0	nm/cm
Maximum value	≥ –20	–7.0	–10.4	–8.3	–9.5	nm/cm

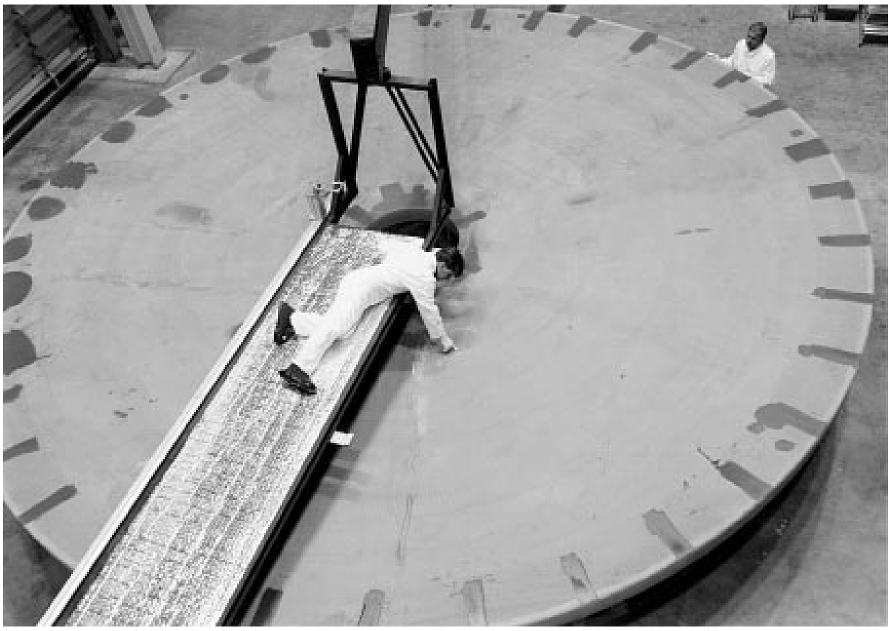

Figure 4: Preparation for the measurement of residual stresses (birefringense measurements).

areas exceed them by a substantial factor (Table 1). Residual stresses were found to be extremely low (Fig. 4). The contract was executed in time, within specifications and budget.

All four blanks are now at REOSC; two of them have been completely processed into finished mirror assemblies, tested and found to comply with the specifications (Fig. 5). They are now in storage prior to their departure to Chile. The third one is under polishing (currently about half a wave RMS wavefront error) and should be completed during the first quarter of 1997. The last one will remain in storage until early 1998, when REOSC will mount axial interfaces and start grinding.

In the light of the achievements realised so far, it is particularly interesting to review the documentation of the mid-80's, when the currently built telescopes (Keck, Gemini, Subaru, LBT, SST – renamed Hobby/Eberly) were in their conceptual design phase. At that time, possible diameters for monolithic mirrors rapidly narrowed to the 8-m range, with the argument that the extrapolation of the mirror technology to the 8-m range represented an ambitious but realistic step beyond the 4-m-class telescopes of the 60's–70's. Key issues were the technology for the blank production, but also the difficulty of handling very large mirrors. The developments undertaken and the results obtained by SCHOTT may lead to the impression that larger monolithic mirrors might be theoretically feasible, e.g. in the 10–12-m range. This may be true from a pure technological point of view, but the experience gathered so far indicates that there would most likely be a noticeable discontinuity in the cost-scaling law above a limit which looms around 8.4 m, essentially set by handling and above all transport constraints.

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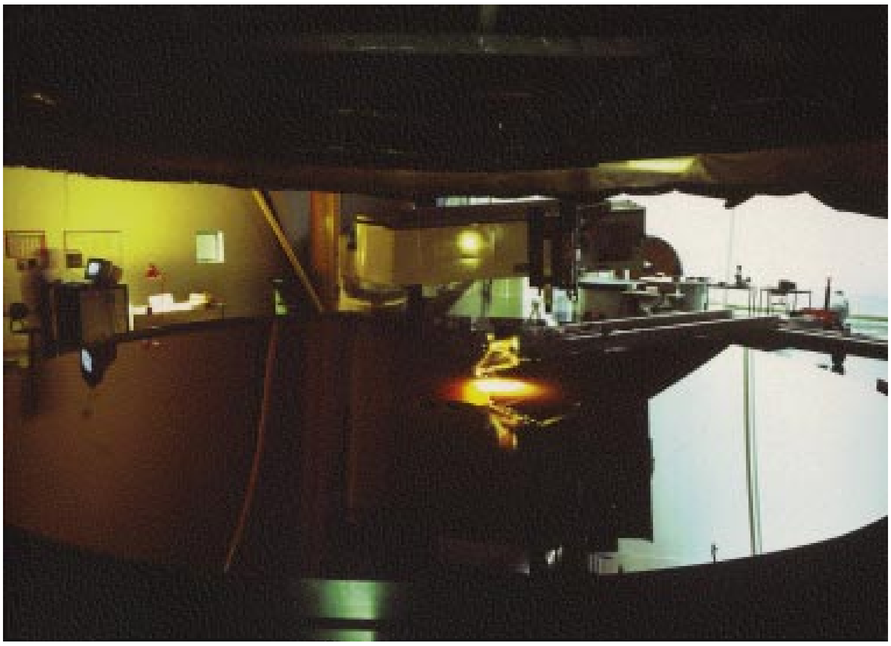

Figure 5: Primary Mirror undergoing acceptance tests at REOSC.

ISAAC Takes Shape

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Description

ISAAC (Infrared Spectrometer and Array Camera) is one of the two VLT instruments being developed by ESO and is planned to be installed at one of the UT1 Nasmyth foci in 1998. Its scientific capabilities include both 1–5 μm imaging over a field of up to 2.5 × 2.5 arcmin and long-slit spectroscopy at nominal resolving powers of ~500 and ~5000. In order to optimise its performance over the full wavelength range, it contains two separate cameras optimised for the 1–2.5 μm and 2–5 μm regions which can be used to directly image either the telescope focal plane or the intermediate spectrum produced by a grating spectrometer. Further details of the instrument design and performance can be found under Very Large Telescope (VLT) Observatory on ESO's WWW Home Page.

ISAAC Integration and First Tests

Our main purpose here is to report on the status of the instrument integration and results of the first tests performed in Garching. As can be seen from the ac-