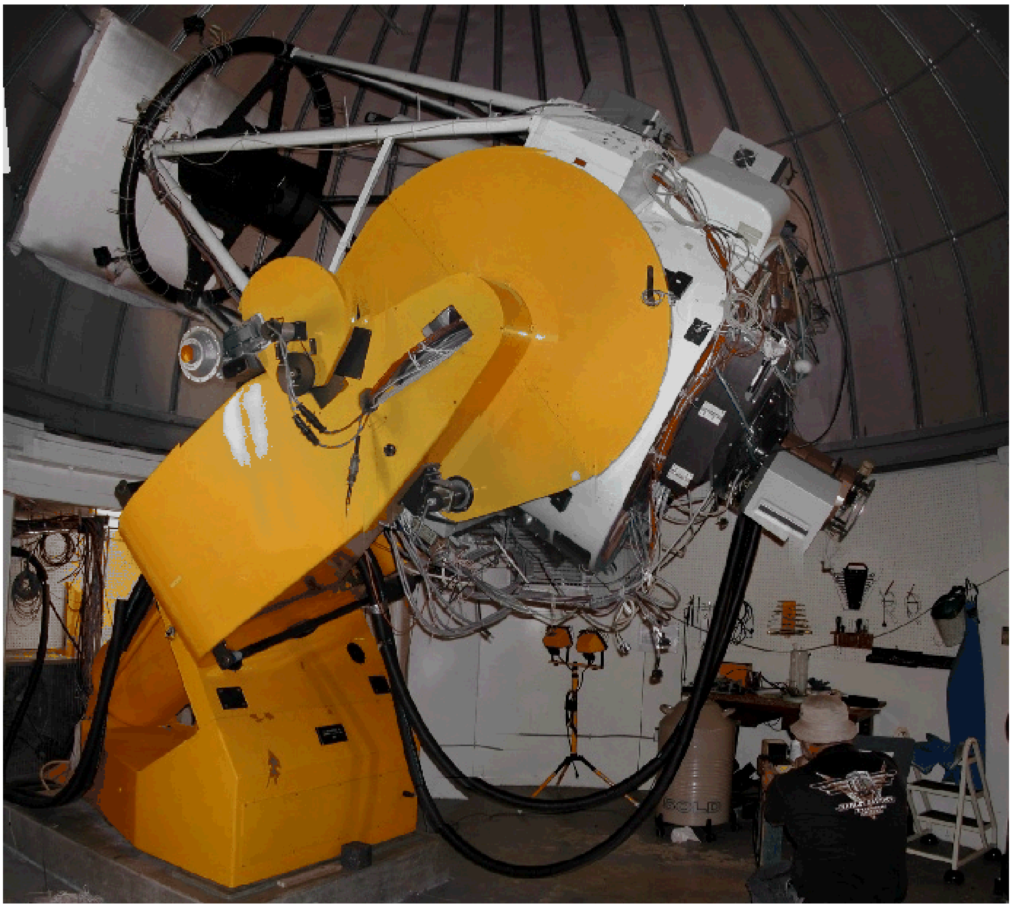
SCHOTT

# Proposal No. 4432 / 2005
for the
# Replacement of the 48" telescope mirror
of the
# F L WHIPPLE Observatory

**Answer to request submitted by Emilio E. Falco**



**June 6th 2005**

## SCHOTT-Proposal prepared by:

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**Content:**

# 1. Introduction

The F.L.Whipple observatory operates a 48” telescope. The telescope is presently equipped with a mirror made of Borosilicate glass. The existing 48” glass mirror faces some technical problems, which should be improved by a replacement mirror: The non-zero thermal expansion of Borosilicate glass causes wavefront distortions during the telescope operation and after several recoating processes also the surface quality of the mirror suffered.
It is intended to replace the existing mirror by a new lightweighted mirror made of the zero-expansion glass ceramics ZERODUR®.

# 2. Executive Summary

SCHOTT has in stock suitable ZERODUR® raw material for the manufacturing of the required mirror blank for the F L Whipple Observatory. In addition to the manufacturing and delivery of the zero expansion glass ceramic raw material itself, SCHOTT is able to pre-shape telescope mirror blanks with complex geometry. The available technical equipment can be adapted easily to the special requirements of the 48” mirror blank. The use of a high quality ZERODUR® mirror blank will significantly improve the scientific results of the telescope.
Due to resticted capacities in polishing Schott is interested to participate only in the work package of “Manufacturing of a lightweighted mirror blank“ and the corresponding documentation.

# 3. Management Approach

## 3.1 Legal Status and Organization

The SCHOTT Group, founded almost 120 years ago is an “International Technology” concern, operating in the special glass sector, headed by the foundation-owned enterprise SCHOTT AG. More than 18.000 employees in over 80 companies are involved in the development, manufacturing and marketing of special glasses and glass-ceramics (like ZERODUR®) as well as components made from these materials. SCHOTT is Europe’s leading special glass manufacturer.
The SCHOTT AG is an Enterprise of the Carl-Zeiss-Stiftung (Foundation). The Carl-Zeiss-Stiftung is the sole owner of the two independently managed enterprises, the CARL ZEISS AG in Oberkochen and the SCHOTT AG in Mainz, Germany.
SCHOTT North America Inc., a U.S. company incorporated in the State of Delaware, is a member of the SCHOTT group of companies with headquarters in Elmsford, New York. The division “Optics for devices” is located in Duryea, Pennsylvania. There, our approximately 400 employees and 700,000 square feet of facilities are dedicated to research, development, production, and marketing of advanced glass and glass ceramics.

## 3.2 History

Astronomy is one of the oldest sciences. The first mirror substrate that SCHOTT built for the observatory at the University of Heidelberg in 1903 had a diameter of 0.72 meters – impressive for that time. The imaging quality of this mirror telescope was so good that it became famous around the world as the "Waltz Reflector", named for its sponsor. As a result of this, SCHOTT was commissioned to construct mirror

substrates of one to two meters in diameter by such observatories as Hamburg Bergedorf (1907), Berlin Babelsberg (1920), Tautenburg near Jena (1949) and for Egypt's largest telescope (1963).
While optical glasses were originally used, followed later by a Borosilicate glass with a low thermal expansion, the invention of the SCHOTT ZERODUR® glass ceramic represented a quantum leap in the development of materials. In the decades to come, it would become the internationally recognized standard material in the construction of telescopes. This new material has practically zero thermal expansion, is easy to process mechanically, and of very high chemical resistance – properties that make it predestined for use in large astronomical mirrors. It was first utilized in telescopes for the observatories at Calar Alto in the south of Spain (1975) and for the European Southern Observatory (ESO) in Chile (1986).
The most significant milestone for ZERODUR® so far was the production of the world's largest monolithic mirror substrate for the 8.2-meter Very Large Telescope (VLT) between 1991 and 1996. Yet this also represented the end of the line for the ever-increasing glass-ceramic monoliths, as the technical limits had now been reached. Subsequently, a new approach was adopted for astronomical mirrors with even larger dimensions, combining many hexagonal ZERODUR® segments. Examples of these are the two Keck telescopes in Hawaii with a diameter of 10 meters and the 10.4-meter "GRANTECAN" telescope currently under construction, which is planned to go into operation next year on La Palma in the Canary Islands.
The 2003 "anniversary" mirror substrate, which SCHOTT delivered in April 2003, has a diameter of 4.1 meters and also is made of one piece. It is intended for "VISTA", the largest wide-angle telescope in the world.
There are more than 30 years of experience with ZERODUR® telescope mirror blanks at SCHOTT, well recognised in the scientific community. The most prominent examples are the four 8.2 m mirror blanks for the Very Large Telescope of the ESO and the blanks for the segmented 10 m primary mirrors of KECK I, KECK II, HET and GRANTECAN. All telescopes equipped with ZERODUR® are operating in an excellent manner to date.

### 3.3 Project Management

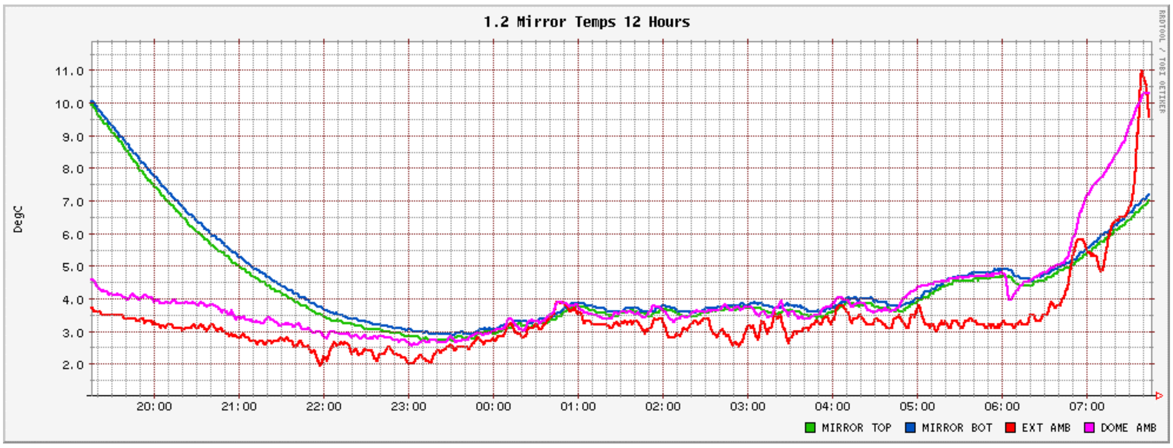
Based on the long experience of SCHOTT in large telescope projects the management approach for the 48” mirror project is designed to continue this successful history. A professional project team is available to ensure an adequate project management, reliable delivery times, an optimised production, and an in-time delivery. The destined team is proven to work in jointly cooperation. It is composed of skilled engineers and scientists with a lot of experience in handling big telescope projects.
As usual for large telescope projects SCHOTT will support the customer and the involved optical polisher with its management and logistic know how and the scientific power of its outstanding research centre. The project team at the F L Whipple Observatory will be informed regularly about the status of the work.

# 4. Technical Approach

## 4.1 Understanding of the problem

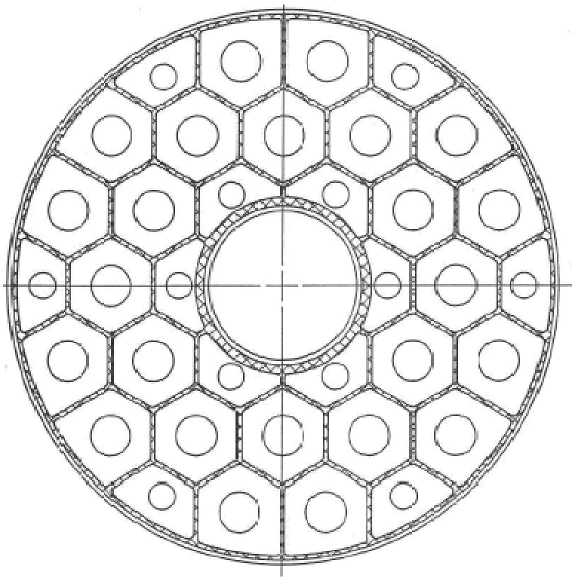
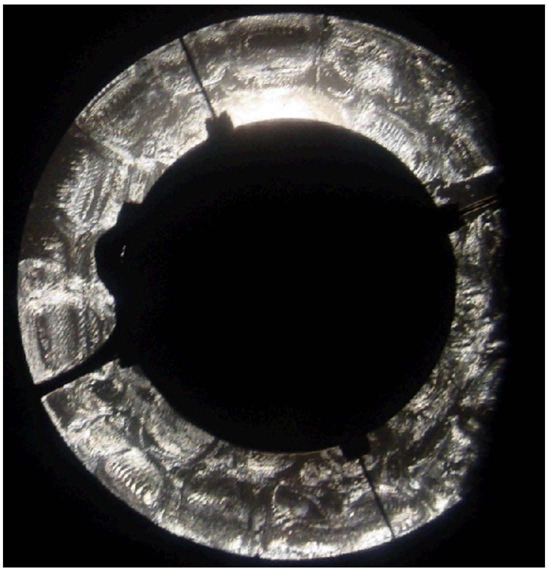
The existing 48” Borosilicate glass mirror faces some technical problems, which should be improved by the proposed replacement mirror.

**Temperature sensitivity:**
The Borosilicate glass material of the existing mirror has a low (but non-zero) CTE of around 3.3* $10^{-6}$ / K. As shown within the next temperature plot, there is some time needed until the temperature of the mirror gets into equilibrium with the surrounding environment. This results in a severe temperature depending deformation of the mirror. By use of the zero expansion glass ceramics ZERODUR this temperature sensitivity could by minimised by a factor of 30 – 50, as the CTE of ZERODUR is only 0 +/- 0.1 * $10^{-6}$ / K.




see: http://linmax.sao.arizona.edu/FLWO/48/bam-support.pdf

**Print through effect during polishing:**
The lightweighting of the existing mirror was designed with large hexagonal structures of about 218 mm diagonal (190 mm flat-flat). The resulting reduced stiffness of the front surface of the individual holes resulted in some polishing pattern, called “print-through effect”. This effect can be seen in the Foucault test images.
The design of the replacement mirror has to consider a stiffer structure or an additional ion beam polishing to correct this disturbing effect.

Left: Structural design of existing mirror
Right: Foucault test of existing mirror, see
http://linmax.sao.arizona.edu/FLWO/48/FOUCAULT/fou06.jpg

**Stiffness of the mirror:**
The existing mirror design with large structures resulted in a reduced overall stiffness of the existing mirror, resulting in an increased sensitivity to gravitational forces. This is shown in the attached spot diagrams for horizon pointing and azimuth pointing. These effects have been partially compensated by an active support system. An improved design has to consider a stiffer structure.

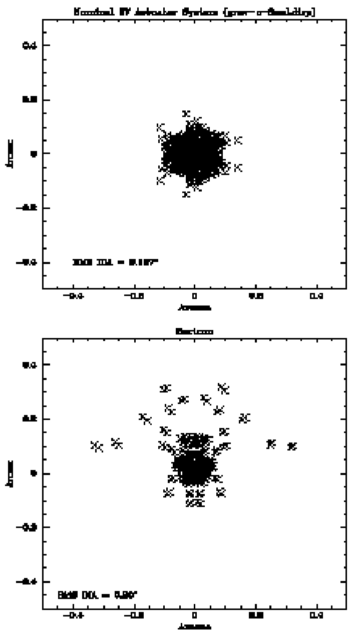


Fig. 4— Spot diagrams for nominal 27 actuator, zenith pointing (top) and horizon pointing (bottom).

Influence of gravity on focus size in different orientations of the existing mirror
http://linmax.sao.arizona.edu/FLWO/48/bam-support.pdf

### 4.2. Proposed design of the replacement mirror:

Schott proposes the following design of the replacement mirror (see sketch below):

1. The use of the zero-expansion glass ceramic material ZERODUR® will avoid a thermal sensitivity of the new mirror.

2. The principal hexagonal structure of the existing mirror should be maintained to a certain extend. In this case the support points of the mirror will remain and the existing active support system of the mirror cell don't have to be changed. (Such changes of the mirror cell would probably create a significant cost increase for the mirror replacement project.)

3. Each hexagonal structure of 190 mm will be replaced by 7 circular blind holes of about dia. 60 mm. Thereby hole diameter and rib thickness have to be optimised by finite element methods. (Blind circular holes are usually the option with the lowest effort for manufacturing.)

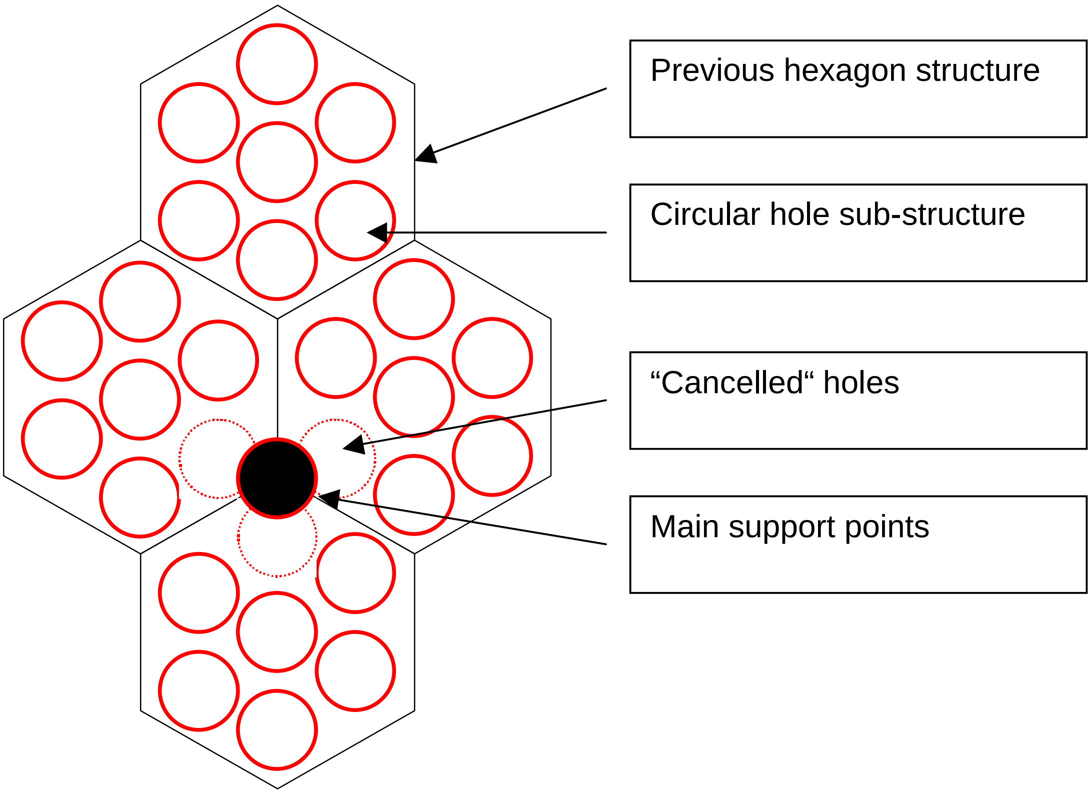
4. The additional ribs by the new sub-structures (with respect to the previous design) will increase the overall stiffness of the new mirror. So gravitational effects in different orientations of the telescope will become less critical during operation.

5. The resulting smaller area of the not-supported frontplate will avoid (or drastically reduce) the print-through effect during polishing. The use of ion-beam polishing methods can probably be avoided.

6. It is proposed to cancel the 3 blind holes in the direct neighbourhood of the 3 main support points of the mirror. The incoming forces at these points will be introduced at an almost "solid" mirror at these points and its stability is therefore improved.

7. In an optimum case also the mass of the mirror would be maintained by the replacement mirror. Nevertheless, this mass requirement is less stringent, if the telescope structure can handle the additional weight and the additional mass can be balanced by a corresponding counterweight. The target mass of the replacement mirror is about 253 kg, corresponding to a lightweighting factor of about 50%.

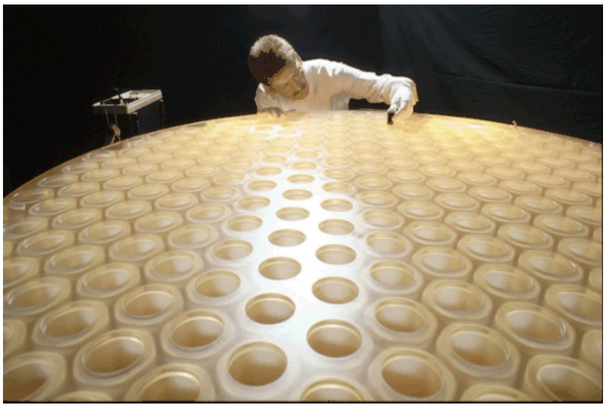
8. The corresponding parameters of the resulting weight of the new mirror and its stiffness should be optimised by finite element calculations. The finite-element calculations are not part of this budgetary offer and should be performed by the customer.

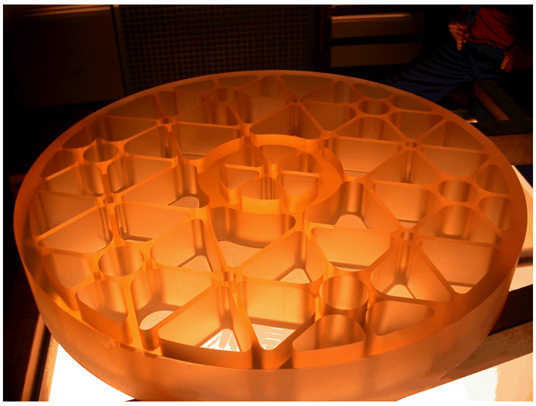



Proposed design of the replacement mirror

**4.3 Proposed manufacturing method**

For the manufacturing of the lightweighted mirror blank the proven grinding process is proposed. At SCHOTT several large and flexible 5-axis CNC grinding machines are available. With these machines complex Zerodur structures with tight tolerances have been produced before. There is a lot of experience with lightweigthed mirror blanks for space-based applications and with secondary or tertiary mirrors of ground based telescopes (see pictures). At present material and CNC machining capacity is available to have a short delivery time for the required mirror blanks.





Examples of lightweighted mirror blanks  made by SCHOTT

### 4.4 Technical data of Zerodur

The following table summarizes the technical data of ZERODUR®. More details can be found in the ZERODUR® catalogue or at the SCHOTT homepage. (http://www.schott.com/optics_devices/english/products/zerodur/index.html).

| **Properties** | **ZERODUR®** |
|---|---|
| Young's Modulus E [GPa] | 90.3 |
| Poisson's Ratio μ | 0.24 |
| Density [kg/m$^3$] | 2530 |
| CTE / • (0°-50°C) [10$^{-6}$/K] | 0.0 ± 0.02 |
| Thermal diffusivity at 20°C [10$^6$ m$^2$/s] | 0.72 |
| Thermal Capacity $c_p$ (20°C) [J/(gK)] | 0.80 |
| Knoop Hardness [HK 0.1/20] | 620 |
| Thermal Conductivity $\bullet_{90\,°C}$ [W/(mK)] | 1.46 |

## 5. Quality Assurance

The Optics Division of the SCHOTT AG Mainz operates a quality management system, which is certified according to the standard ISO 9001 revision of 2000 emphasising process orientation. The certification was performed by Lloyd's Register Quality Assurance, Cologne, Germany in July 2004. The Q.M. system covers all product lines of the Optics Divisions. In projects for astronomical mirror blanks we have been audited by customers successfully since many years.
Our laboratories for the measurement of physical and chemical properties are accredited by the German authority GAZ Association for the accreditation and certification GmbH on the basis of the standard series EN 45000, EN 29000 and ISO 9000.

### 5.1 Test and inspection procedures:

Quality measures are taken after each major processing step. General inspection procedures for ZERODUR® consist of:
(a) Internal quality inspection:
Internal quality inspection consists of bubbles and inclusion inspection, striae inspection/measurement and stress measurement. These inspections are carried out after individual processing steps:

- After melting and raw annealing (raw ZERODUR® casting in the glassy state)
- After ceramization (raw ZERODUR® casting)
- During final inspection (finished blank)

(b) Geometrical dimensions:
Geometrical dimensions are tested after individual processing steps at the grinding machine (intermediate results) and during final inspection of the finished blank. To fulfil the need of high accuracy metrology of large ZERODUR® mirror substrates during processing we use a large Zeiss CMM (types PRISMO 7 / PRISMO 10) with an accuracy in the range of ±1 µm/m distance.
(c) Material properties:
CTE (Coefficient of Thermal Expansion) measurements are carried out for individual pieces of raw material after the ceramisation and the re-annealing process.

Additionally the homogeneity will be tested by taking samples distributed in the blank near the net shape of the finished part. Other material properties (density, heat capacity, thermal conductivity) are nearly independent of the melting and ceramisation / re-annealing process and will be measured only once per melting campaign.

## 6. ROM price estimation

The final specification and the corresponding tolerances are presently not defined and may be subject of technical changes. Therefore this price estimation can be used for budgetary purposes only. A binding offer will be submitted on request.

It is our pleasure to submit our ROM price estimation as follows:

| **Description** | **Qty** | **Approx. Delivery Time** | **ROM Price per unit** | **Unit** |
|---|---|---|---|---|
| **Plano-concave mirror blank**<br>• Material: Zerodur in Standard quality<br>• CTE: Expansion class 2 (0 +/- 0.1 * $10^{-6}$ / K)<br>• Outer diameter: 1219.2 +/- 0.25 mm<br>• Shoulder at outer diameter hole: dia. 1206.5 mm +/- 0.25 mm<br>• Edge thickness: 207 +/- 0.25 mm<br>• Central hole: dia. 330.2 +/- 0.25 mm<br>• Shoulder at central hole: dia. 342.9 mm +/- 0.25 mm<br>• Wedge: < 0.5 mm<br>• Flatness of back surface: 0.4 mm<br>• Radius of curvature: R –4590.9 (concave sphere)<br>• Profile tolerance of the pre-shaped mirror surface: 0.2 mm (ground with D76)<br>• Weight of blank: (t.b.d.)<br>• Lightweighted structure:<br>o blind holes (circular or hexagonal shape, t.b.d.)<br>o lightweighting factor about 40 - 50 %<br>o structure adapted to maintain the position of the previous 30 axial supporting points (3 hard points + 27 for actuators)<br>o rib thickness within a range of 10 +/- 2 mm (t.b.d., see weight limit specification)<br>o typical thickness of mirror front surface: 20 to 30 mm (t.b.d.)<br>• Surfaces matt, ground with D151 (except mirror surface, which is ground with D76)<br>• No etching, no re-annealing<br>• All edges with protection chamfers | 1 | 3 – 4 months | 300,000 USD | 1 PC |

| | |
|---|---|
| Pricing terms: | EXW Mainz / packing included |
| Validity of offer: | July-31-2005 |
| Terms of payment: | 30 days net, term of payment from date of invoice |
| Delivery time: | Offered delivery times are legal after order receipt.<br>Raw material is subject to prior sale. |

This budgetary offer is based on our general terms of delivery and payment, which you can receive on request from our sales department or download at:
http://www.schott.com/english/company/legal1.html

Please do not hesitate to contact us if you have any question.

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