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HIGH STABILITY HOLLOW CUBE CORNER

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ABSTRACT

SESO has developed in the field of a R and T program of CNES a hollow cube corner in which there is no cement for bonding the three mirrors and with silicon, a good thermal conductivity material, both of which allows to guarantee a very good thermal stability particularly if the cube corner is enlighted by the sun on part of its surface. The complete assembly includes also the mechanical holder allowing to fix the cube corner on a baseplate without distorting it.

We will present the conceptual design, the technology used for assembling the three parts of the cube, simulations made on environmental behaviour, results achieved on a mock-up of the cube corner (wavefront distortion, angular accuracy, coating reflectivity, weight …).

1. CONCEPT

Cube corners are well known and used to send back the light in the same direction than the incident beam thanks to three reflexions on three mirror surfaces having 90° angle between them.

The easiest solution to manufacture such devices is to realise a cube of glass and to cut each corner but when working for space the weight becomes very critical (density of glass ~ 2.5 g/cm^3).

When the collecting surface increases there are two possible solutions:

- Use many small cube corner (Figure 1)
- Use one large cube corner (Figure 2)

Fig. 1: Many small cube corners

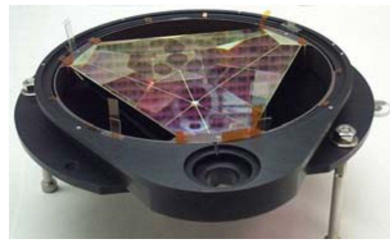


Fig. 2: Large cube corner

The main disadvantage of both solutions is the weight and for the second one the length of the beam path in the glass (order of magnitude of twice the size of the diameter of the collecting surface) of the cube corner leading to effect of inhomogeneity of refractive index of the material incompatible with the requested wavefront error.

Criticity on the wavefront error is increased if we introduce some inhomogeneity of temperature due to variation of index with temperature ($10x10^{-6}$/°C for example with silica).

So that is why the hollow cube corner where there is no optical material used in transmission offers a good solution as far as the mechanical assembly is stable with environment.

In order to improve the stability of this assembly, we have to choose the material of the three reflecting mirrors to minimize the effect of a thermal gradient. Table 1 gives a comparison of the merit factor between silica and silicon.

Table 1: Merit factor

Merit factor	Silica	Silicon
Density	2.2	2.32
Module of Young MPa	72500	130000 approx. (crystal)
CTE 10^{-6}	0.51	2.33
K=conductivity W/m/°K	1.38	130
Calorific capacity J/Kg/°K	772	752
Merit Factor = $\frac{K}{CTEx10^{-6}}$	2.7	55.8

Even if the thermal expansion of Silicon is five times greater than SiO2, the conductivity which allows to have a more homogeneous temperature is 100 times better with Silicon.

The other choice we made to improve stability is to use a technique in which there is no other materials than Silicon between the mirrors (or a layer so thin that it has no impact on the stability) as this technique is called here below irreversible adherence.

2. IRREVERSIBLE ADHERENCE

The irreversible adherence is obtained on the silicon parts after a prior flat polishing of the two surfaces.

These surfaces are coated with a material (thickness < 1 µm) which after pieces are put in contact (as per a process similar to optical contacting) allows to create a binding without cement through exchange of electrons.

On Figure 3 we present what happens when such assembly is tested: breakage happens outside the flat joint.

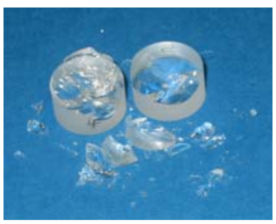


Fig. 3: Breakage after shearing stress

In case of silicon irreversible adherence we made samples of 2 cylinders of 10 mm diameter and 10 mm height. Once contacted they were tested for shearing stress. We present on Figure 4 the shearing stress obtained on 18 samples.

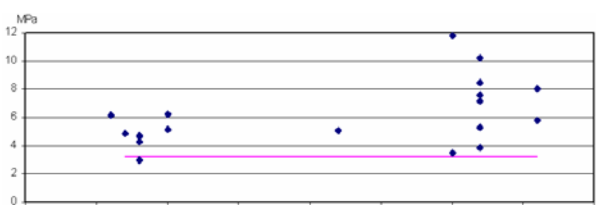


Fig. 4: Shearing stress obtained on 18 samples

As can be seen the shearing stress has always been greater than 3, 5 MPa, going up to 10 MPa.

We would like to point out that for optical contacting the criteria that we use for shearing stress is 1 MPa.

To demonstrate and validate that the joint has a very small thickness, we polished one sample perpendicular to the flat optical contacted area.

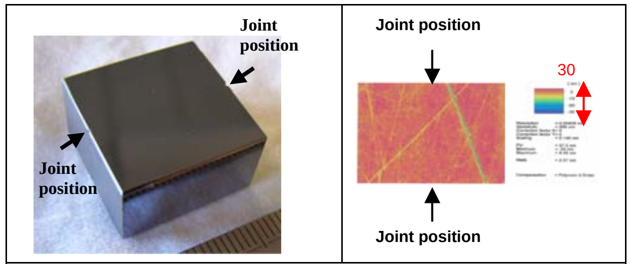


Fig. 5: Test tube - Roughness

From these analyses we can conclude that nothing can be seen down to 0.7 µm (Figure 5) (pixel resolution of the roughness measurement. For information, the blue line on the roughness picture is a 20 nm deep scratch of 2 µm width. The junction should have appeared as a vertical line.

3. DESIGN OF THE CUBE CORNER

Cube corner is made with 3 triangular plates of silicon, which are bond by edges. Surface of the collecting area is 50 cm² (See Figure 6).

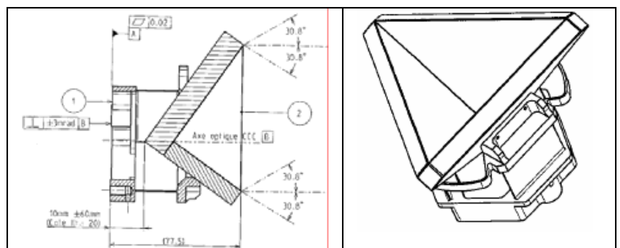


Fig. 6: Drawings

Final Element Analysis has been made with a 3D model of 12250 modes and 53940 elements (see Figure 7) the Z axis is called the optical axis.

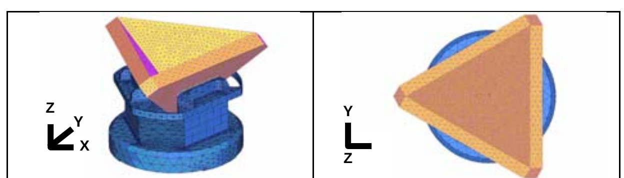


Fig. 7 Cube Corner with its mount

The cube corner itself once assembled is cemented on a mechanical Deformable Flexture Mount, which allows to clamp it on a base plate. Analysis of this assembly has been made with Finite Element Analysis leading to a first mode at a frequency > 1000 Hz.

Flexibility has been integrated in the design by three invar elastic blades allowing to compensate the difference of thermal expansion between silicon and invar.

- Quasi static charge analysis

When submitted to acceleration of 30 g, we have calculated the stress with a security coefficient of 1.25. Analysis has been made for acceleration perpendicular to the mechanical γz directions in the interface plane (γx and γy).
We compared it to a 5 MPa maximum stress that we allow in the silicon, 75 MPa in Invar and 3.5 MPa in contacted joint.

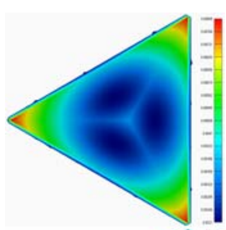
Table 2: Stress

Silicon Cube Corner	Calculated Stress (MPa)	Security Coefficient JD	Increased Stress (MPa)	Margin	
γx	0.8	1.25	1	4	5 MPa
γy	0.8	1.25	1	4	
γz	0.8	1.25	004	11.5	
Flexibles blades	**Calculated Stress (MPa)**	**Security Coefficient JD**	**Increased Stress (MPa)**	**Margin**	
γx	11.6	1.25	14	4.2	75 MPa
γy	10.6	1.25	13.2	4.7	
γz	2.5	1.25	3.1	23.2	
DFM cementing	**Calculated Stress (MPa)**	**Security Coefficient JD**	**Increased Stress (MPa)**	**Margin**	
γx	1.2	1.25	1.5	1.2	3.5 MPa
γy	1.2	1.25	1.5	1.2	
γz	0.3	1.25	0.4	7.2	

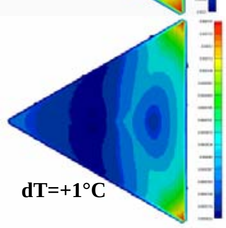
- Thermal environment calculation

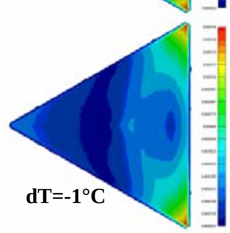
We have calculated the wavefront error for a beam of 40 mm diameter travelling centred on each mirror facets and the corresponding facets angle for the different following conditions by comparison with the nominal 20°C

- Homogeneous temperature -40°C.

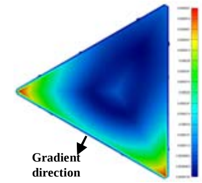


- Thermal inhomogeneity of 1°C on one facet. The two other remaining at 20°C.

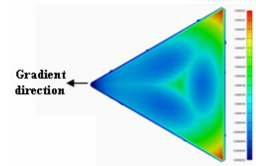




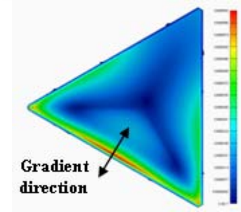
- In the plane of one facet



- Along one of edge



- Perpendicular to one facet



Results are summarized on Table 3.

Table 3: Results obtained

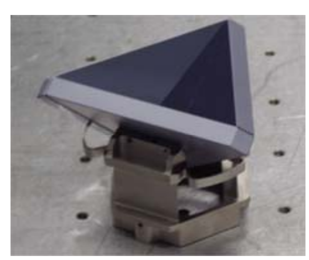
	Wavefront error (nm RMS)	Variation of tilt between Facets XY/Facets XZ (Arcsec.)	
T1=-40°C	4.1	0,0003	0,0000
T2=+60°C	1.0	0,0006	0,0000
dT=+1°C	1.5	0,0401	0,0257
dT=-1°C	3.1	0,0410	0,0248
Grad1°C flat	0.9	0,0090	0,0119
Grad1°C edge	0.8	0,0108	0,0016
Grad1°C thickness	2.6	0,0179	0,0204

In Conclusion:

⇒ First mode ~ 1000 Hz
⇒ Design is compatible with the stress limit of 3.5 MPa obtained on the shear stress of irreversible adherence.
⇒ Wavefront error induced by thermal environment is less than 6 nm RMS.
⇒ Angle variation < 0.05".

4. RESULTS

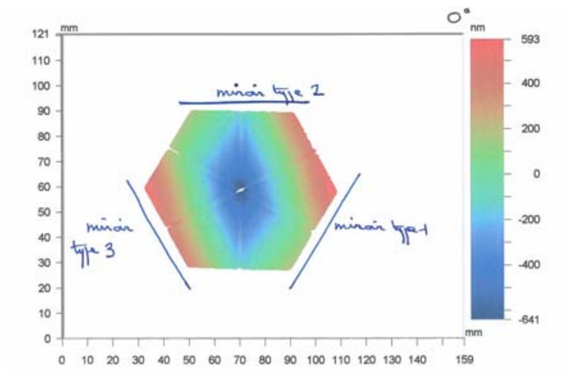
The cube corner was realised with a small offset of 2.5" on the 90°: 89°57'5" between the three facets.



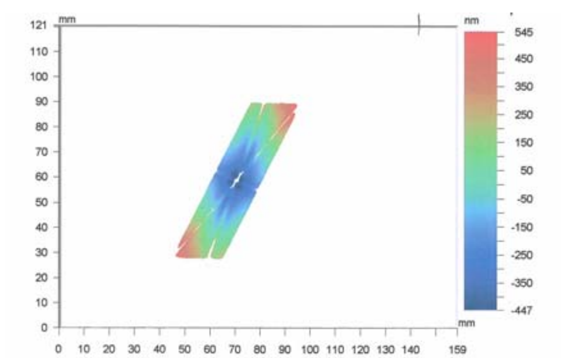
4.1 Wavefront error

- Full aperture

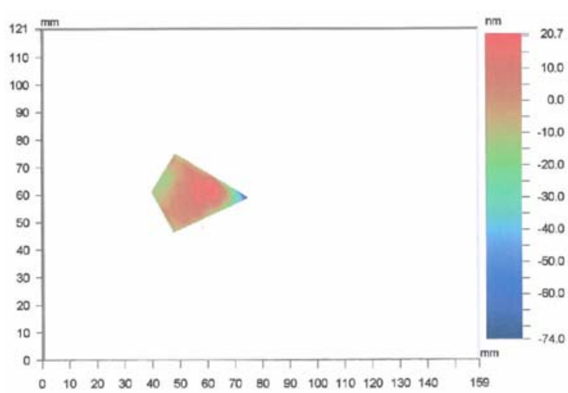
At 0° overall



At incidence 30°



- On one sub pupil



Each facets of the cube corner had a flatness better than 30 nm RMS leading to 9 nm to 17 nm RMS on each sub pupil.

4.2 Coating

We used a silver protected coating which have been qualified for Pleiades Telescope allowing to achieve in all the range of incidence (up to 30° with cube corner axis) a reflectivity > 70% with ATOX > 20 Krad.

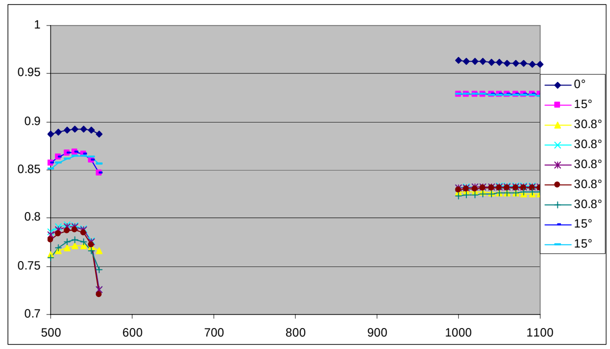


Fig. 8: Measurements on samples

4.3 Angle

We can achieve the requested angle with an error of ±1".

4.4 Weight

Total weight with mechanical interface < 460g for a useful surface perpendicular to the optical axis of 50 cm².

4.5 Angular stability

Angular stability over 3 months: < 0.025", which is near the accuracy of the interferometric measurement.

4.6 Thermal test environment

To validate the influence of a gradient due to enlightening of one facet of the cube corner we measured the angle of two facets with an interferometer, one facet being enlightened by a powerful beam (see Figure 9).

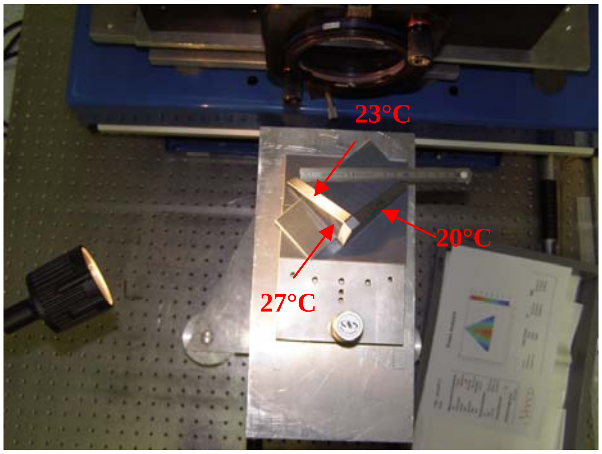
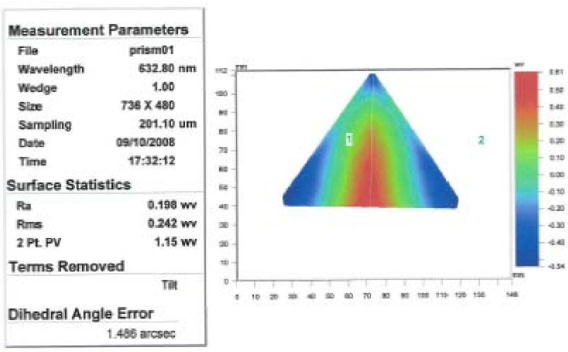
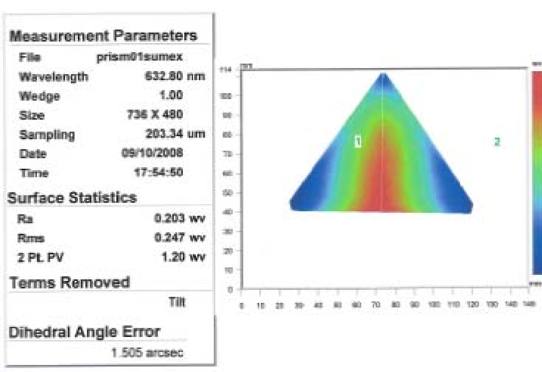


Fig. 9: Enlightened facet
Measurement with thermal gradient

Measurements of angle before and with the thermal quotient are shown in Figure 10.



Before thermal gradient



With thermal gradient
Fig. 10: Angle of measurements

The temperature increase one the enlightened facet was 7°C creating a change of angle less than < 0.02".

5. CONCLUSION

We have been able to use a good thermal conductive material for the manufacture of aHollow Cube Corner and have verified that, with the mechanical design of the DFM and the technique used to assemble the three parts of the cube corner, we were able to achieve a good stability.

We would like to conclude this report with a specific acknowledgement to CNES (FRANCE) for their confidence in SESO about the R&D contract CNES 6009500 of May 5th, 2006.