CHARA Technical Report

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Small Mirror Specifications

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1. INTRODUCTION AND GENERAL INFORMATION

The CHARA Array will employ five 1-m size, alt-azimuth style telescopes at a site on Mount Wilson in southern California. The telescopes will be housed separately and operated remotely from a central laboratory. Light from each telescope will follow a path to the Coudé focus of the telescope, where there will be one to three reflections required to balance the polarization and phase delay properties of the various beams. The light will be directed by subsequent flat mirrors through vacuum pipes to the central laboratory. There, additional flat mirrors will further balance the polarization and phase delay, then direct the beams in the POPs, which are optical delay segments of various length, required to equalize the optical delays. The light will then be directed through a periscope arrangement into the OPLEs, for fine adjustment of optical delay. The light will pass through beam compressors, reducing the nominal beam diameter to several centimeters. Flat mirrors will then direct the beams into the beam combination room and the various parts of the beam combination system.

This document summarizes specifications for manufacture of the numerous flat mirrors required for this optical layout.

2. MIRROR BLANK SUBSTRATES

The material specified for the mirror substrates is the titanium silicate glass sold under the trade name ULE.

If the substrates are procured as precut blanks, they should satisfy the prescription in Table 1. The tolerances are listed in Table 2. All edges should be beveled 0.04 $\pm$0.02 inch, except for the central alignment holes, which should be beveled 0.03 $\pm$0.01 inch

The tolerances on the blanks are set out in Table 2.

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TABLE 1. Mirror substrates dimensions.

Item	Pieces	Shape	Diameter (inch)	Thickness (inch)
1	5	Circular concave, central hole	14.06	2.06
2	35	Circular flat, central hole	8.00	1.26
3	40	Circular flat, central hole	6.50	1.06
4	7	Circular flat, central hole	6.00	1.06
5	5	Circular flat, mounting cavity	See CHARA TR XXX	
6	25	Circular flat	2.00	0.56
7	5	Circular convex	3.00	0.56

TABLE 2. Mirror substrates tolerances.

Dimension	Tolerance
Diameter	$+0.02/-0.00$ inch
Thickness	$+0.02/-0.00$ inch
Diameter of central holes	$+0.01/-0.00$ inch
Concentricity of central holes to outer diameter	$\sim$0.020 inch

3. FINISHED OPTIC SURFACE SPECIFICATIONS

3.1. General Requirements

All external surfaces not polished shall be ground with #80 grit or finer.

Central cavities/holes shall be concentric with the outer circumference to within 0.02 inch.

Each piece will be inscribed on the back with a 4-digit identification code to be supplied by CHARA. Each piece will have a permanent fiducial mark on the side.

In operation, the surface requirements for these optics are more stringent for sub-apertures than for the full aperture. The specifications distinguish a reduced aperture, over which the better surface is required, and a clear aperture over which the poorer surface is acceptable. The reduced aperture is a circular footprint within the clear aperture. The specifications require that the surface quality be obtained for any reduced aperture over the clear aperture.

Furthermore, both RMS and PTV errors are treated differently in the specifications. The RMS error applies to the full clear or reduced apertures, while the PTV error does not apply within an excluded zone near outside and inside beveled edges.

Optical testing shall be carried out with full-aperture interferometric test equipment capable of resolving surface to spatial scales of 1% of the full diameter of the piece. Optics must be delivered with test documentation including a direct image of the fringe pattern, with the location of the fiducial mark noted. An analysis of the residual aberrations confirming surface figure will also be supplied with the test results, showing at least peak-to-valley error and RMS residual from flat over the clear and reduced apertures (defined below), and also the best fit sphere and RMS residual from sphere within the reduced aperture.

3.2. Central alignment cavity and hole

Many of the pieces have a through hole in the center for alignment purposes. This consists of a 0.50 ±0.01 inch diameter cavity from the back of the mirror, which ends 0.25 ±0.04 inch from the front surface. A smaller, 0.060 +0.01/−0.00 inch hole penetrates through to the front of the mirror. At the 0.080 inch hole penetration of the front of the mirror, the bevel should be 0.030 ±0.01.

3.3. Item 1, Beam Reducer Primaries

Item 1, the Beam Reducing Telescope Primary, is discussed in detail in CHARA Technical Report No. 57.

3.4. Item 2, 8-inch mirrors

For these pieces, the entire front surface of the optic inside the described bevels should be figured flat. The clear aperture includes only a 6-inch high band across the center of the mirror — that is, a surface approximately 6×8 inches. In meeting the specification, the mirror may be rotated to select the orientation of the clear aperture. The mirror must be marked on the side with a permanent fiducial, indicating the axis of the selected reduced aperture.

The reduced aperture is defined as a footprint 2.5 inch in diameter anywhere within the clear aperture.

The RMS specification applies to the entire clear aperture.

The PTV specification applies to the clear aperture, but excludes regions within 0.5 inch of any bevel.

These mirrors have the central alignment cavity described above.

Other specifications are in Table 3.

TABLE 3. Specifications for 8″ mirrors

Diameter (inches)	8.00 (+0.02/−0.00)	
Thickness (inches)	1.20 (+0.02/−0.00)	
Clear aperture height	6.0	
Reduced aperture diameter	2.5	
PTV excluded zone	0.50	
Bevels	0.04 (±0.02)	
Alignment cavity and hole		See descriptive paragraph
Flatness (RMS waves on surface)	0.020	Over clear aperture
Flatness (PV waves on surface)	0.20	Over clear aperture
Flatness (RMS waves on surface)	0.010	Over reduced aperture
Scratch	60	Over clear aperture
Dig	20	Over clear aperture

3.5. Item 3, 6.5-inch mirrors

For these pieces, the entire front surface of the optic inside the described bevels (the clear aperture) should be figured flat. For specification purposes, the "reduced aperture" is defined. The reduced aperture extends only to within 0.50 inch of any bevel.

These mirrors have the central alignment cavity described above. Other specifications are in Table 4.

TABLE 4. Specifications for 6.5″ mirrors

Diameter (inches)	6.50 (+0.02/−0.00)	
Thickness (inches)	1.00 (+0.02/−0.00)	
Reduced aperture diameter	2.5	
PTV excluded zone	0.50	
Bevels	0.04 (±0.02)	
Alignment cavity and hole		See descriptive paragraph
Flatness (RMS waves on surface)	0.020	Over clear aperture
Flatness (PV waves on surface)	0.20	Over clear aperture
Flatness (RMS waves on surface)	0.010	Over reduced aperture
Scratch	60	Over clear aperture
Dig	20	Over clear aperture

3.6. Item 4, 6-inch Mirrors

For these pieces, the entire front surface of the optic inside the described bevels (the clear aperture) should be figured flat. For specification purposes, the "reduced aperture" is defined. The reduced aperture extends only to within 0.50 inch of any bevel.

These mirrors have the central alignment cavity described above. Other specifications are in Table 5.

TABLE 5. Specifications for 6″ mirrors

Diameter (inches)	6.00 (+0.02/−0.00)	
Thickness (inches)	1.00 (+0.02/−0.00)	
Reduced aperture diameter	2.5	
PTV excluded zone	0.50	
Bevels	0.04 (±0.02)	
Alignment cavity and hole		See descriptive paragraph
Flatness (RMS waves on surface)	0.020	Over clear aperture
Flatness (PV waves on surface)	0.20	Over clear aperture
Flatness (RMS waves on surface)	0.010	Over reduced aperture
Scratch	60	Over clear aperture
Dig	20	Over clear aperture

3.7. Item 5, Elliptical mirrors

These pieces will be completely specified in a future CHARA Technical Report.

3.8. Item 6, 2-inch mirrors

For these pieces, the entire front surface of the optic inside the described bevels (the clear aperture) should be figured flat. For specification purposes, the "reduced aperture" is defined. The reduced aperture extends only to within 0.25 inch of any bevel.

These mirrors have the central alignment cavity described above. Other specifications are in Table 6.

TABLE 6. Specifications for 2″ mirrors

Diameter (inches)	2.00 (+0.02/−0.00)	
Thickness (inches)	0.50 (+0.02/−0.00)	
Reduced aperture diameter	2.5	
PTV excluded zone	0.50	
Bevels	0.04 (±0.02)	
Alignment cavity and hole		See descriptive paragraph
Flatness (RMS waves on surface)	0.020	Over clear aperture
Flatness (PV waves on surface)	0.20	Over clear aperture
Flatness (RMS waves on surface)	0.010	Over reduced aperture
Scratch	60	Over clear aperture
Dig	20	Over clear aperture

3.9. Item 7

Item 7, the Beam Reducing Telescope secondary, is discussed in detail in CHARA Technical Report No. 57, as updated July 1998.

4. A BUDGET DRIVEN COMPROMISE

Estimates showed that it would be relatively expensive to obtain all of the optics to the flatness specifications listed above. In order to control costs and keep options open, several procurement strategies were developed.

First, all of the substrates were acquired in a single, bulk purchase. This resulted in significant savings in materials costs. By separating the procurement of the substrates from the contracts for optical figuring, CHARA accepts some risk of possible disagreement over whether or not the substates are of the required quality, for example to meet the dig spec, which is material dependent.

Second, it was decided to initially procure the flats figured to a reduced specification. This specification will be ample for infrared operation of the array. At visible wavelengths, it will result in some reduction in visibility. However, the importance of this reduction will not be known accurately until the full optical system has been tested with the actual atmosphere.

The expectation is that, if improved optical quality is desired, flat optics can be figured to better tolerance. In fact, by procuring the flats initially to moderate tolerance, and thus attracting bids from many qualified vendors, and later soliciting bids to improve the flats to a more stringent specification, there should be a savings in total cost. Several prospective vendors confirmed that this expectation is reasonable. At least, there should be no cost penalty. And by determining the final specifications after initial system wavefront and visibility tests, the specification can be prepared with greater confidence.

For reference, the specifications utilized in preparing the invitation to bid are attached below.

Appendix 1. 2-inch Flat Specifications

A. INVITATION TO BID

CHARA invites bids to fabricate 25 flat mirrors. CHARA will supply properly selected and dimensioned ULE substrates, as described in Table 7. Supplied substrates will have been ground with #80 grit or finer, and beveled approximately 0.03 inch at 45°. Blank dimensions will be satisfactory as supplied. Finished thickness specification allows optional removal of additional material during further fine grinding. Bids are invited to fine grind, polish and figure the mirror surfaces.

B. FINISHED OPTIC SPECIFICATIONS

Each piece will be inscribed on the back with a 4-digit identification code to be supplied by CHARA. Each piece will have a permanent fiducial mark on the side.

Optical testing shall be carried out with full aperture interferometric test equipment capable of resolving surface to spatial scales of 1% of the full diameter of the piece. Optics must be delivered with test documentation including a direct image of the fringe pattern, with the location of the fiducial mark noted, and a statement as to whether the image is direct or inverted. An analysis of the residual aberrations confirming surface figure will also be supplied with the test results, showing at least peak to valley error and RMS residual from flat, and also the best fit sphere and RMS residual from sphere.

TABLE 7. Mirror substrates dimensions.

Item	Pieces	Shape	Diameter (inch)	Thickness (inch)
1	25	Circular Flat	2.00 (+0.04/−0.00)	0.56 (+0.04/−0.00)

The clear aperture is 1.8 inch in diameter.

These mirrors have no central hole or cavity.

Specifications are in Table 8.

TABLE 8. Specifications for 2″ mirrors

Diameter (inches)	2.00 (+0.04, -0.02)	
Thickness (inches)	0.56 (+0.04, -0.02)	
Clear aperture diameter	1.8	
Bevels	0.03 (±0.02)	
Flatness (PTV waves on surface)	0.05	Over clear aperture
Scratch	60	Over clear aperture
Dig	20	Over clear aperture

Appendix 2. 6-inch Mirror Specifications

A. INVITATION TO BID

CHARA invites bids to fabricate 7 flat mirrors. CHARA will supply properly selected and dimensioned ULE substrates, as described in Table 9. Supplied substrates will have been ground with #80 grit or finer, and beveled approximately 0.03 inch at 45°. Blank dimensions will be satisfactory as supplied. Finished thickness specification allows optional removal of additional material during further fine grinding. Bids are invited to fine grind, polish and figure the mirror surfaces.

B. FINISHED OPTIC SPECIFICATIONS

Each piece will be inscribed on the back with a 4-digit identification code to be supplied by CHARA. Each piece will have a permanent fiducial mark on the side.

Optical testing shall be carried out with full aperture interferometric test equipment capable of resolving surface to spatial scales of 1% of the full diameter of the piece. Optics must be delivered with test documentation including a direct image of the fringe pattern, with the location of the fiducial mark noted, and a statement as to whether the image is direct or inverted. An analysis of the residual aberrations confirming surface figure will also be supplied with the test results, showing at least peak to valley error and RMS residual from flat and also the best fit sphere and RMS residual from sphere.

The clear aperture is 5.5 inch in diameter.

Specifications are in Table 10.

TABLE 9. Mirror substrates dimensions.

Item	Pieces	Shape	Diameter (inch)	Thickness (inch)
1	7	Circular flat	6.00 (+0.04, -0.00)	1.06 (+0.04, -0.00)

TABLE 10. Specifications for 6″ mirrors

Diameter (inches)	6.00 (+0.04/−0.02)	
Thickness (inches)	1.06 (+0.04/−0.02)	
Clear aperture diameter	5.5	
Bevels	0.03 (±0.02)	
Flatness (PTV waves on surface)	0.05	Over clear aperture
Scratch	60	Over clear aperture
Dig	20	Over clear aperture

Appendix 3. 6.5-inch Mirror Specifications

A. INVITATION TO BID

CHARA invites bids to fabricate 40 flat mirrors. CHARA will supply properly selected and dimensioned ULE substrates, as described in Table 11. Supplied substrates will have been ground with #80 grit or finer, and beveled approximately 0.03 inch at 45°. Blank dimensions will be satisfactory as supplied. Finished thickness specification allows optional removal of additional material during further fine grinding. Bids are invited to drill a central hole, fine grind, polish and figure the mirror surfaces.

B. FINISHED OPTIC SPECIFICATIONS

Each piece will be inscribed on the back with a 4-digit identification code to be supplied by CHARA. Each piece will have a permanent fiducial mark on the side.

Central cavities/holes shall be concentric with the outer circumference to within 0.02 inch.

Optical testing shall be carried out with full aperture interferometric test equipment capable of resolving surface to spatial scales of 1% of the full diameter of the piece. Optics must be delivered with test documentation including a direct image of the fringe pattern, with the location of the fiducial mark noted, and a statement as to whether the image is direct or inverted. An analysis of the residual aberrations confirming surface figure will also be supplied with the test results, showing at least peak to valley error and RMS residual from flat, and also the best fit sphere and RMS residual from sphere.

The clear aperture is 6.1 inch in diameter.

Specifications are in Table 12.

B.1. Central alignment cavity and hole

All of the pieces have a through hole in the center for alignment purposes. This consists of a 0.50 ±0.01 inch diameter cavity from the back of the mirror, which ends 0.50 ±0.04 inch from the front surface. A smaller, 0.060 +0.01/−0.00 inch hole penetrates through to the front of the mirror. At the 0.060 inch hole penetration of the front of the mirror, the bevel should be 0.030 ±0.01.

TABLE 11. Mirror substrates dimensions.

Item	Pieces	Shape	Diameter (inch)	Thickness (inch)
1	40	Circular flat	6.50 (+0.04, -0.00)	1.06 (+0.04, -0.00)

TABLE 12. Specifications for 6.5″ Mirrors.

Diameter (inches)	6.50 (+0.04/−0.02)	
Thickness (inches)	1.06 (+0.04/−0.02)	
Bevels	0.03 (±0.02)	
Clear aperture	6.1	
Alignment cavity and hole		See descriptive paragraph
Flatness (PTV waves on surface)	0.05	Over clear aperture
Scratch	60	Over clear aperture
Dig	20	Over clear aperture

Appendix 4. 8-inch Mirror Specifications

A. INVITATION TO BID

CHARA invites bids to fabricate 35 flat mirrors. CHARA will supply properly selected and dimensioned ULE substrates, as described in Table 13. Supplied substrates will have been ground with #80 grit or finer, and beveled approximately 0.03 inch at 45°. Blank dimensions will be satisfactory as supplied. Finished thickness specification allows optional removal of additional material during further fine grinding. Bids are invited to fine grind, polish and figure the mirror surfaces. Central holes are to be added to 25 of the mirrors.

B. FINISHED OPTIC SPECIFICATIONS

Each piece will be inscribed on the back with a 4-digit identification code to be supplied by CHARA. Each piece will have a permanent fiducial mark on the side.

Central cavities/holes shall be concentric with the outer circumference to within 0.02 inch.

Optical testing shall be carried out with full aperture interferometric test equipment capable of resolving surface to spatial scales of 1% of the full diameter of the piece. Optics must be delivered with test documentation including a direct image of the fringe pattern, with the location of the fiducial mark noted, and a statement as to whether the image is direct or inverted. An analysis of the residual aberrations confirming surface figure will also be supplied with the test results, showing at least peak to valley error and RMS residual from flat, and also the best fit sphere and RMS residual from sphere.

The clear aperture is 7.5 inch in diameter.

Specifications are in Table 14.

B.1. Central alignment cavity and hole

Twenty-five of the pieces have a through hole in the center for alignment purposes. This consists of a 0.50 ±0.01 inch diameter cavity from the back of the mirror, which ends 0.50 ±0.04 inch from the front surface. A smaller, 0.060 +0.01/−0.00 inch hole penetrates through to the front of the mirror. At the 0.060 inch hole penetration of the front of the mirror, the bevel should be 0.030 ±0.01.

TABLE 13. Mirror substrates dimensions.

Item	Pieces	Shape	Diameter (inch)	Thickness (inch)
1	35	Circular flat	8.00 (+0.04/−0.00)	1.26 (+0.04/−0.00)

TABLE 14. Specifications for 8″ mirrors

Diameter (inches)	8.00 (+0.04/−0.02)	
Thickness (inches)	1.26 (+0.04/−0.02)	
Clear aperture diameter (inches)	7.5	
Bevels	0.03 (±0.02)	
Central hole (25 pieces)		See descriptive paragraph
Flatness (PTV waves on surface)	0.05	Over clear aperture
Scratch	60	Over clear aperture
Dig	20	Over clear aperture