

Silicon Elements for IR Objective Lenses

TYDEX produces a wide range of elements made of silicon. We ensure strong control on every step of element production, from material selection to the measurement of obtained parameters of polished elements and coating characteristics. That is especially important in the manufacturing of precision imaging systems. This type of approach to the production of a set of large silicon optics for IR objective is described below.



Figure 1. Photo of Si meniscus lens D210 mm and plano-convex lens D160 mm.

The objective is intended for operating in two middle IR bands: 1.6-3.0 μm and 3.5-5.5 μm . Its design incorporates 17 elements: 14 meniscus and plano-convex lenses with diameters from 10 mm to 210 mm and 3 plates with dimensions up to 134x198 mm.

When manufacturing such multi-element imaging devices two important points should be taken into consideration: transmittance of the whole system and image distortion. These parameters depend on material quality (i) and surface accuracy (ii). Below we discuss our approach to control of these parameters (we will not touch the third critical point - coating parameters).

Material selection and control

For imaging systems the right choice of material is of utmost very importance. Defects in the material can cause image distortion and violate the system operation. This is the reason why so much attention is paid to selecting the material and its control.

To provide the proper quality of material, silicon ingots with special parameters (dislocation-free optical grade monocrystalline Cz-Si with high homogeneity and transparency in the working range) were grown. After a few required ingots with diameter up to 219mm were ready the quality of material (resistance homogeneity, dislocation density, transmittance in the working range) is being controlled on samples prepared from each ingot. The typical transmission curve is presented here.

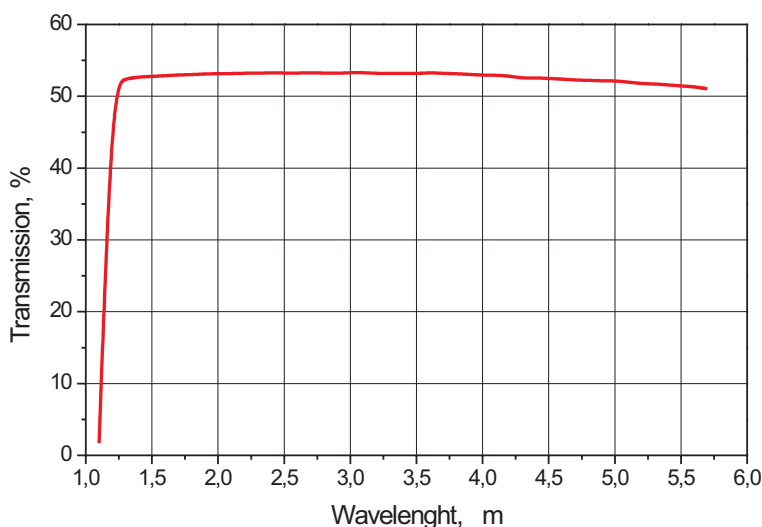


Figure 2. Silicon transmission in the 1.1 - 5.7 μm spectral range. Sample thickness is 10 mm.



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SURFACE ACCURACY CONTROL

As mentioned above, the second important parameter that should be considered is surface errors. Modern equipment allows to carry out complete interferometric control of a the whole surface or any part of it. Computer data processing enables us to obtain detailed information about different kinds of errors: regular errors (astigmatism, zonal error, coma), local errors, peak-to-valley value, etc. In addition, representation of errors becomes easy to interpret.

For interferometric control Fizeau scheme is applied, $\lambda_c = 0.6328 \mu\text{m}$ (HeNe laser line). Additional equipment such as telescopic expanders and measuring objectives is used if required by surface shape and radius of curvature. Evaluation of the form error of a surface is being carried out in phase mode by means of measuring the deformation of the wavefront reflected from the controlled surface compared to test reference surface. Specialised integrated software is used to create phase data arrays and their further power polynomial approximation for surface error calculations.

Here we present as examples the results of such control for 2 surfaces: 1 – concave surface of meniscus D210 mm lens, and 2 – plane surface of 198x134 mm plate.

1. Interferometric measurements of errors of meniscus lens D210 mm

Controlled surface: concave $R = -206.99\text{mm}$
Test area: clear aperture – central D206mm
Measurement units: microns
Reference surface: sphere

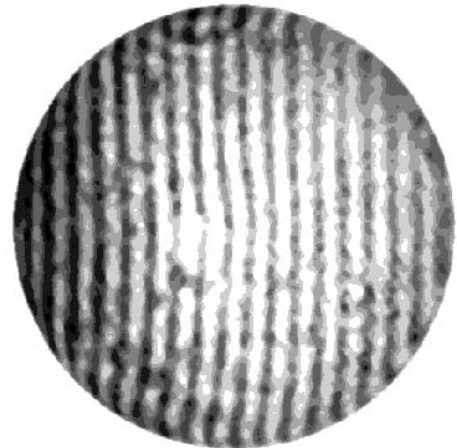


Figure 3. Interferogram of surface.

Regular errors:

D=	.080	LX=	2.839	LY=	-.013	C=	2.829	RMS(W)=	.031		
A=	.050	FIA=	.354					RMS(W-A)=	.023	FA=	.442
B0=	-.025	RZ=	.037					RMS(W-Z)=	.029	FZ=	.131
B2=	.149										
B4=	-.149										
C=	.110	FIC=	164.892					RMS(W-C)=	.028	FC=	.178

Local errors:

R= .139
RMS(M)= .015

Parameters of surface:

RMS	MIN	MAX	R	STRL	STRH
.031	-.144	.092	.237	.964	.988
X :	-1.000	.000			
Y :	.000	-1.000			



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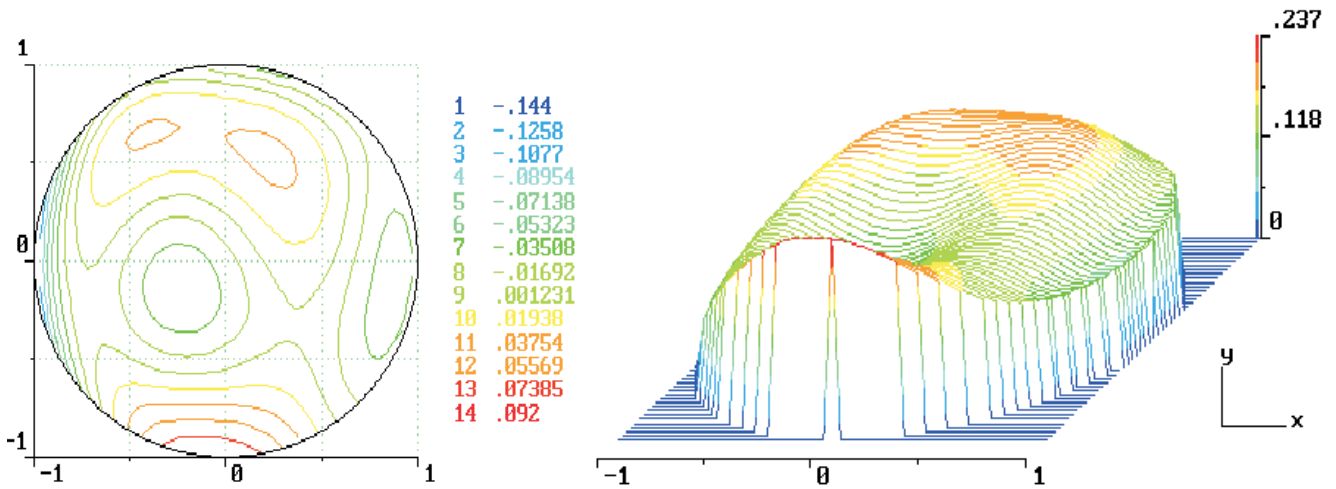


Figure 4. Reconstructed wavefront topography presented at planar and 3-d plots.

2. Interferometric measurements of errors of plane parallel plate 198x134 mm

The surface undergoes measurements in 2 areas: center zone of dimensions 70x70 mm (approximately the area occupied by incident ray) and the whole aperture 194x130 mm.

Controlled surface S1: plane $R = \text{infinity}$
 A/ Test area: 70 x 70 mm
 Measurement units: microns
 Reference surface: plane

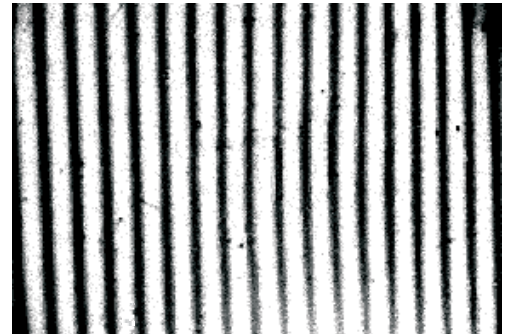


Figure 5. Interferogram of surface.

Regular errors:

D= .000 LX= 1.447 LY= .033 C= .964 RMS(W)= .014
 A= .045 FIA= 82.986 RMS(W-A)= .010 FA= .489
 B0= -.014 RZ= .023 RMS(W-Z)= .012 FZ= .235
 B2= .064
 B4= -.045
 C= .012 FIC= 173.740 RMS(W-C)= .014 FC= .009

Local errors:

R= .076
 RMS(M)= .007

Parameters of surface:

RMS	MIN	MAX	R	STRL	STRH
.014	-.035	.044	.079	.993	.998
X :	-.680	.680			
Y :	.680	-.680			



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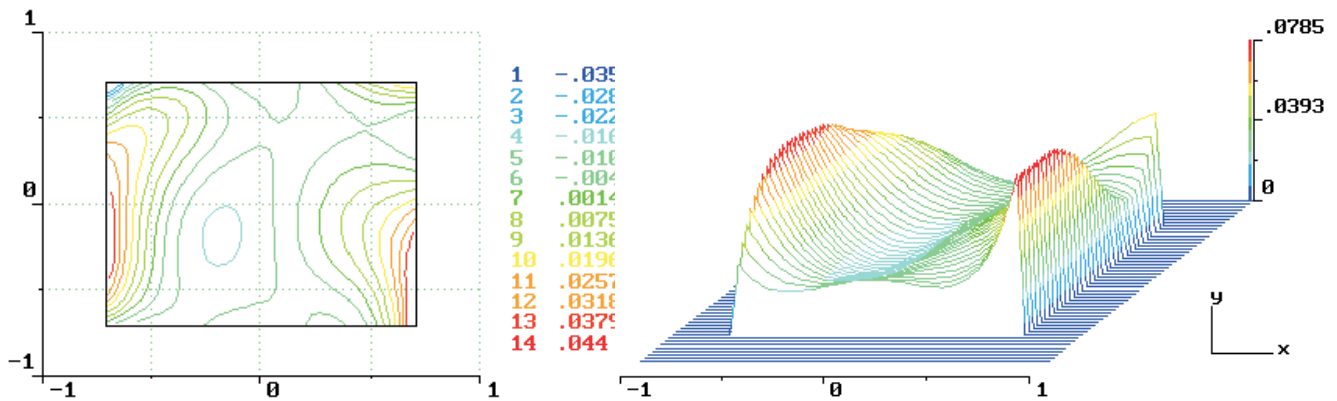


Figure 6. Reconstructed wavefront topography presented at planar and 3-d plots.

B/ Test area: 194 x 130mm
 Measurement units: microns
 Reference surface: plane

Regular errors:

D= .000 LX= 2.811 LY= .053 C= 2.045 RMS(W)= .024
 A= .104 FIA= 81.477 RMS(W-A)= .011 FA= .787
 B0= -.020 RZ= .083 RMS(W-Z)= .016 FZ= .561
 B2= .039
 B4= .117
 C= .022 FIC= 50.186 RMS(W-C)= .023 FC= .014

Local errors:

R= .077
 MS(M)= .012

Parameters of surface:

RMS	MIN	MAX	R	STRL	STRH
.024	-.036	.076	.112	.978	.993
X : -.200	-.680				
Y : -.480	.440				

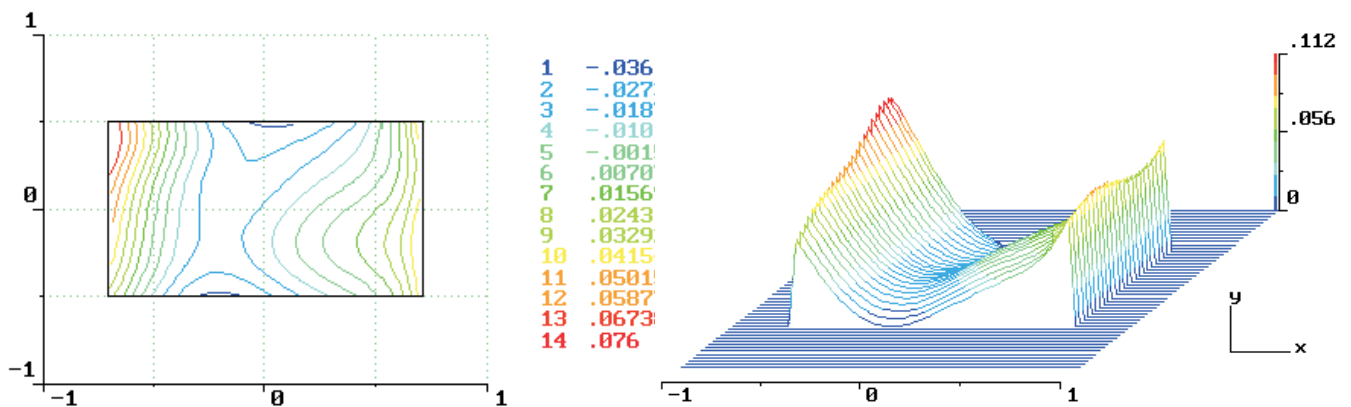


Figure 7. Reconstructed wavefront topography presented at planar and 3-d plots.

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The detailed description of the notation is presented here

Part 1. Regular errors

D, Lx, Ly, C	Parameters of reference surface D – sag of the sphere at the edge of pupil (D=0 for plane reference surface) Lx, Ly – tilt of sphere C – constant
RMS(w)	RMS of wavefront with regard to reference surface
A, FIA	value and angle of turn of astigmatism
RMS(w-a)	RMS of wavefront beyond astigmatism
FA	statistic estimation of the contribution of astigmatism to the complete wavefront distortion
B0,B2,B4,...	coefficients of zonal error at corresponding power P ($p^2 = x^2 + y^2$) or at Zernike polynomial
RZ	span of zonal error
RMS(w-z)	RMS of wavefront except zonal error
FZ	statistic estimation of the contribution of zonal error to the complete wavefront distortion
C, FIC	value and angle of turn of coma error
RMS(w-c)	RMS of wavefront except coma
FC	statistic estimation of the contribution of coma error to the complete wavefront distortion

Part 2. Local errors (errors of wavefront with power higher than 4th)

R	span of local errors
RMS(M)	RMS of local errors

Part 3. Parameters of surface under control

RMS	RMS of surface error (RMS = RMS(w))
MIN	minimal value of surface (valley)
MAX	maximal value of surface (peak)
R	span (PtV)
STRL	lower bound of Schtrel number
STRM	upper bound of Schtrel number
X, Y	test area coordinates

Such thorough control on each step of production can guarantee that all parameters of the item meet specifications required by customer and that the device will operate in a proper way.



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