June 18, 1999

Optical survey of silicon detector modules

H.-G. Moser

Max Planck Institut für Physik, Munich, Germany

Abstract

By observing the distorsions of a regular grid pattern reflected by the module surface the surface shape of a module can be reconstructed. This method allows to resolve a sagitta of 10 μm over the full length of a module (12 cm).

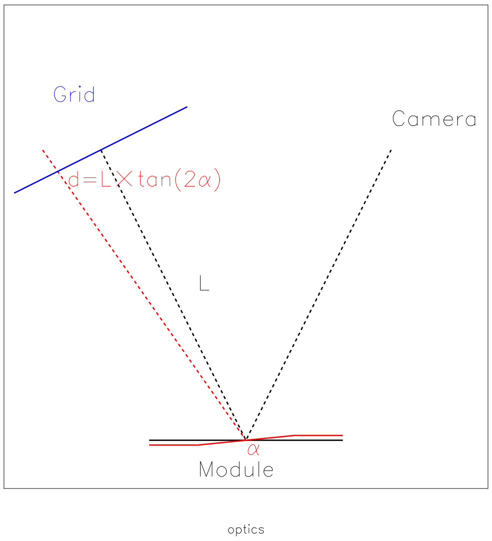

Figure 1: Principle of measurement: A surface distorsion changes the reflection angle and causes a displacement of the grid pattern viewed by a video camera.

1 Introduction

The method offers a simple and cheap way for:

- Quality control.
- Measurment of thermal distorsions.

2 Principle of measurement

As shown in fig. 1 a surface distorsion with angle α changes the original reflection angle β to $\beta + 2\alpha$ (in the projection as shown in figure 2). Hence the grid position is displaced by $\delta \approx L\tan(2\alpha)$. So, measuring δ the surface deformation angle α can be derived. For the exact relation we refer to fig. 2 and the following definitions:

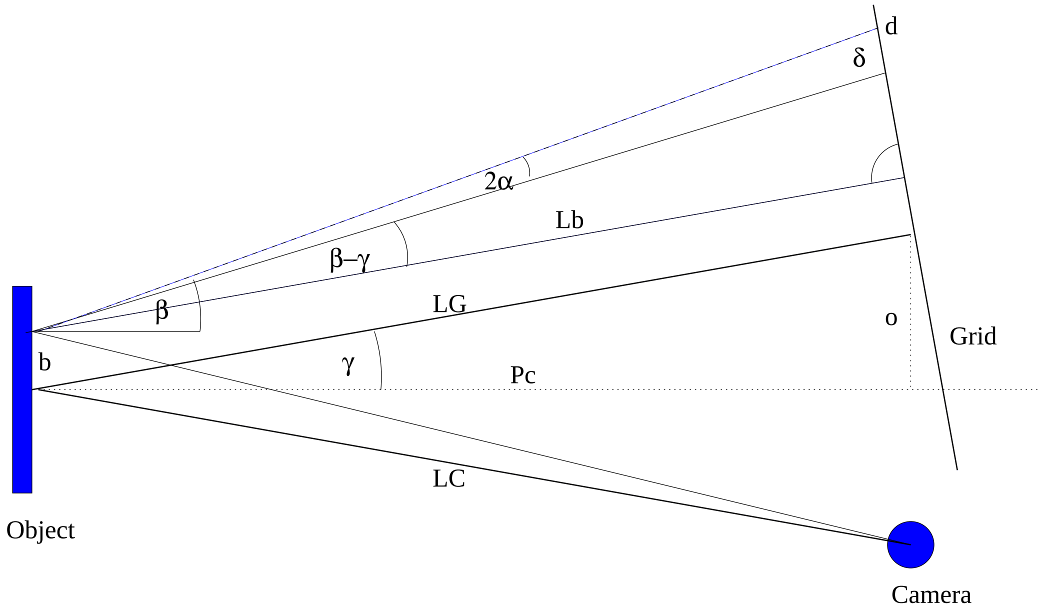

Figure 2: Parameter definitions

L_c	distance camera - object
L_g	distance grid - object
o	displacement grid center - axis of setup
$\gamma = \sin^{-1}(o/L_g)$	viewing angle of camera
$P_c = L_c \sin(\gamma)$	projected distance camera - object
b	position of object
$\beta = \tan^{-1}((o+b)/P_c)$	viewing angle of b
$L_b = L_g - b\sin(\gamma)$	distance b - grid
$X = \frac{L_c}{L_g+Lc}$	reduction factor of grid projected on module

Now the difference between actual an displaced position of b is given by:

$$\delta = L_g \tan(\beta - \gamma + 2\alpha) - L_g \tan(\beta - \gamma) \quad (1)$$

$$= L_g \frac{\tan(2\alpha)}{\cos(\beta-\gamma)} \quad (2)$$

A similar relation holds for the orthotogonal projection.

A severe systematic error would appear if the geometry of the setup changes. E.g if the module is displaced out of its plane by δ this introduces (here we simplify for $\gamma = 0$):

$$L'_g = L_g - \delta$$

$$L'_c = L_c - \delta$$

this will change the magnification of the imaged grid, and apparently

$$g' = g\frac{f}{L_g + L_c}\frac{L_g + L_c - 2\delta}{f} = g(1 - \frac{\delta}{L})$$

(assuming $L_g \approx L_c \approx L$). This introduces a change of $\tan\alpha$ by

$$\Delta\tan\alpha = \frac{g - g'}{2L} = \frac{g\delta}{2L^2}$$

This applies locally, and gives a z deviation of

$$\Delta z = Xg\Delta\tan\alpha = \frac{g^2\delta}{2L^2}$$

Integrated over the full module this results in a parabolic distorsion

$$z_{tot} = X\frac{1}{2}\frac{M}{g}^2 g\Delta\tan\alpha = X\frac{1}{2}M^2\frac{\delta}{2L^2}$$

Numerically this is

$$z_{tot} \approx \delta \times 10^{-3}$$

So one millimeter displacement gives a distorsion of one micron !

3 Setup

The setup is shown in fig. 3. We use:

- Camera: Hitachi HVC20 (1/2" CCD 795(H) x 596(V))
- Lens: 4.0/36 mm
- Framegrabber: NI PCI-1408
- Software: Labview/ImagVision

This is identical with assembly stage, so only an additional video camera is necessary.
The dimensions of the setup have to be chosen satisfying following critia:
The camera has a 1/2" CCD, in x this corresponds to 6.4 mm active length covered by 796 pixels. Hence the angular resolution using a lens f is:

$$\beta = \frac{6.4\ mm}{796}\frac{1}{f}.$$

*

*In practice the resolution is better. The image of a gridline is distributed over a couple of pixels and calculating the center of gravity using a certain range of the line results in a sub-pixel resolution.

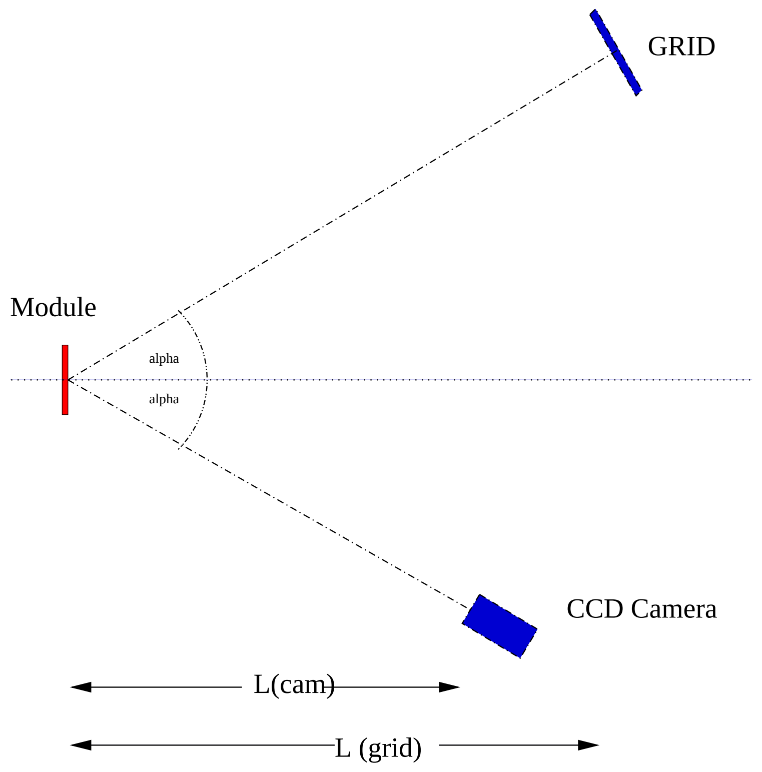

Figure 3: Schematic Setup

The module has a lenght of 12 cm, hence the distance between camera and module should be

$$L_c = \frac{120\ mm}{6.4\ mm} f \approx 20f$$

so that the module covers the CCD. Given that, the grid dimension at distance L_g from the module has to be

$$d_{grid} = \frac{L_c + L_g}{f} \times 6.4\ mm.$$

Concerning the resolution which should be achieved we want to resolve a kink in the module with 10 μm displacement. The deflection angle is then

$$2\alpha \approx 2 \times \frac{10\ \mu m}{5\ mm} = 4 \times 10^{-4}$$

This corresponds to a camera view angle of

$$\beta' = 2\alpha \frac{L_g}{L_g + L_c}$$

Using a camera lens with $f = 36\ mm$ one obtains and requiring $\beta = \beta'$ we find:

$$L_c = 675\ mm \qquad L_g = 825\ mm$$

Clearly a point of the grid projected back to the object has a certain size. E.g for the 4.0/36 mm lens the point will be spread over 5 mm. Hence only structures larger than ≈ 5 mm can be resolved. Since the distorsion of a module should be continuous, and hence spread out over a large size, this should not be a problem. Only steps, like where the two detectors are joined together, can cause problems. Certainly it helps to reduce the aperture of the lens.

4 Reconstruction algorithm

Asume a series of N grid lines along y which are equally spaced in x (Δx). The software scannes orthotogonal to the lines along y_j and finds the actual x-position x^a_{ij} $(i = 1, N)$. Then the difference to the expected position is calculated: $\delta x_{iJ} = x^a_{ij} - x^e_{ij}$, which is then converted in the surface angle $\tan \alpha_{ij} = \delta x_{ij}/(2L_g)$. The x-position is converted in module coordinates by $x_{ij} = X \times x^e_{ij}$. This gives a series of angles and positions. The surface contour z^x_{ij} is now calculated using a spline interpolation (starting with $z^x_{1j} = 0$):

$$ax^2 + bx + c = z_x$$

$$2ax + b = \tan \alpha$$

with

$$ax^2_{ij} + bx_{ij} + c = z^x_{ij}$$
$$2ax_{ij} + b = \tan \alpha_{ij}$$
$$2ax_{i+1,j} + b = \tan \alpha_{i+1,j}$$

so, a, b and c can be calculated and then

$$z^x_{i+1,j} = ax_{i+1,j} + bx_{i+1,j} + c$$

For each line at constant y_j one gets a surface contour z^x_{ij}. Using the orthotogonal grid lines along x line contours z^y_{ij} at constant x_i along y_{ij} can be calculated.
The absolute deviation must now be calculated along a certain path in the x-y plane. E.g. it is arbitraily defined that $z^x_{mn} = z^y_{mn} = 0$ which implies the definition $z^x_{mj} \rightarrow z^x_{mj} - z^x_{mn}$ and $z^y_{in} \rightarrow z^y_{in} - z^y_{nm}$. To reach a point x_k, y_l one can chose a path first along x giving $z_{kn} = z^x_{kn}$, then one moves along x resulting in $z_{kl} = z^x_{kn} + z^y_{kl}$. Another path would be to go first along y and then along x resulting in $z'_{kl} = z^y_{ml} + z^x_{kl}$. Within errors both results should be the same.
In fact the condition that $z'_k l = z_k l$ for any path can be used to correct for systematic effects. Especially if the grid is rotated in the x-y plane results in differences which can be easily corrected imposing consistency of different reconstruction paths.

5 Examples

5.1 Absolute measurements

A calibration of the system can be obtained by reconstructing the surface of a flat mirror. An example is shown in fig. 6. The mirror surface was measured using a Mitotoyo coordinate

measurng machine to be flat within 4 μm (maximal difference beween lowest and highest point). The reconstruction yields a deviation of 7 μm, which confirms the expected resolution of about 10 μm. If the mirror is distorted by screwing it on a bowed mount, the resulting distorsion is clearly resolved (fig. 7).
A real prototype module is shown if figure 8. Here the distorsion is 47 μm.
The remaining deviations of 7 μm as seen in picture 6 may have following origin:

- residual distorsions of the mirror.
- lens distorsions
- distorsions of the (printed) grid
- deviations of the center of gravity algorithm for grid reconstruction

In principle it is possible to improve on each of these items. However, since the module tolerances required are in the order of 50 μm this is not necessary for our application.
A second example is the measurement of the flatness of a real CIS silicon detector. The detector was put on a flat surface without constraining it. The measurement shows a wave-like distorsion with an amplitude of 20 μm. The reconstructed surface shape is shown in Fig. 9.

5.2 Relative measurements

The main uncertainty of absolute measurements is the definition and calibration of the absolute grid coordinates. Relative measurements, however, do not suffer from these problem and can reach an even better resolution. A relative measurement means to measure the differences of two grids, e.g. during a thermal cycle. The first grid image serves a reference and the differences to these reference grid is measured using the following images. Reconstructed is the difference of the surface contour corresponding to those images. Clearly the absolute location of the gridlines does not matter any more, as long as the position of the module is not chaged during the series. An example is shown in figures 10 and 11: A prototype module was equipped with a heater foil mounted between the two back to back detectors. The module was fixed at the two location points (separated in y). The reference picture was taken. Then the module was heated to about 50 deg and a second picture was taken. The difference shows a clear bowing along y as expected due to thermal expansion and a tilt in x (10). The heater was switched off and the module allowed to cool down again. Then the next picture was taken and compared to the first one (11). The module went back in its old shape, the residual distorsions are in the order of 2 μm, showing the accuracy of this relative measurement.

6 Conclusions

The optical survey offers a low cost method to test the mechanical properties of the module and offers a quality control method. What the method can do:

- Mapping of the surface contour with 10 μm precision.

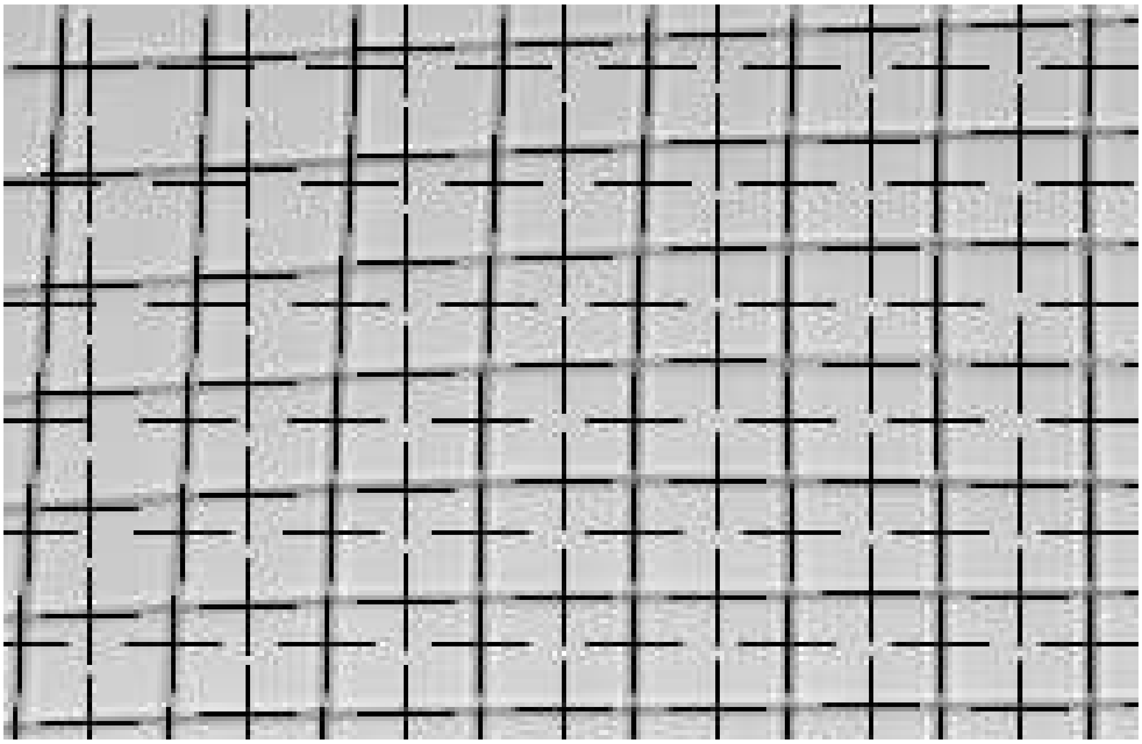

Figure 4: Picture of the reflected grid. The black crosses indicate the grid coordinates found by the pattern recognition (due to the printing the image has lost most of its initial quality).

- Real time reconstruction under thermal cycling.

What it cannot do

- Correlate both surfaces of a module (at least that's not easy)
- Measure the absolute thickness.
- Spot steps or very small structures (below a couple of mm).

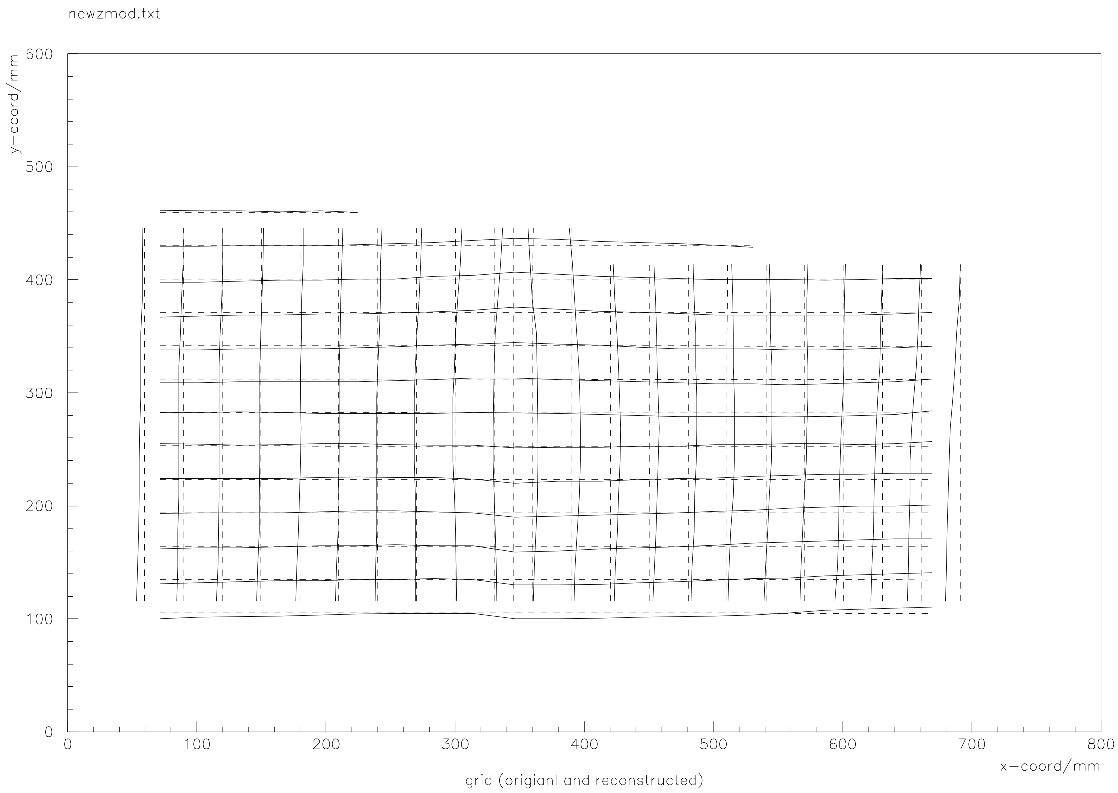

Figure 5: Reconstruced image of reflected grid (solid lines). The dashed lines show the expected positions for a perfectly flat surface

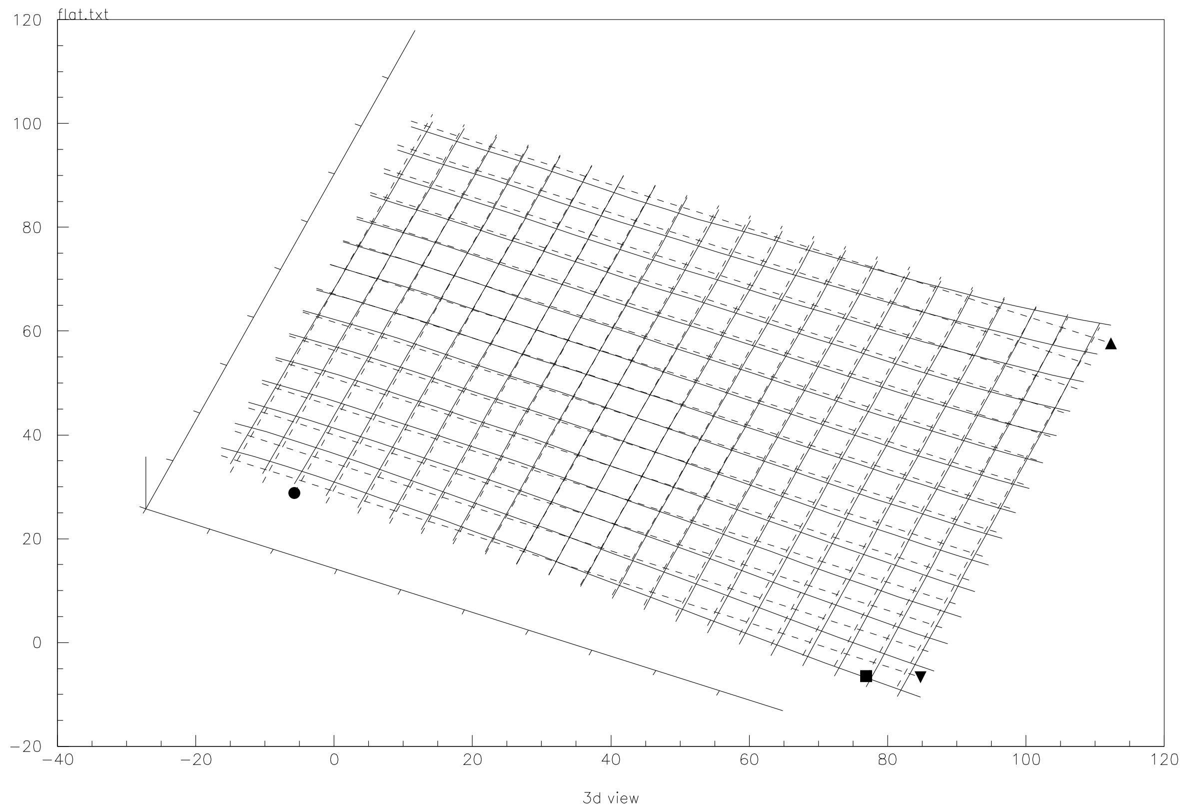

Figure 6: Reconstructed surface of a flat mirror. The flatness of the mirror is measured to be better then $4\mu m$. The reconstruction shows a maximal distorsion of $7\mu m$, which compares well with the expected resolution of $10\mu m$.

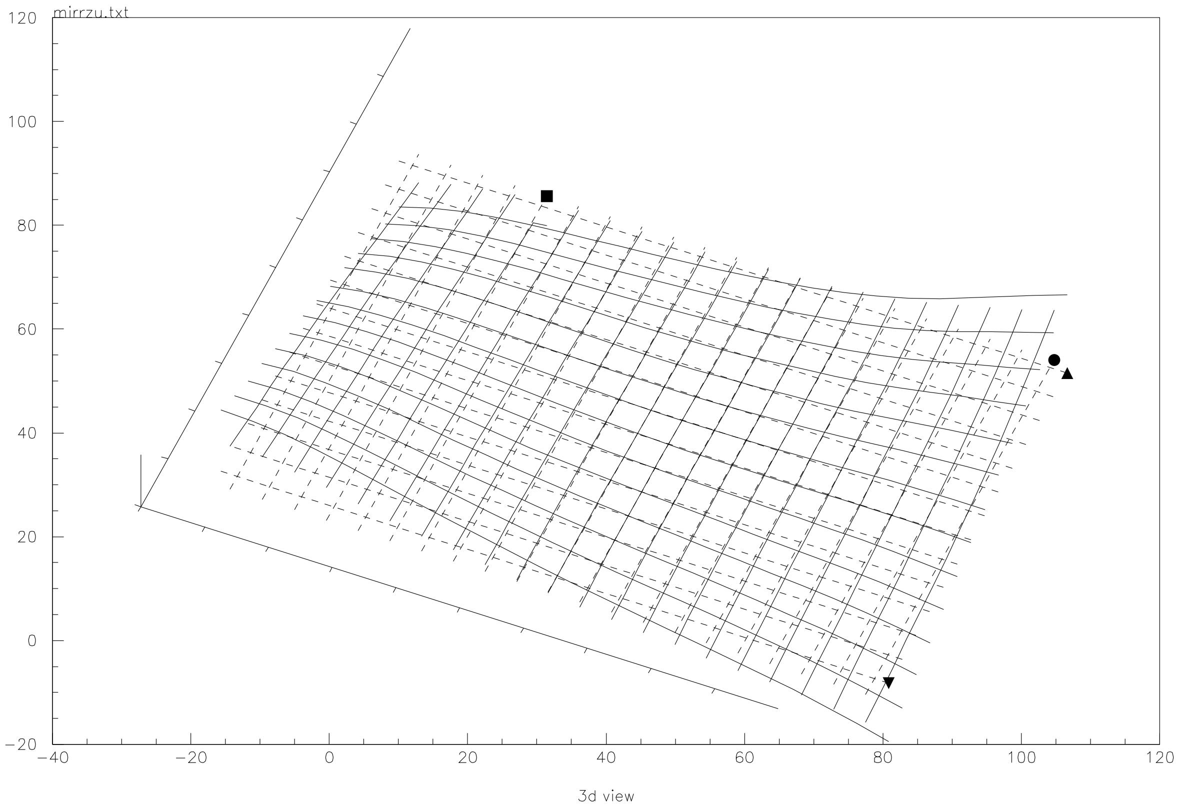

Figure 7: Reconstructed surface of a the same mirror, no slightly bowed by the mirror mount. The distorsion of the mirror was measured to be about $35\mu m$. The reconstruction shows a distorsion of $27\mu m$.

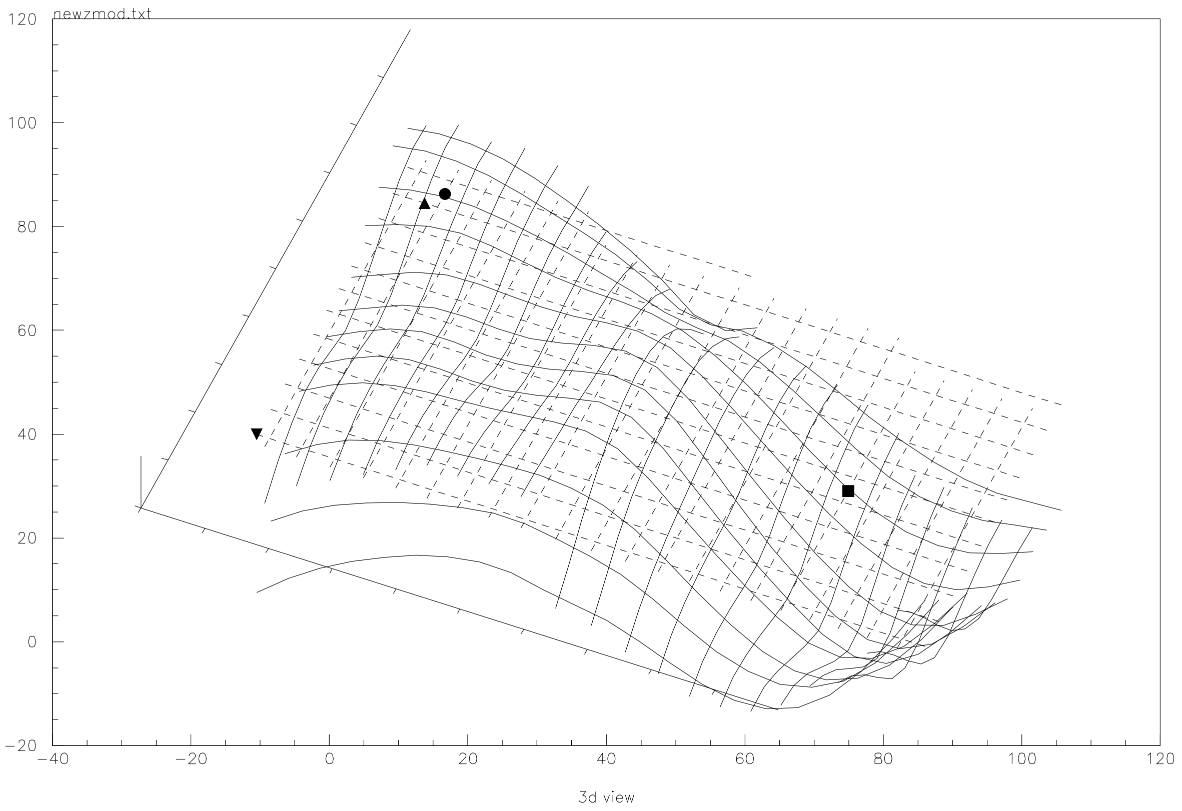

Figure 8: Reconstructed surface of a prototype module. The reconstruction shows a distortion of $47\mu m$.

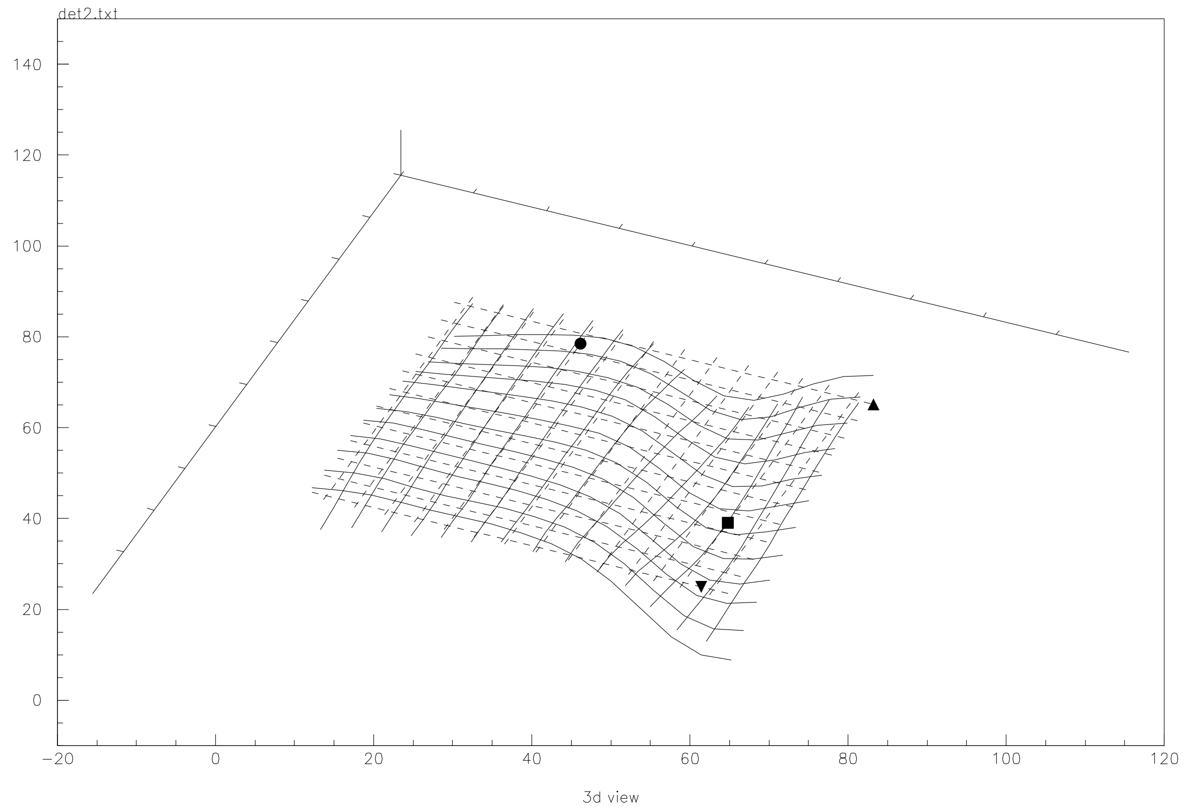

Figure 9: Surface shape of CIS wedge detector. The totla bowing amplitude is 20 μm.

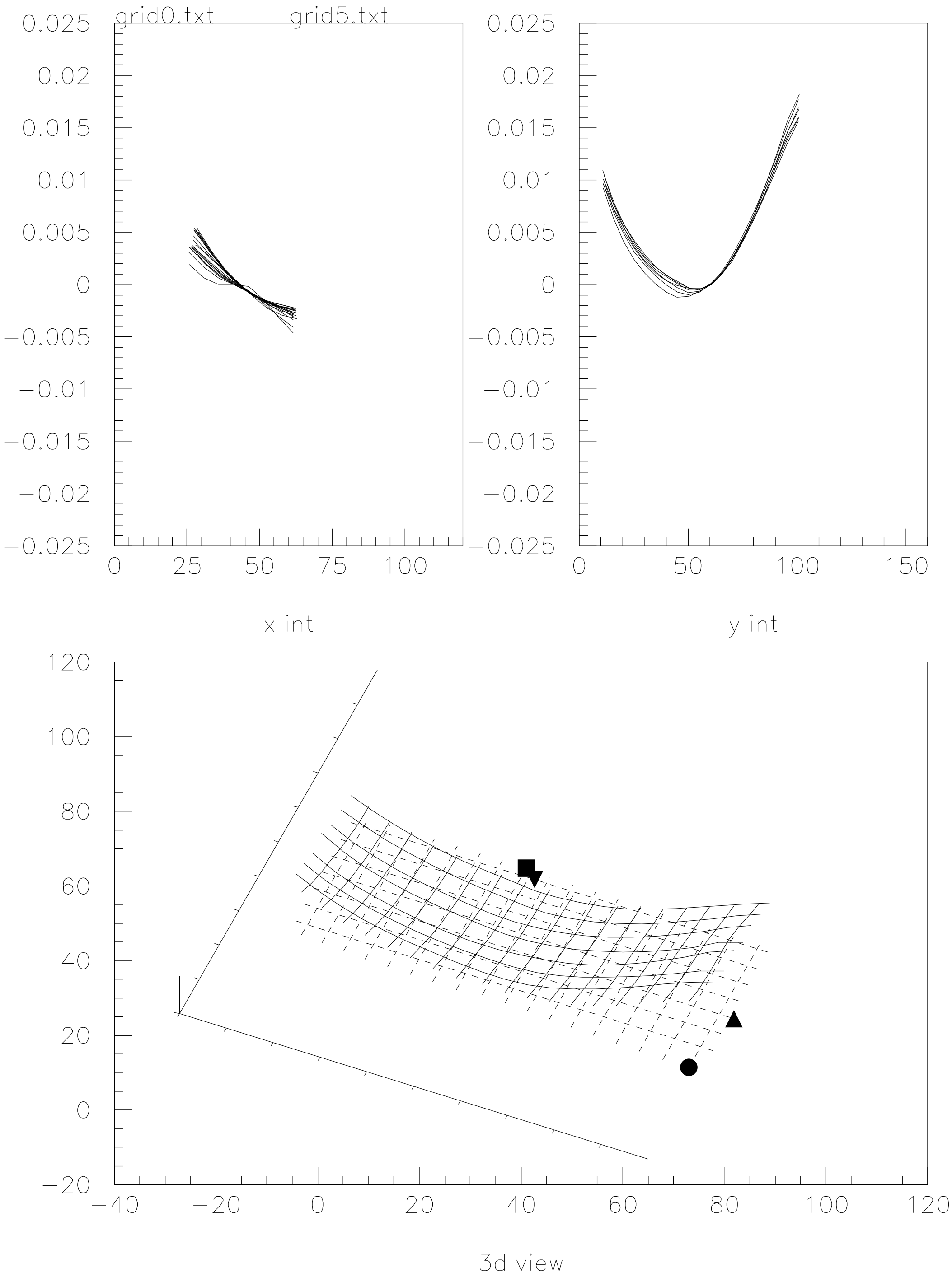

Figure 10: Surface shape difference after heating on prototype module.

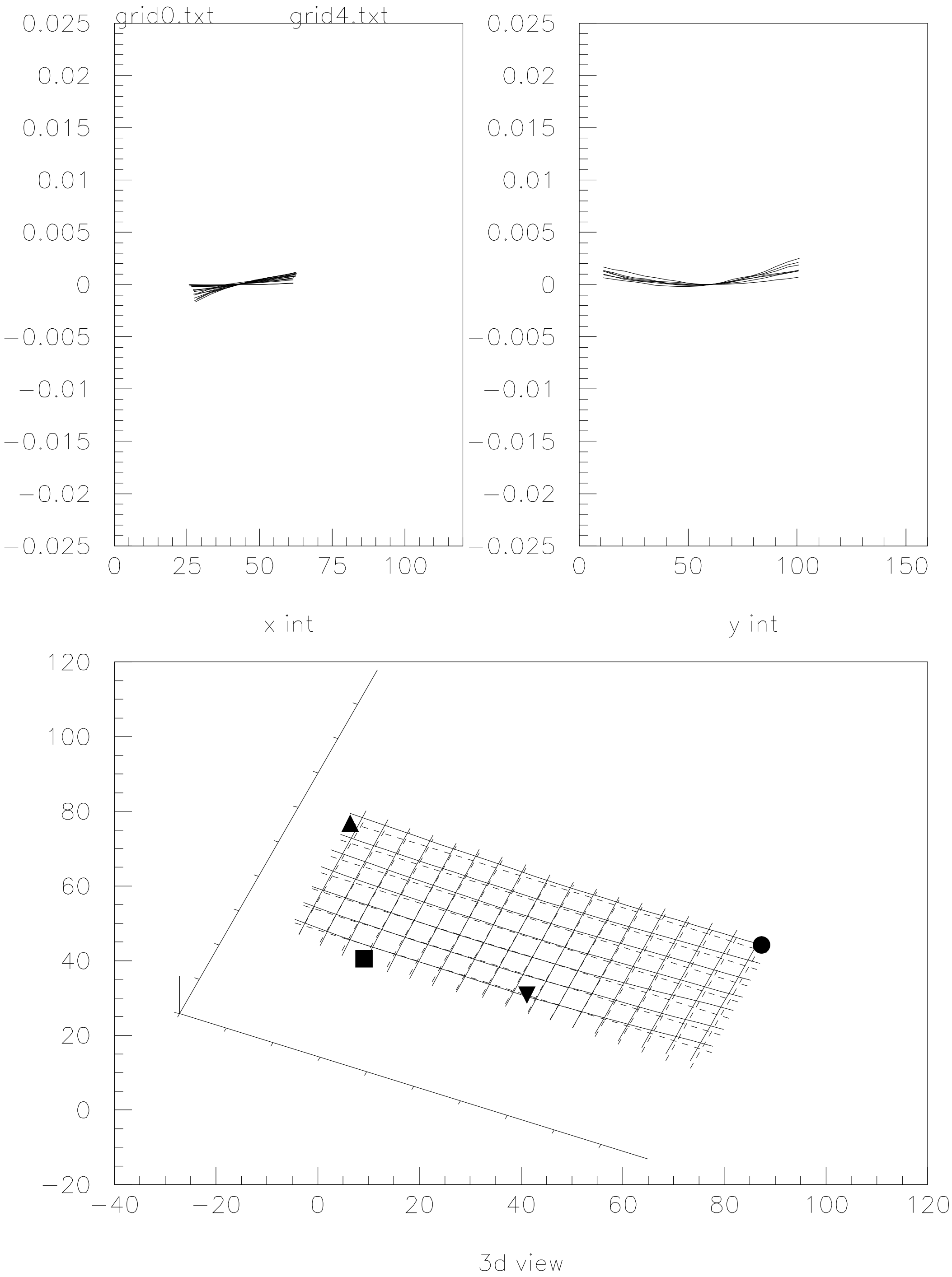

Figure 11: Surface shape differrence after temperature cycle.

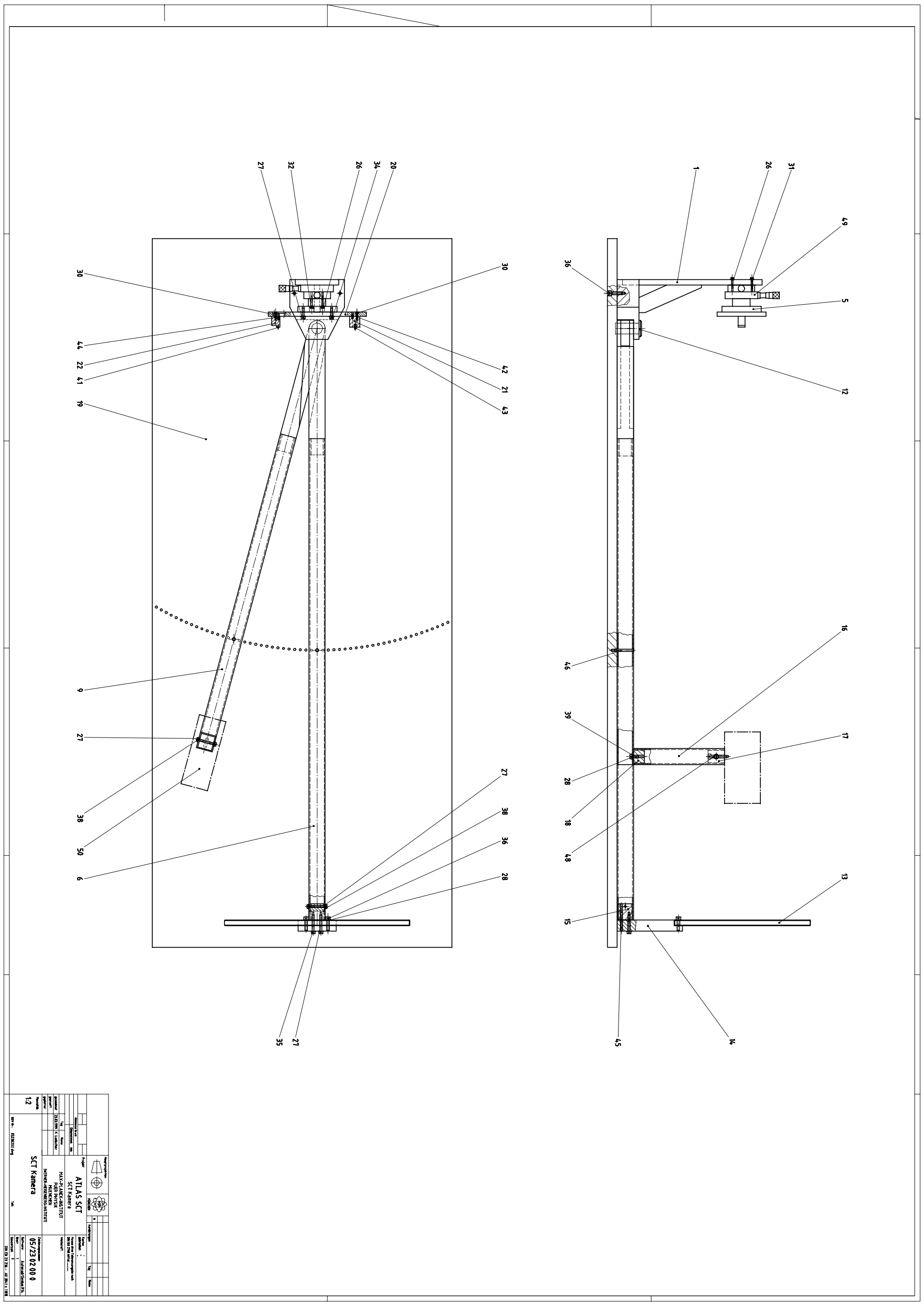

Figure 12: Final setup for measurements.