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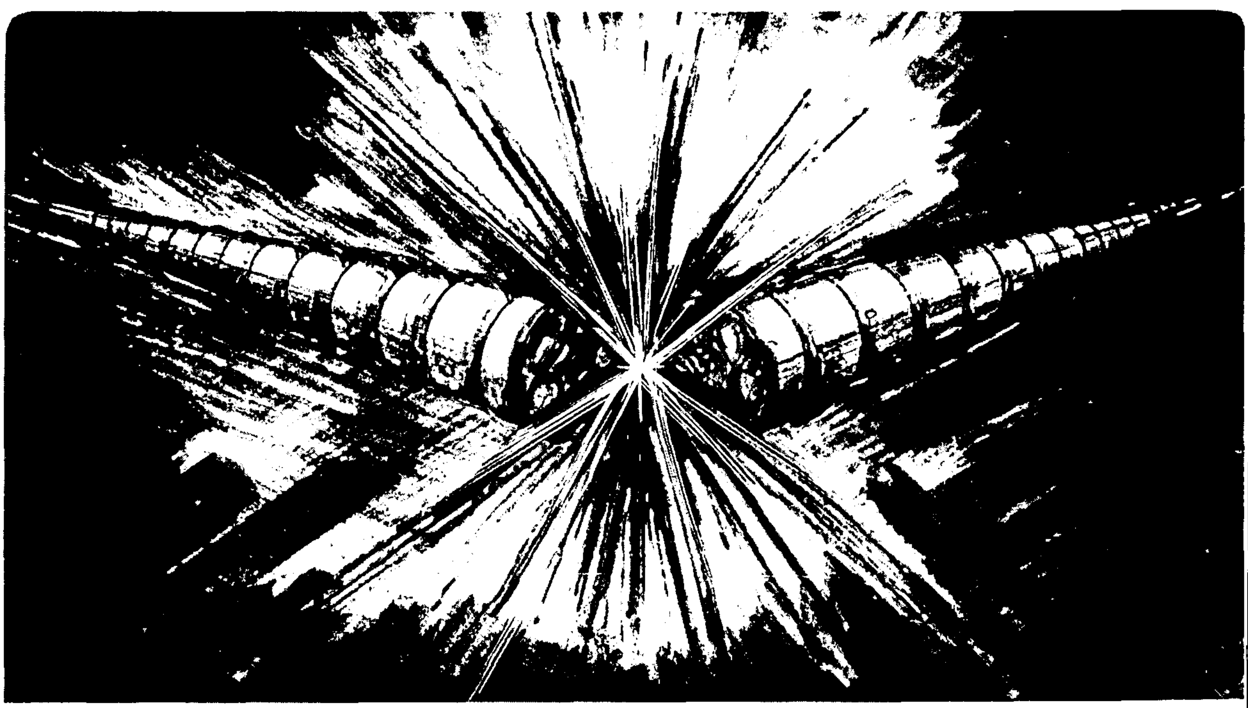

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A VARIABLE RADIUS MIRROR FOR IMAGING THE EXIT SLIT OF AN SGM UNDULATOR BEAMLINE AT THE ALS

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A Variable Radius Mirror for Imaging the Exit Slit of an SGM Undulator Beamline at the ALS.

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Bendable metal mirrors have been implemented in two SGM undulator beamlines at the ALS. A piezo–electric actuator is employed to deform the mirror to image the SGM exit slit which moves longitudinally in the beamline as the grating rotates. The design and performance of these mirrors is discussed. Computed deformations and slope errors are compared to those found during optical metrology. The soft x–ray spot size produced at the experiment is shown.

1. INTRODUCTION

When the spherical grating monochromator (SGM) design was adopted for the first undulator beamlines at the ALS the need to move the monochromator slits during scanning was problematic. The decision to keep the entrance slit fixed in the fixed illumination from the storage ring involves little penalty; the SGM is no longer a Rowland circle instrument, but it is still capable of high resolution ($R \approx 8{,}000$) limited by the best available grating figure. The monochromator now requires an exit slit which slides longitudinally to stay at the grating focus. A bendable mirror with a variable tangential radius was implemented to image this slit, at any position, onto the experiment, and to give some flexibility as to the position of the experiment chamber on different horizontal branches after the monochromator.

As the bending of the mirror becomes large, deformations are observed, both in computations and during metrology. These would be a problem if the mirror had been bent into shape from a polished flat. Instead, the mirrors were polished spherical and the tangential radius adjusted by small amounts. This keeps the bending small and the associated slope errors to acceptable levels and allows the motion to be driven by a (UHV) piezo–electric actuator. Mirrors are now operational in two beamlines, and can be easily focused as long as there is a signal to optimize. This signal may be an explicit measurement of the size of the spot at the sample, or the yield in a spectrometer with a limited field of view.

2. MIRROR DESIGN

Figure 1. shows the mirror substrate and the geometry of the shaping cuts[1], made by electrical–discharge machining (EDM), which control the bending. The substrate dimensions were identical for the two mirrors, except for the EDM cuts. The thickness required of the top plate is given by:

$$t(w) = t_0 \{ 1 - |2 w/L| \}^{1/3}$$

where t_0 is the thickness at the middle, w is the distance from the middle along the top surface and L is the mirror length (300mm). The radius added by bending is given by:

$$\rho(F) = (E\, b\, t_0^3) / (3\, L\, F)$$

where E is Young's modulus, b is the width of the mirror and F is the force applied in the middle. The tangential radius is then:

$$R(F) = \{ 1 / R_{polished} + 1 / \rho(F) \}^{-1}$$

The material must be polishable and strong enough to withstand the stresses in the flexures. Because of experience polishing 'glidcop'[2], plated with electroless–nickel, this was the material of choice. Young's modulus for 'glidcop' is 10.7×10^{10} N m^{-2}. The thickness in the middle (18mm) is chosen to render negligible the sag due to gravity. The mirror was heavy (12kG); this caused problems during polishing and made the mounting more difficult, but for the future, it leaves open the possibility of water cooled benders.

PZT actuators offer limited stroke but can develop large forces. The lever geometry which is cut into the mirror multiplies the horizontal stroke of the PZT by three, into vertical motion of the center of the top plate. The backing of the mirror bends a little but the double flexures at either end ensure that the effects of this are simply a reduction in the available range of bending. The PZT we adopted[3] was just capable of bending the mirror through the maximum range of radii, from $R \approx 33$m (polished in the relaxed position) to $R \approx 65$m, with a change in sag of 200μm. In this case the PZT developed 90μm of stroke unloaded, was resisted by a force of 2100 N which compressed its stroke to 70μm, which after the 3:1 multiplying lever, was just sufficient. The maximum stress occurs in a corner of the lever pivot flexure which carries the reaction to the PZT load and was computed to be 10^8 N m^{-2} which is 50% of the micro–yield point (10^{-6} permanent strain).

The mirrors' shortest operational radius is a few meters longer than the polished radius, so that when the PZT is installed and adjusted the mirror is slightly bent, the corresponding force holds everything together and the slope errors on the surface are from polishing.

The mirror usually operates at close to unity magnification with negligible geometric aberrations. It images a slit as narrow as 10μm, located 2m to 3m upstream of the mirror, to image locations 2m to 5m downstream. Under these conditions the r.m.s. slope errors should be as small as 1μrad to avoid broadening the image. By polishing the mirror to its smallest operational radius and bending to larger radii the range in which the aberrations are negligible involves only moderate bending. For images beyond 3m downstream the bending is severe and slope errors arise associated with bending. However, the magnification is then greater than 1 and aberrations limit the size of the image. In use at the farthest image distance the magnification can be greater than 2 and the marginal ray deviation at the focus due to the third order aberration (called spherical aberration or coma) is then more than 100μm, so that bending errors are still unimportant.

3. FINITE ELEMENT ANALYSIS AND METROLOGY

Finite element analysis (FEA) was carried out to confirm that the flexures are strong enough to survive, yet sufficiently weak to rotate as required without unduly stressing the optical surface. A particular problem was the central flexure hinge which rotates through approximately 2mrad as the lever rotates. If the slope error at the surface is to be about 1μrad the flexure must be about 2000 times more flexible than the bent mirror itself. In fact it was made 0.5mm thick and elongated to 1mm for flexibility, as shown in the detail of figure 1.

Figure 2. shows the comparison between computed slope errors due to bending and those measured during metrology with the PZT installed and operational. The computations were made with RASNA[4]. The measurements were made using the ALS 'long trace profiler'[5], in which the mirror was reversed and the average taken, to eliminate systematic measurement errors.

Two mirrors, with minimum radii of 75m and 33m, have been built and installed in two undulator beamlines.

For the long radius mirror (75m to 250m) we show only the difference between the figure measured during bending and the figure in the relaxed position. This is because of a deformation problem which arose due to baking after inadequate heat treatment and led to an intrinsic figure which was in error by 4μrad r.m.s. in the relaxed position. We wish to show only the errors which occur due to bending.

For the short radius mirror (33m to 60m) there was no such problem and the absolute measured slope errors are shown.

The computations show the deformation of the top surface due to rotation of the central flexure, and give slope errors asymmetric along the mirror surface, in broad quantitative agreement with the measurements. The errors increase as the bending becomes more severe.

4. PERFORMANCE IN THE BEAMLINE

Some problems were encountered during polishing these mirrors due to their weight, the properties of the locking mechanism which was employed during polishing and also, in the case of the longer radius mirror, due to baking after inadequate heat treatment. Nevertheless the end result was two mirrors with minimum operational radii and intrinsic r.m.s. slope errors of 75m, 4.0µrad and 33m, 1.2µrad respectively.

The vacuum properties of the PZT were good, the mirror tanks were pumped with a 200 l/s ion pump to a base pressure of about 5.0×10^{-10} Torr.

Figure 3. shows the measured vertical profile of the soft x–ray spot at the experiment when imaging a 10µm exit slit using the 75m radius mirror on ALS beamline 7.0, with a magnification of 1.3. This profile is broadened by the intrinsic slope errors, which are not important with wider slits. The slope errors due to bending are smaller and negligible. This image contains all of the resolved flux, and can be made with approximately unity magnification at any operational photon energy, for any position of the exit slit at either of two interchangeable experiment locations.

7. CONCLUSIONS AND FUTURE DEVELOPMENTS

These copper bendable mirrors have solved the immediate problem of refocusing a moving exit slit in an SGM beamline.

We have seen that the rotation of the central flexure in this design causes significant surface slope errors, which were rendered unimportant here by arranging that they appear only under conditions when geometrical aberrations are more significant than the bending errors. Other arrangements of flexures have been invented[1] which avoid this rotation and offer the possibility of severe bending with very small errors. If this possibility is realized, mirrors could be shaped, bent severely, polished flat and allowed to relax to a cylinder with good figure. Sub–microradian r.m.s. slope errors have not yet been achieved by this technique. Even without a rotating central flexure careful FEA computations will be required as part of the design process. We have seen that such computations do model the bending, and that sufficiently accurate shapes can be cut.

For future bendable mirrors a new material may be better. The principle problem with 'glidcop' is the weight and a dispersion strengthened aluminum may be an improvement, if it could be coated and polished. Silicon might be good, as long as it could be machined and bonded to metal. However, water cooled benders may take advantage of the thermal properties of 'glidcop'. The bending geometry is capable of operating with holes drilled the length of the mirror to carry water, with some modification of the profile.

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3. Model PI242.40 from Physik Instrumente GmBH.

4. Rasna Corp. 2590 N. First Street, #200, San Jose, CA 95131

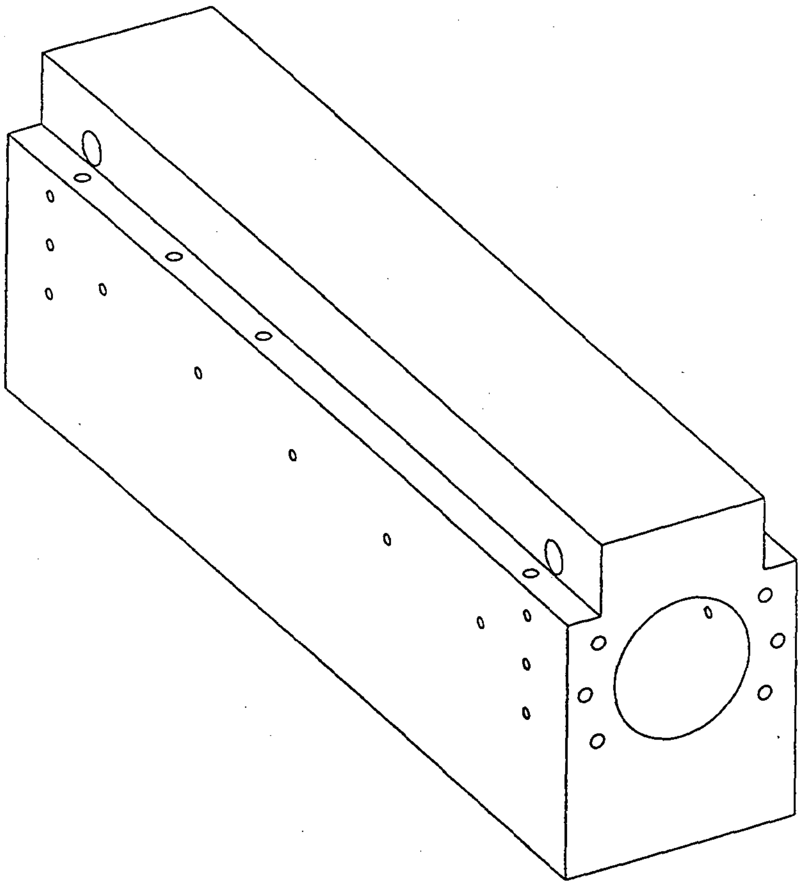
5. S. C. Irick, SPIE, 1720 (1992) 162

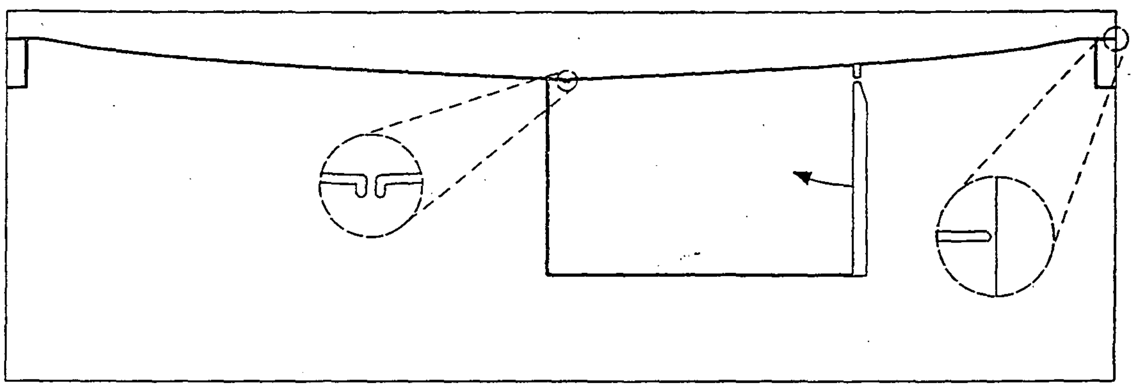
FIGURE CAPTIONS

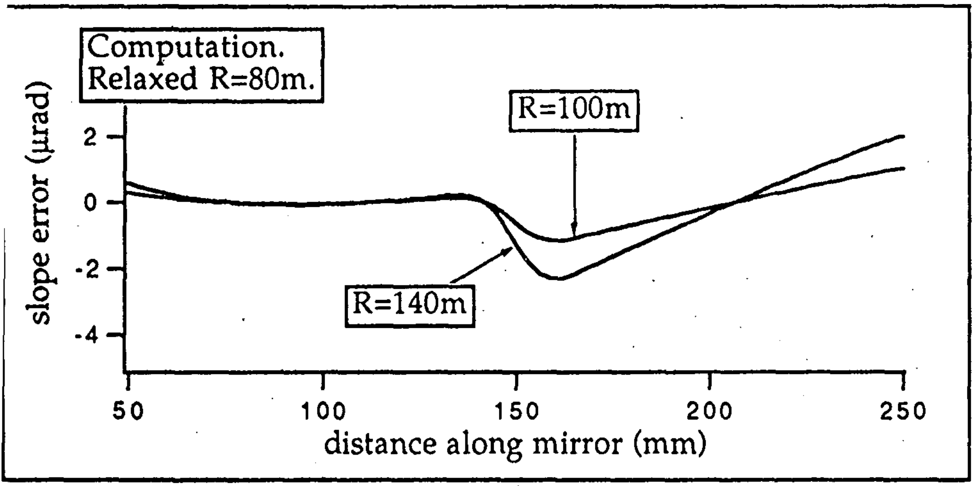
Figure 1. The mirror substrate, shown in isometric projection and the EDM cuts seen from the side. The PZT resides in the cylindrical hole in the body of the mirror. The pattern of EDM cuts shown includes the cubic profile of the top plate, the flexures and the 3:1 lever which converts the horizontal PZT extension to vertical motion of the center of the mirror surface.

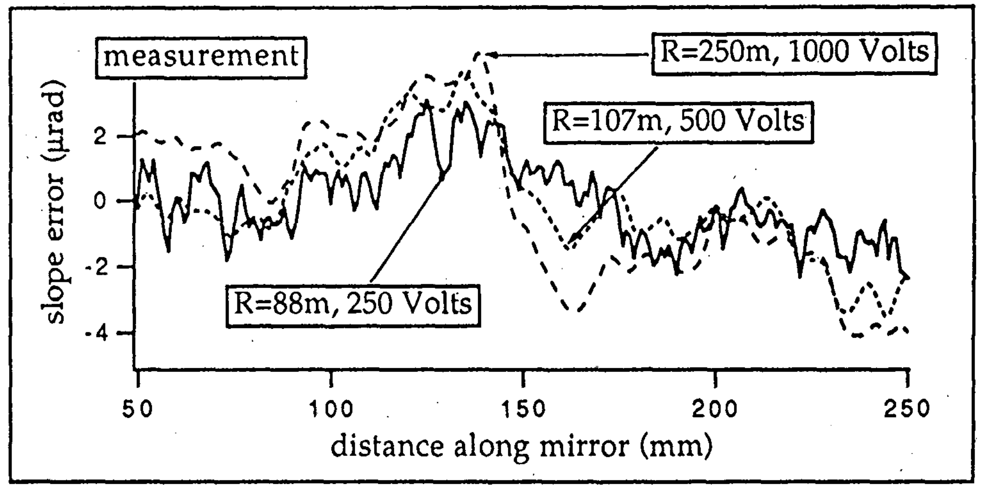
Figure 2. Computed and measured slope errors along the length of the mirrors due to bending to various radii as the bending is increased. One mirror has a range of radii from 75m to 250m, the other from 33m to 60m.

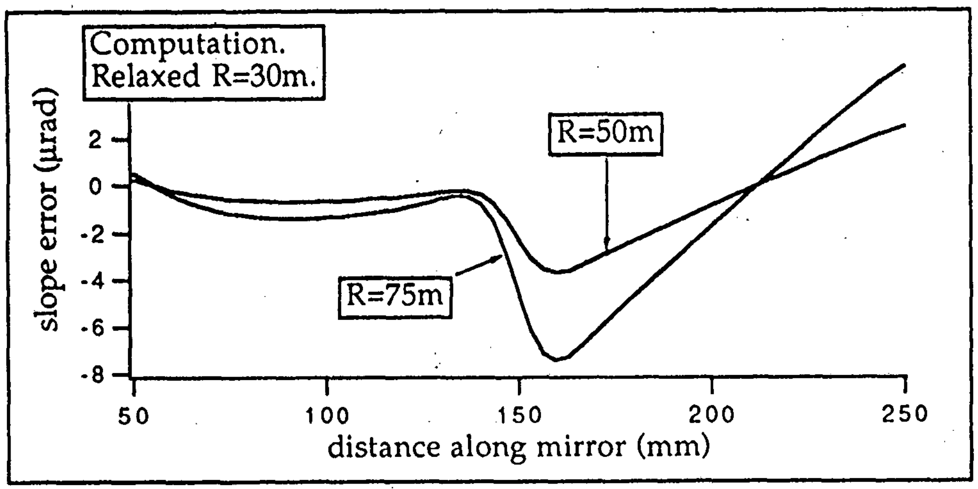
Figure 3. The measured vertical image of a 10μm exit slit at a magnification of 1.3 on ALS beamline 7.0. The measurement was made by scanning a photo-emissive knife edge through the beam, after varying the PZT voltage to bring the mirror into focus.

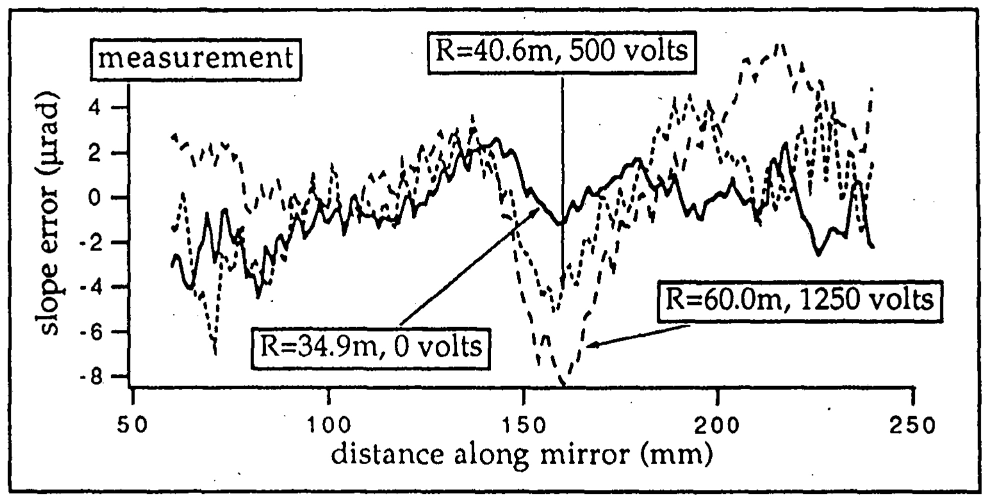


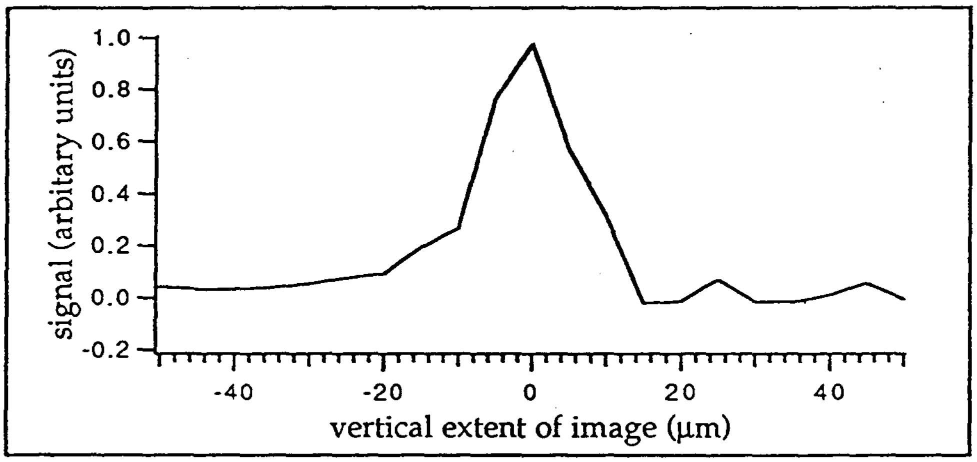



Computation.
Relaxed R=80m.
R=100m
R=140m
slope error (µrad)
2
0
-2
-4
50
100
150
200
250
distance along mirror (mm)


measurement
R=250m, 1000 Volts
R=107m, 500 Volts
R=88m, 250 Volts
slope error (µrad)
2
0
-2
-4
50
100
150
200
250
distance along mirror (mm)


Computation.
Relaxed R=30m.
R=50m
R=75m
slope error (µrad)
2
0
-2
-4
-6
-8
50
100
150
200
250
distance along mirror (mm)


measurement
R=40.6m, 500 volts
R=60.0m, 1250 volts
R=34.9m, 0 volts
slope error (µrad)
4
2
0
-2
-4
-6
-8
50
100
150
200
250
distance along mirror (mm)


signal (arbitary units)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-40
-20
0
20
40
vertical extent of image (μm)

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