Bimorph mirrors: The Good, the Bad & the Ugly

Can these “wild outlaws” be tamed?



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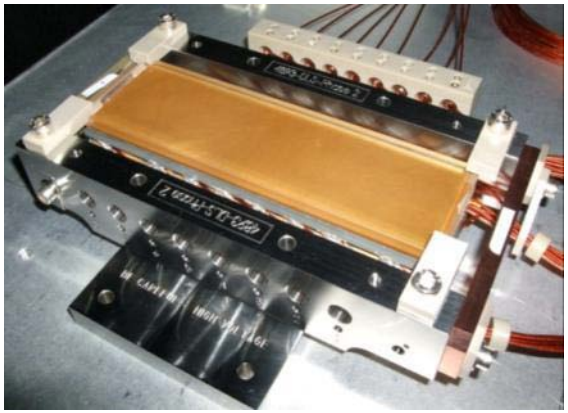
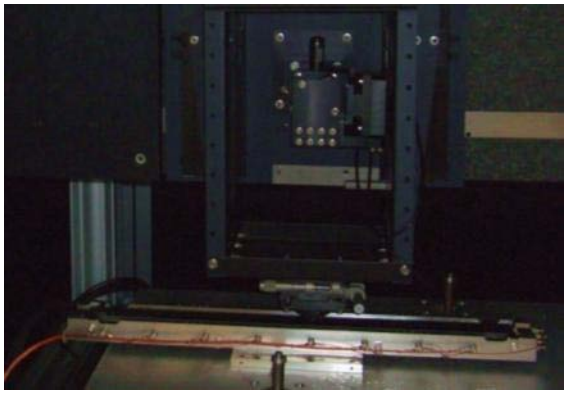




Overview

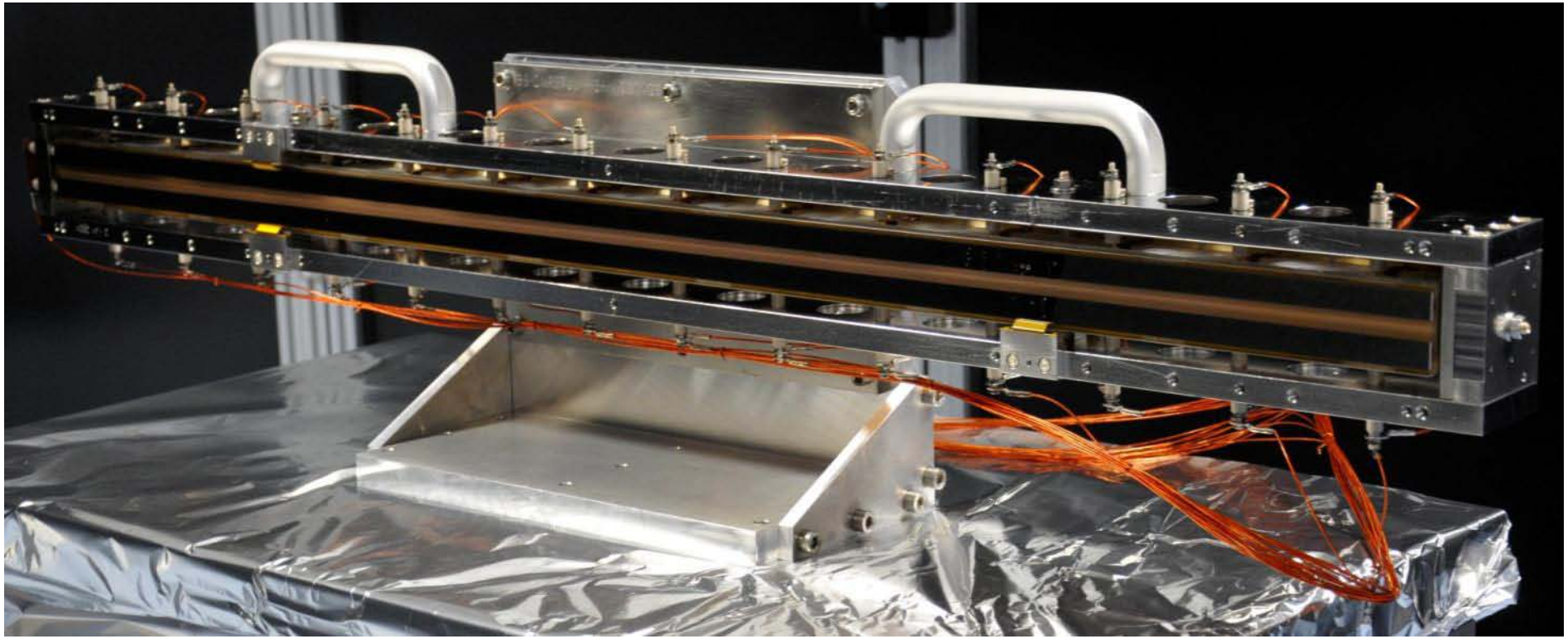
- Introduction to bimorph mirrors
- The Good
- The Bad
- The Ugly …& “beauty treatments”?
- The Future
- Conclusions

Introduction

- Mirror performance limited by figure errors (mm's → L):
  - Polishing defects
  - Gravitational sag
  - Mounting strains
  - Thermal bumps induced by high powered photon beams
- How can figure errors be reduced? Use bimorph technology!

HFM3 (MX beamlines)

1050mm long, 14 piezos, 2 coating stripes



Piezo power!

- By applying appropriate voltages to the bimorph piezos, global figure & localised figure errors are dynamically corrected to create a well defined photon beam

Bimorph mirrors have exceptional potential
…but how can this be harnessed?

- Many degrees of freedom?
- How do the piezos behave?
- Quick & easy optimisation would be nice!

In-situ (X-ray) beamline testing at DLS

- Kawal Sawhney (SRI) et al

  Characterisation of a novel super-polished bimorph mirror

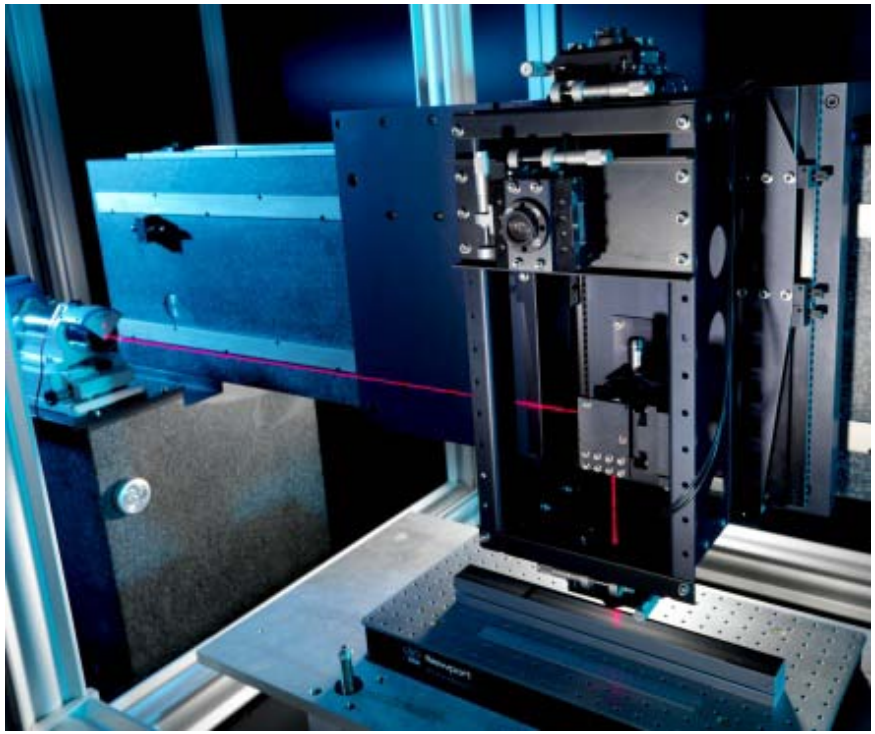
- John Sutter et al

  Measurement and analysis of X-ray mirror slope errors under beamline operating conditions

- Hongchang Wang et al

  At-wavelength metrology using Moiré Fringe analysis method based on two dimensional grating interferometer

Ex-situ testing: Diamond-NOM



- Non-contact, slope measuring profiler
- Scan range: 1500mm x 300mm
- Slope errors <50nrad rms
- Sub-nm repeatability
- Upward or side facing acquisition
- Thermal stability <10m°C
- 1st replication of BESSY-NOM concept
- EPICS control (now used at NSLS-II)

"The Diamond-NOM: a non-contact profiler capable of characterizing optical figure error with sub-nm repeatability"

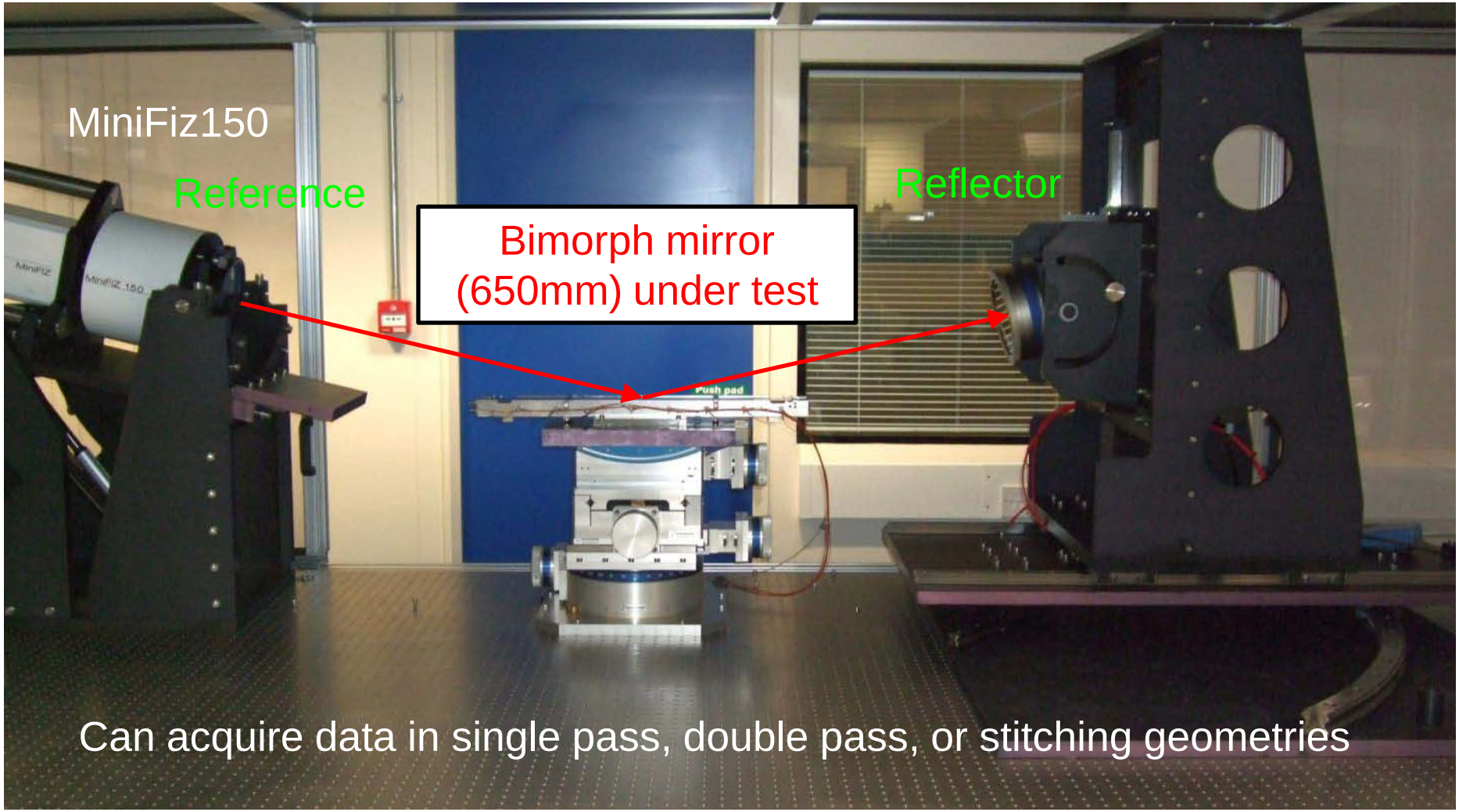
S. G. Alcock, K. J. S. Sawhney, S. Scott, U. Pedersen, R. Walton, F. Siewert, T. Zeschke, F. Senf, T. Noll, and H. Lammert.

Nucl. Instr. and Meth. A, Volume 616, Issue 2-3, p. 224-228 (2010)

“MiniFiz” Fizeau interferometer

“A double-pass Fizeau interferometer system for measuring the figure error of large synchrotron optics”

G. D. Ludbrook, S. G. Alcock, S. Scott, Proc. SPIE 7801 (2010).



MiniFiz: 2D topography

- Capture 2D topography of mirror surface in <1minute

  → Dynamic effects & enables rapid iterations of modifications

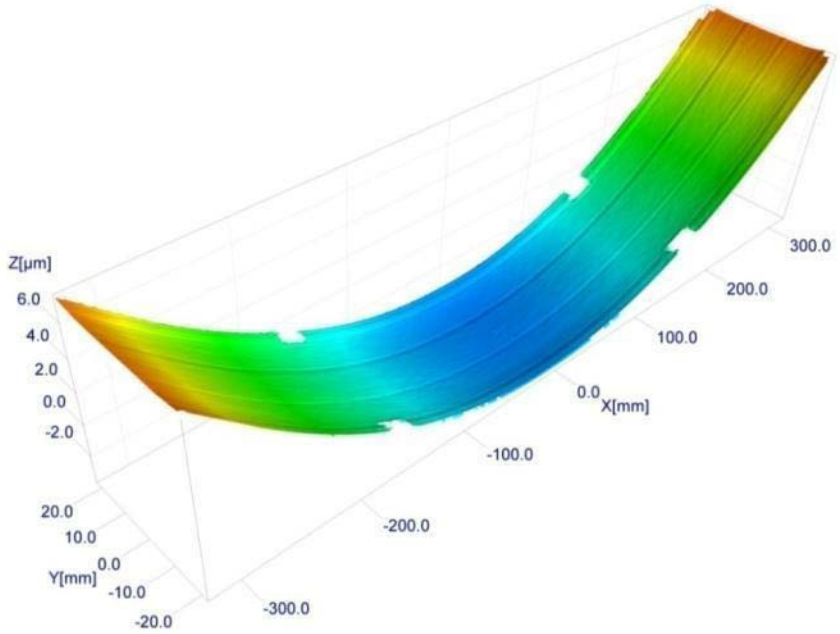


Figure of I04 VFM
(over full surface 650mm)

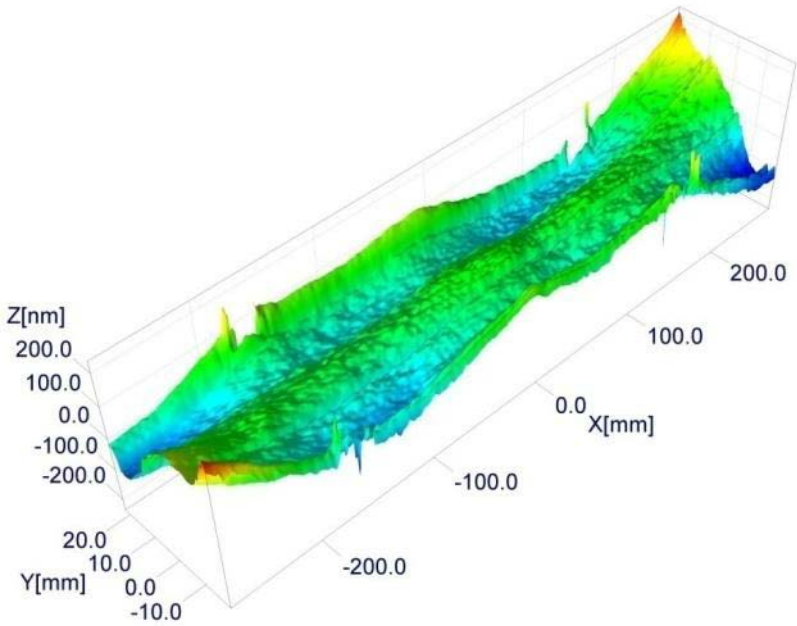


Figure error of I04 VFM
(over active surface 550mm)

The Good

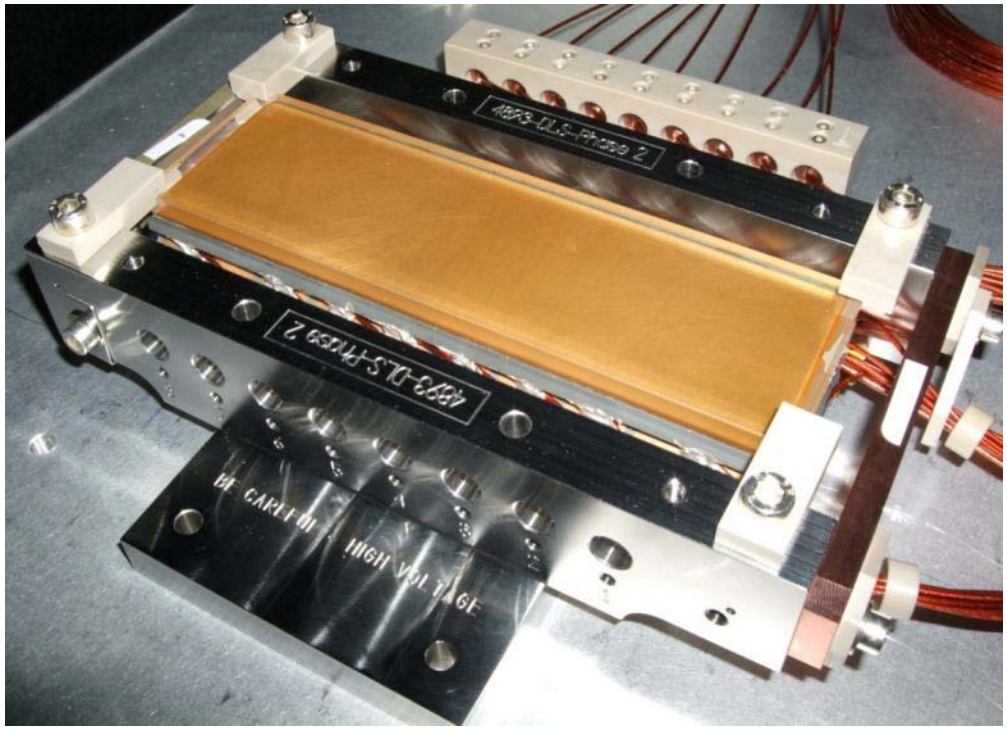
- Correcting slope / figure errors:
  - Polishing defects
  - Clamping / mounting strains
  - Heat-bump

- Range of elliptical (or parabolic) figures
- Highly flexible for different beam sizes / focal distances
- Top-hat or defocused spot?
- Correction of upstream optical aberrations

So much potential!

Super-polished (EEM) bimorph mirror

- 8 piezo bimorph (SESO), 150mm long, silica substrate
- EEM treatment (JTEC) on central ~120mm
- Elliptical pre-figure (p=41.5m, q=0.4m, θ=3mrad)



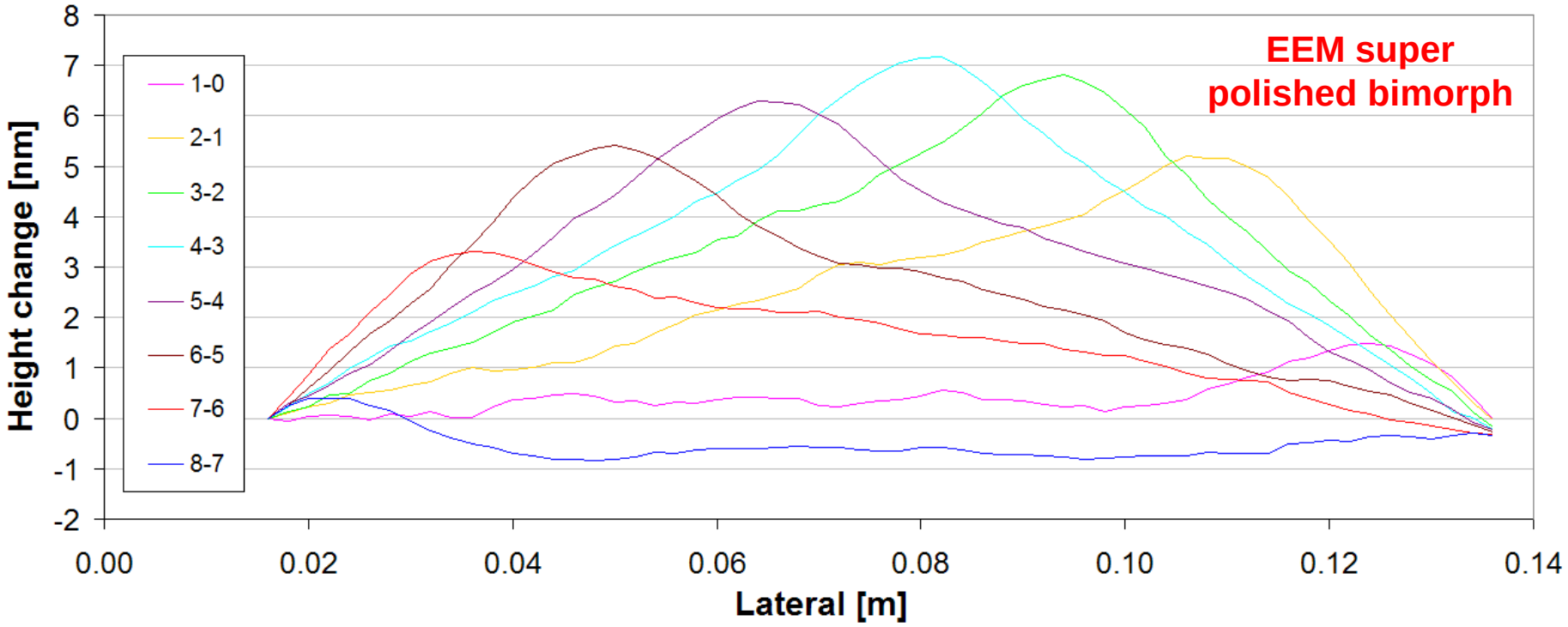
Kawal SRI talk

World's 1st super-polished bimorph mirror

Piezo response functions

- Assess how piezos respond to applied voltage (+25V)

→ Matrix gives figure corrections & bend parameters



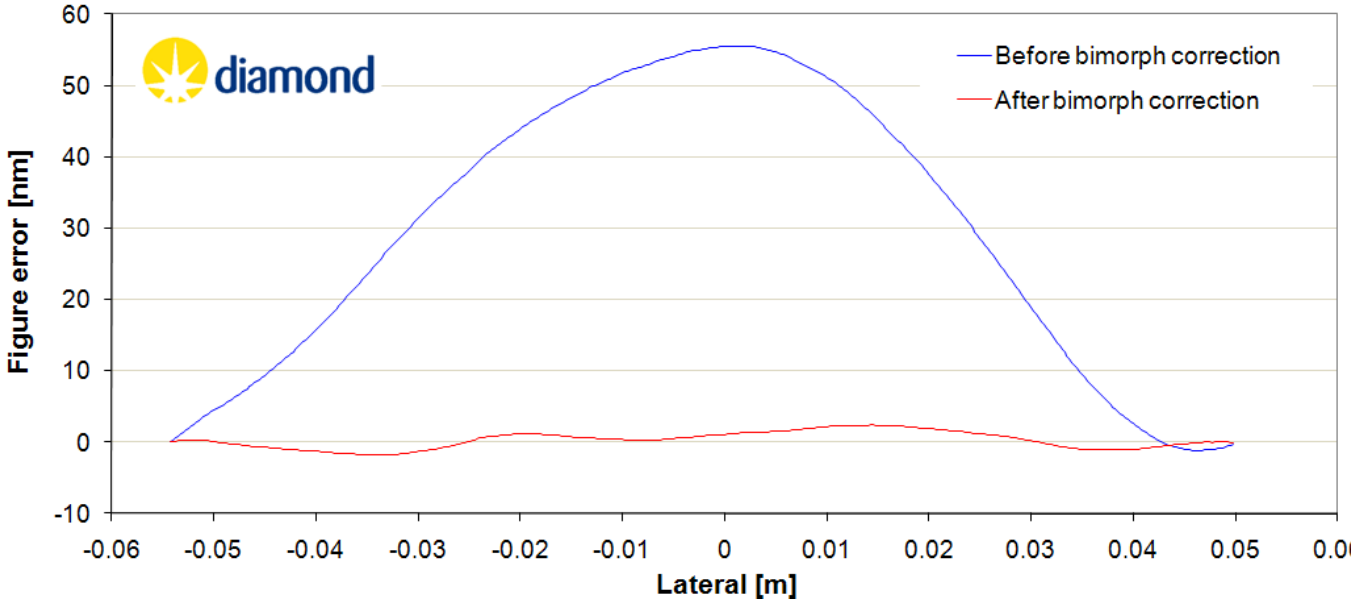
Sub-nanometre figure control using Diamond-NOM

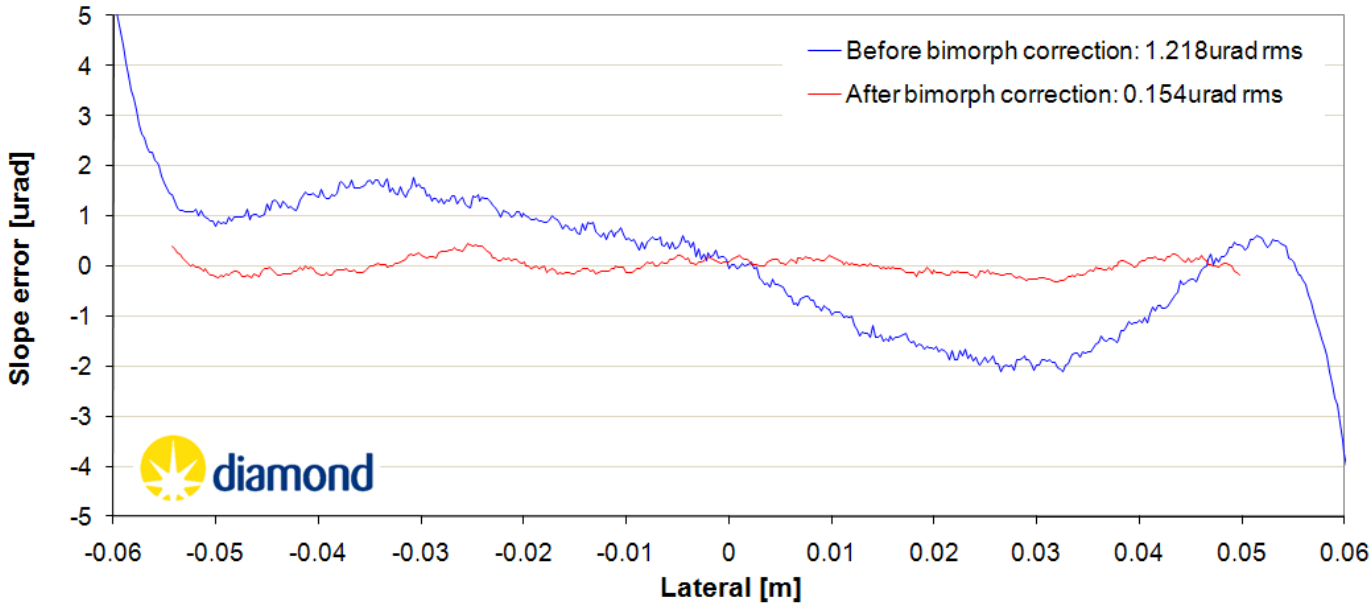
Super-polished (EEM) bimorph mirror

Figure error
<1nm rms

p=41.5m,
q=0.4m,
θ=3mrad

Slope error
~154nrad rms





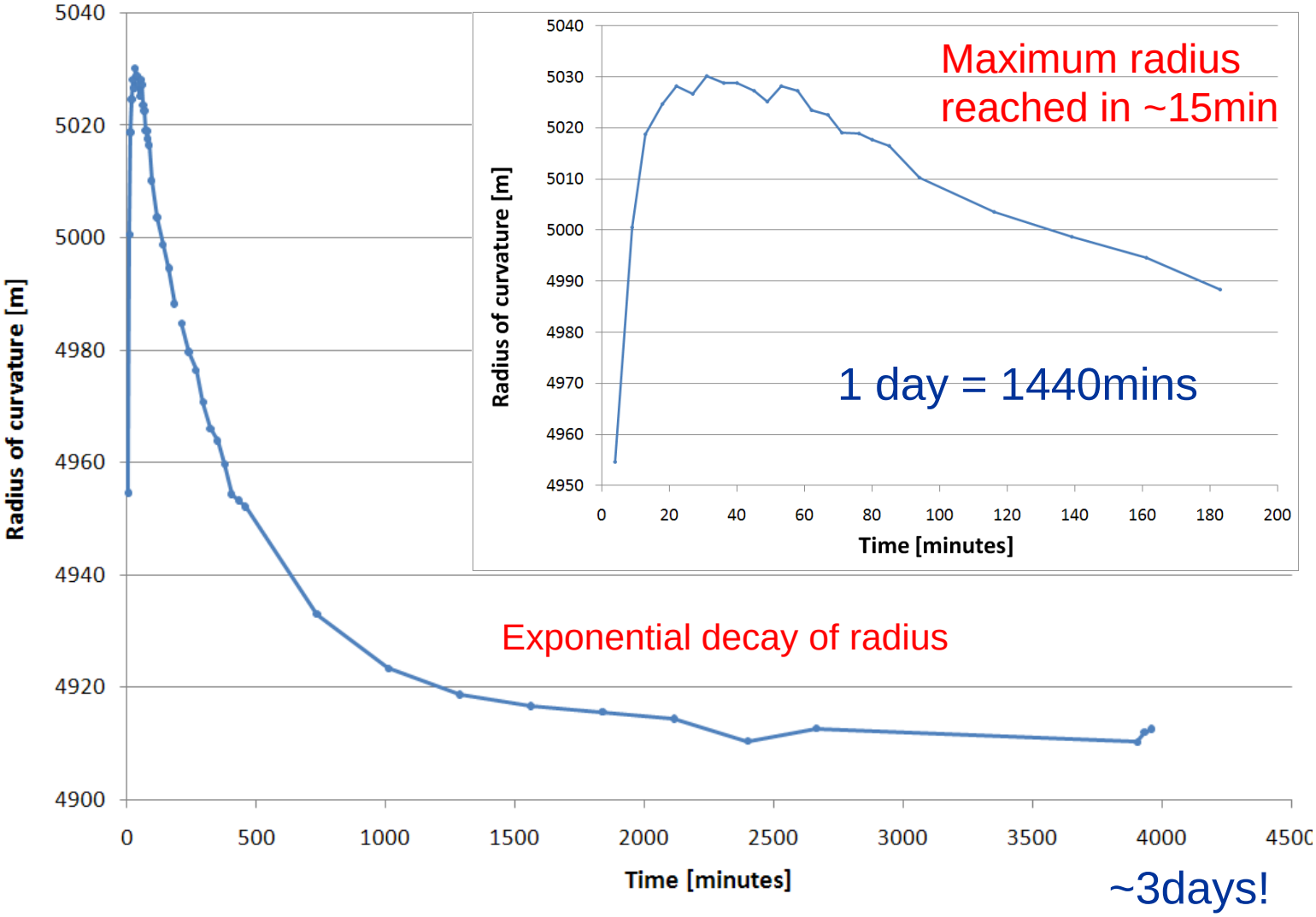
The Bad

- Change of radius with time
- Expensive (+ power supply)
- Problems communicating with HV power supply?
- Expert operator required?

Can these bad points be overcome?

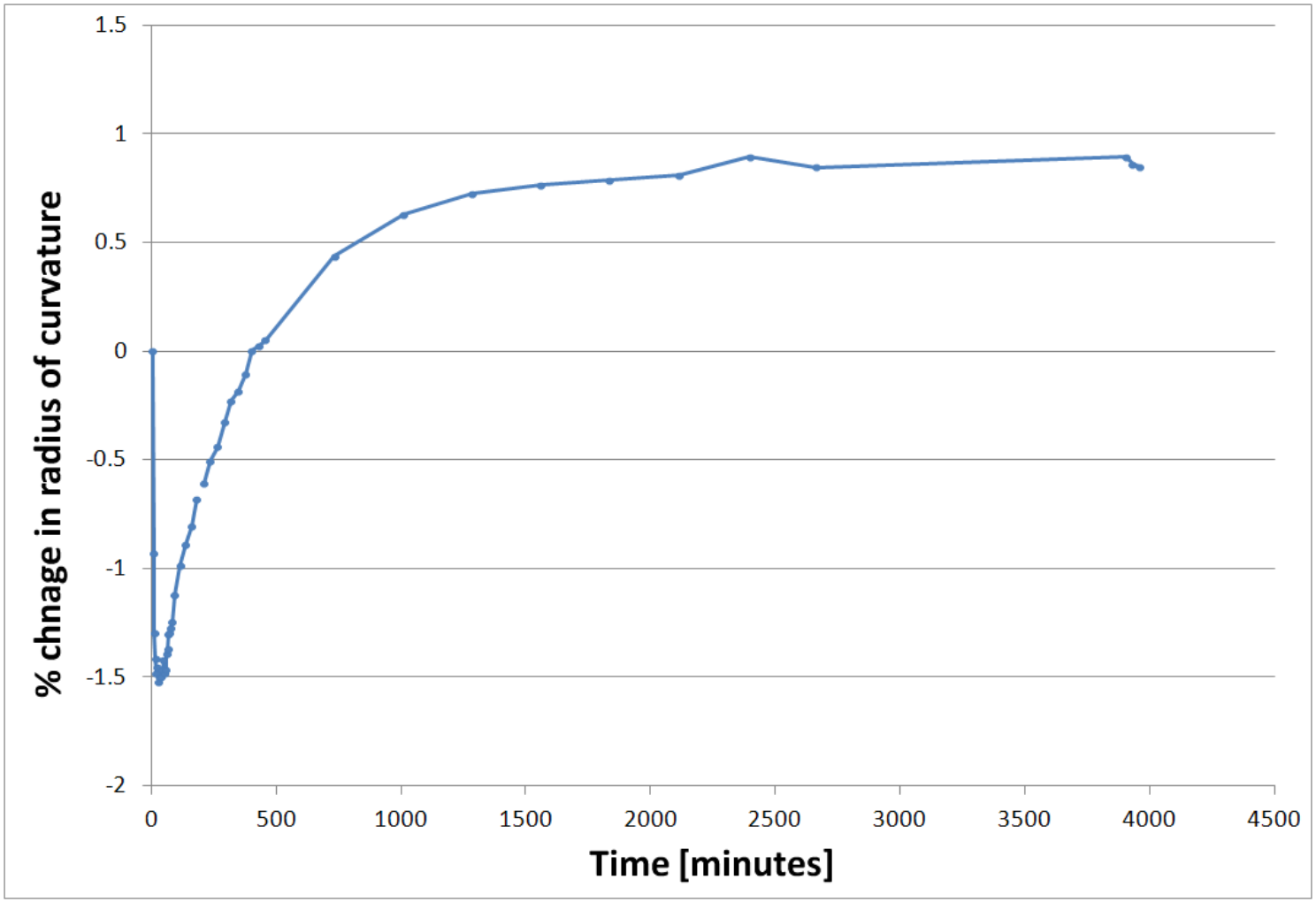
Dynamics of 600mm VFM bimorph

- Apply voltages & record curvature (4min for each Diamond-NOM scan)



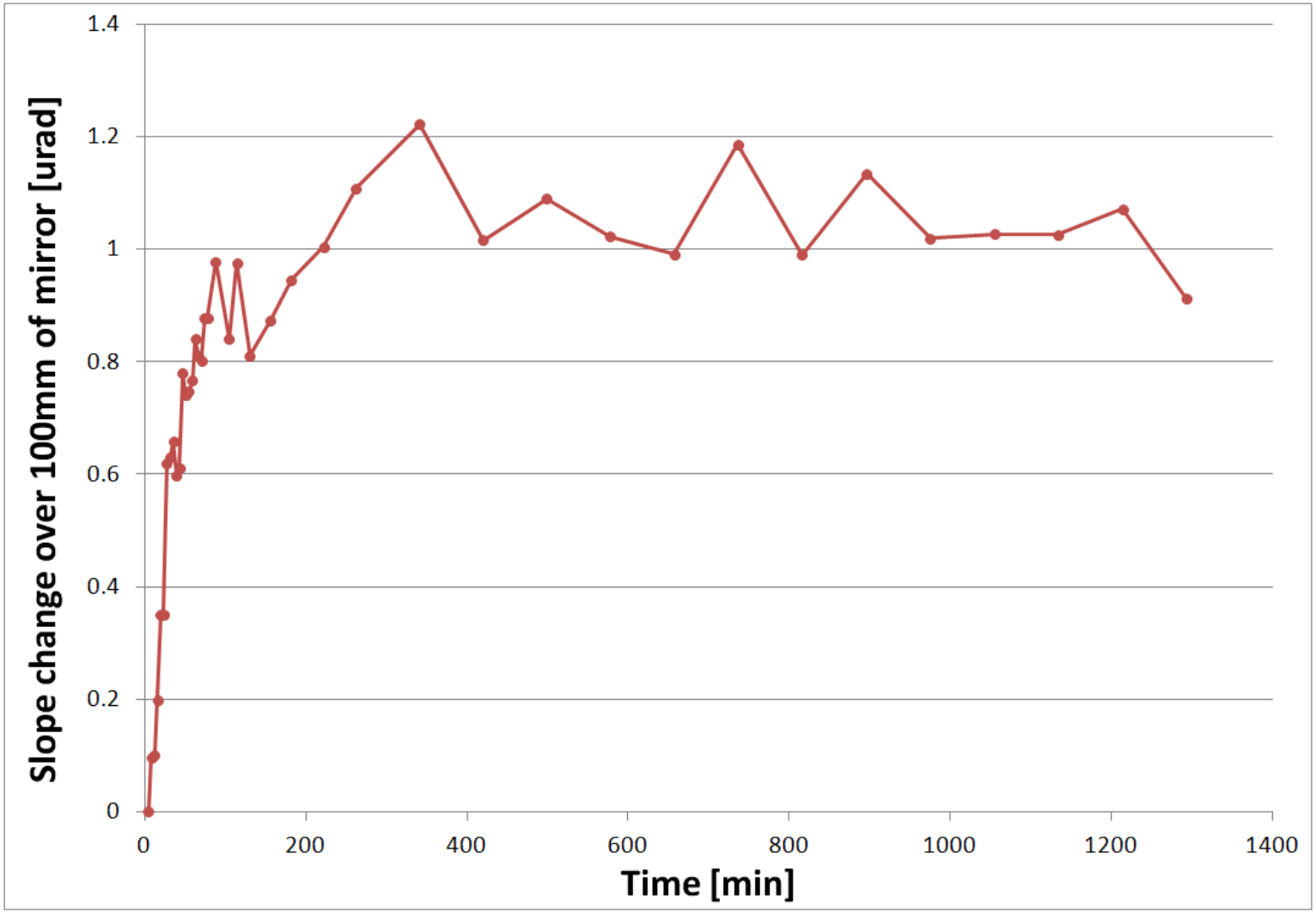
Dynamics of 600mm VFM bimorph

- Radius change by ~2% over several hours / days



Dynamics of 150mm EEM bimorph

- Change from 400V to 500V & observe slope change (between two points on mirror 100mm apart)



The Ugly

- **Junction Effect!!!**

→ larger beam spot & unwanted structure

- **Mounting / clamping defects**

→ holder & “stiff” electrical contacts?

Can we apply “beauty treatments”?

Bimorph construction: end view

Manufactured at SESO, France (patented)

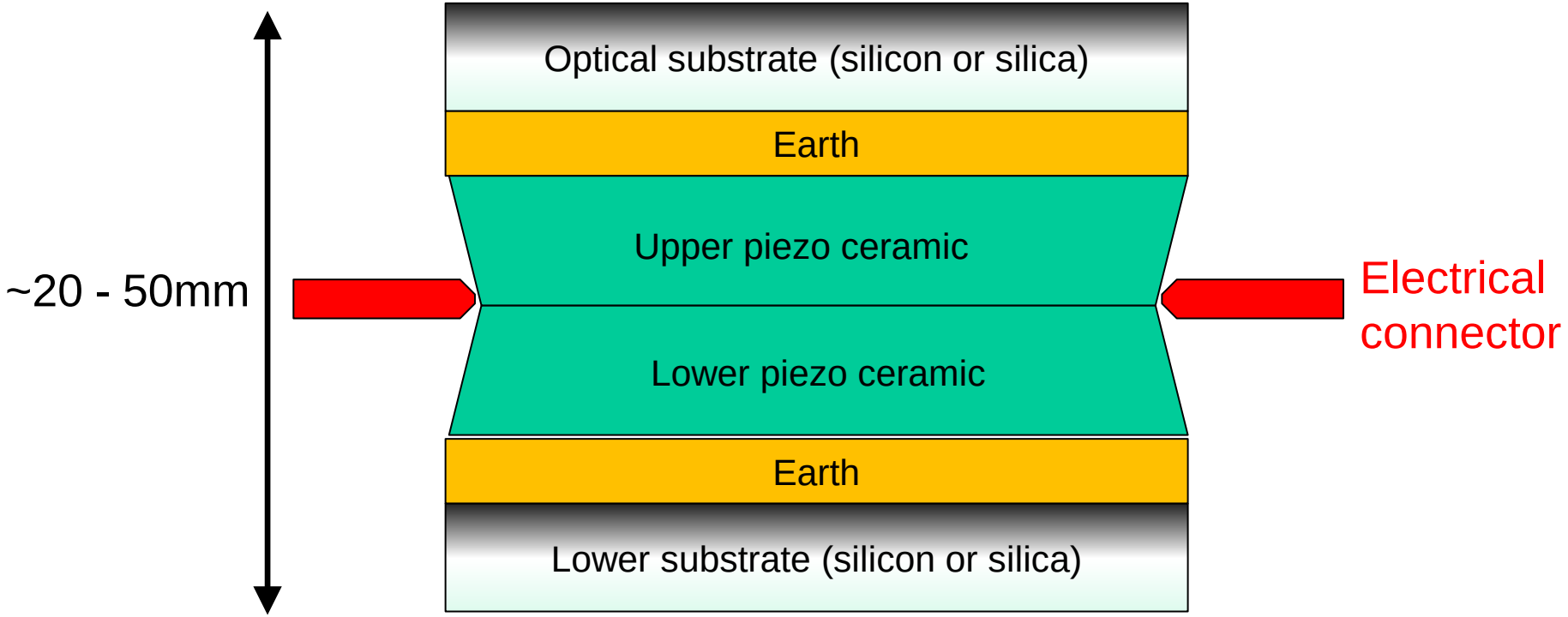
United States Patent
Carre et al.

(10) Patent No.: US 7,618,149 B2
(45) Date of Patent: Nov. 17, 2009

BIMORPH MIRROR WITH TWO PIEZOELECTRIC LAYERS SEPARATED BY A CENTRAL CORE OF SEMIRIGID MATERIAL

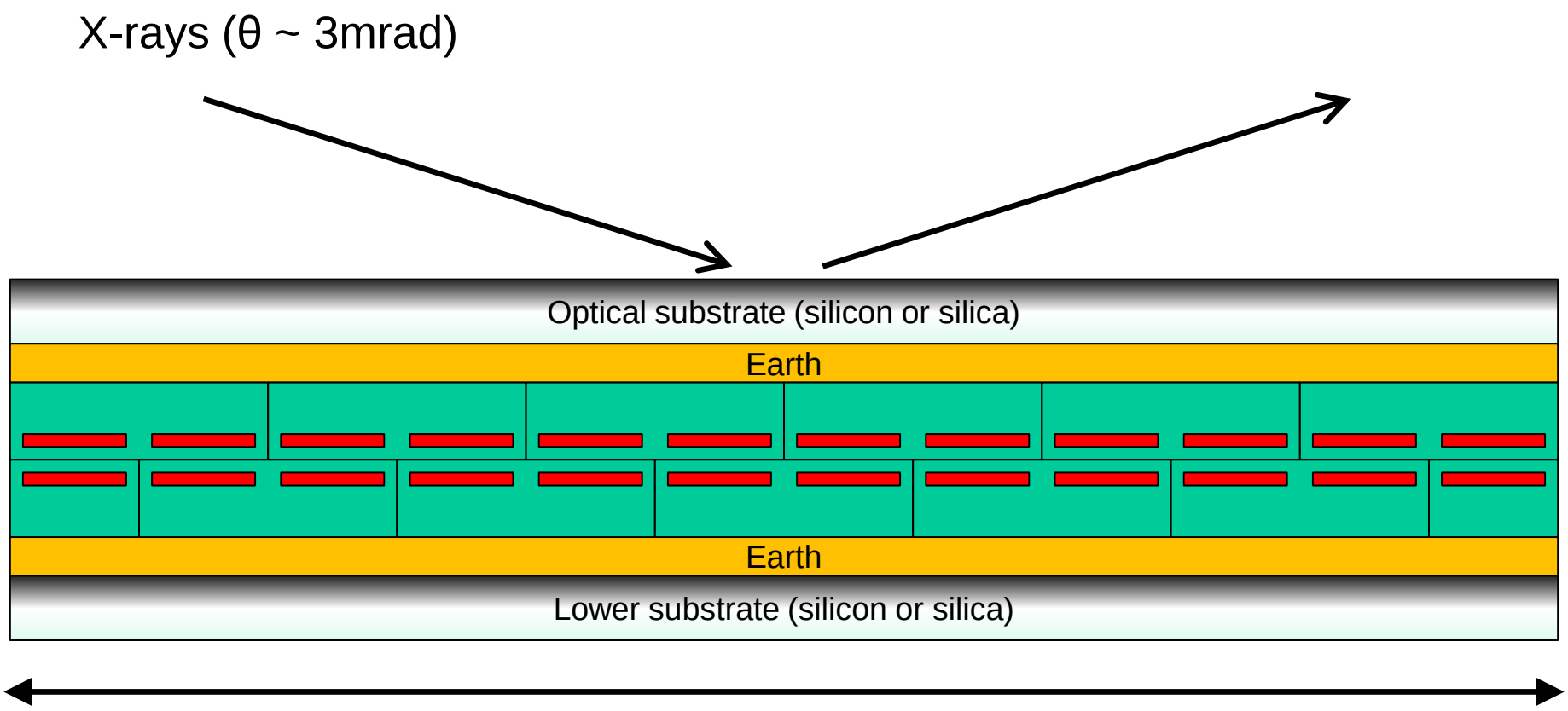
Inventors: Jean-François Carre, Pertuis (FR); Jean Jacques Ferme, Velaux (FR)

Assignee: Societe Europeenne de Systemes Optiques (FR)

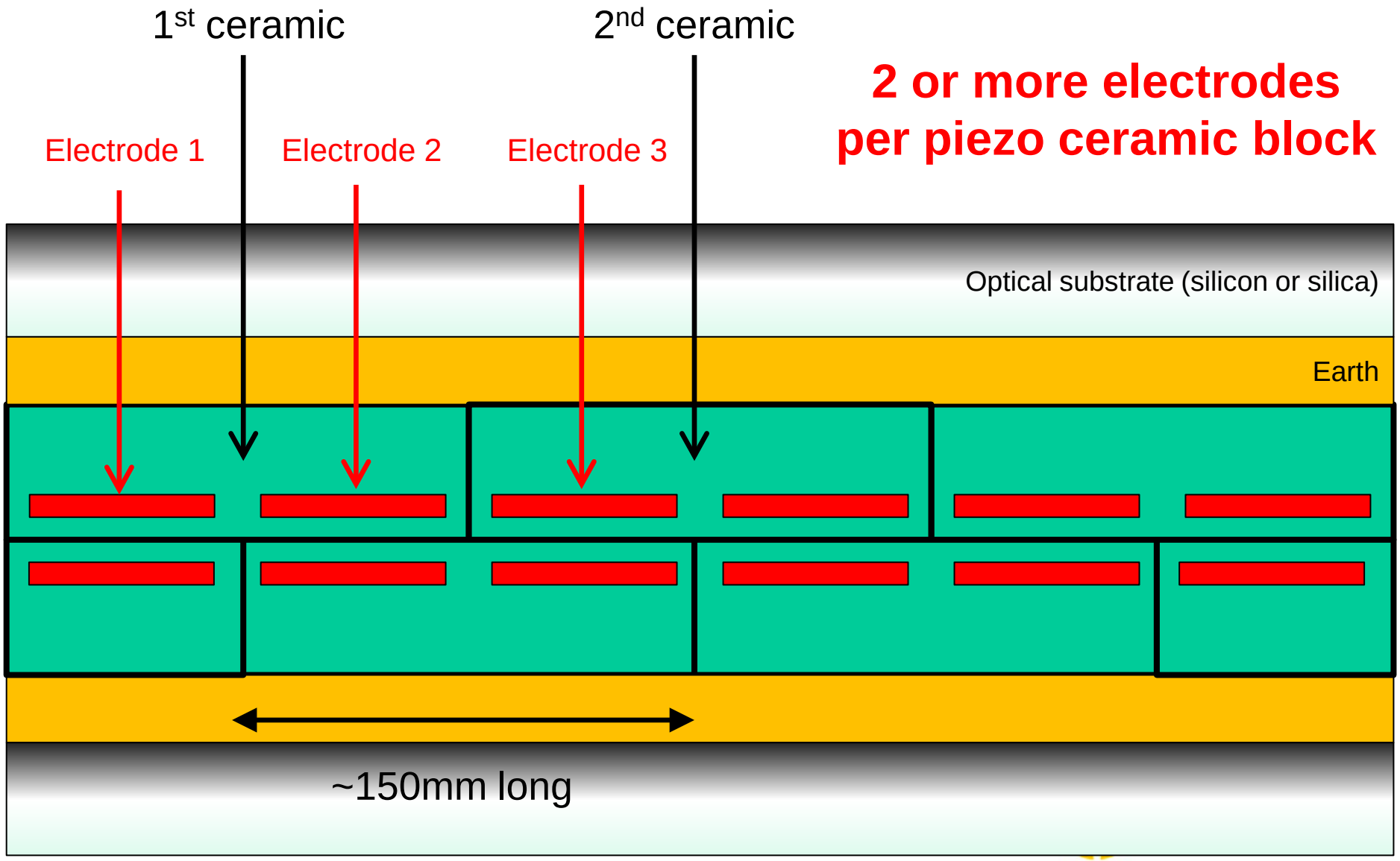


End view

Bimorph construction: side view



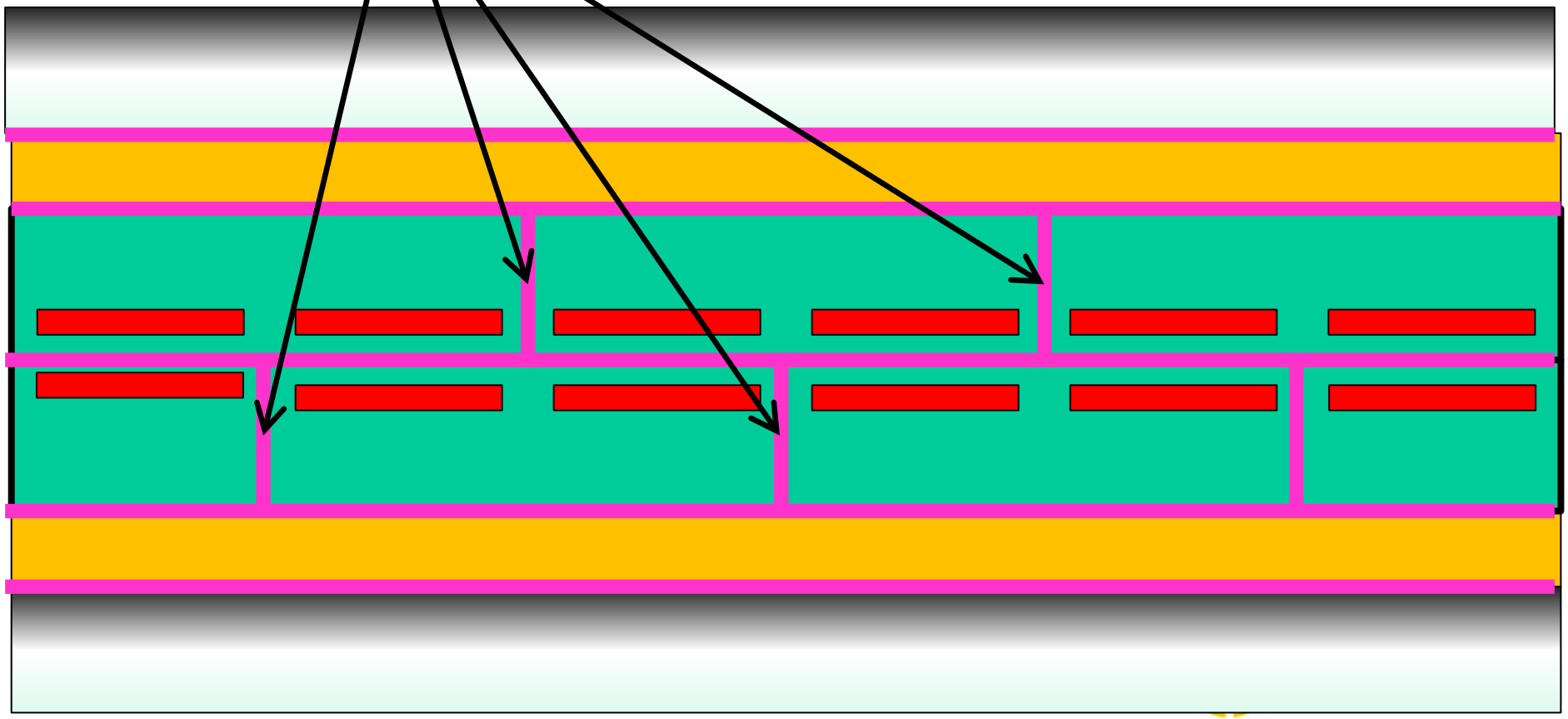
Zoomed side view



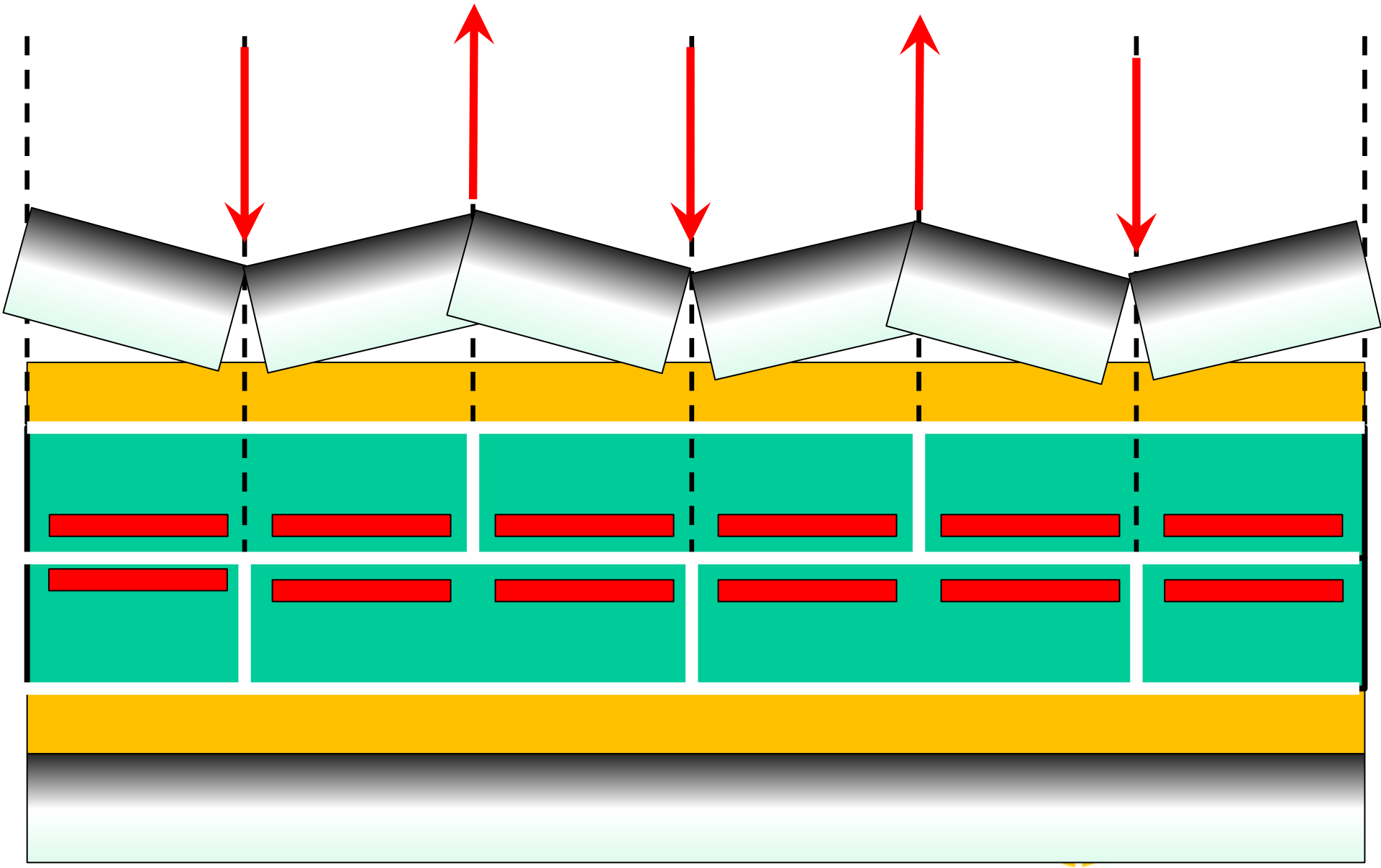
Junction effect

Glue between
piezo ceramics

Does glue "cure" over several months and / or exposure to UHV???

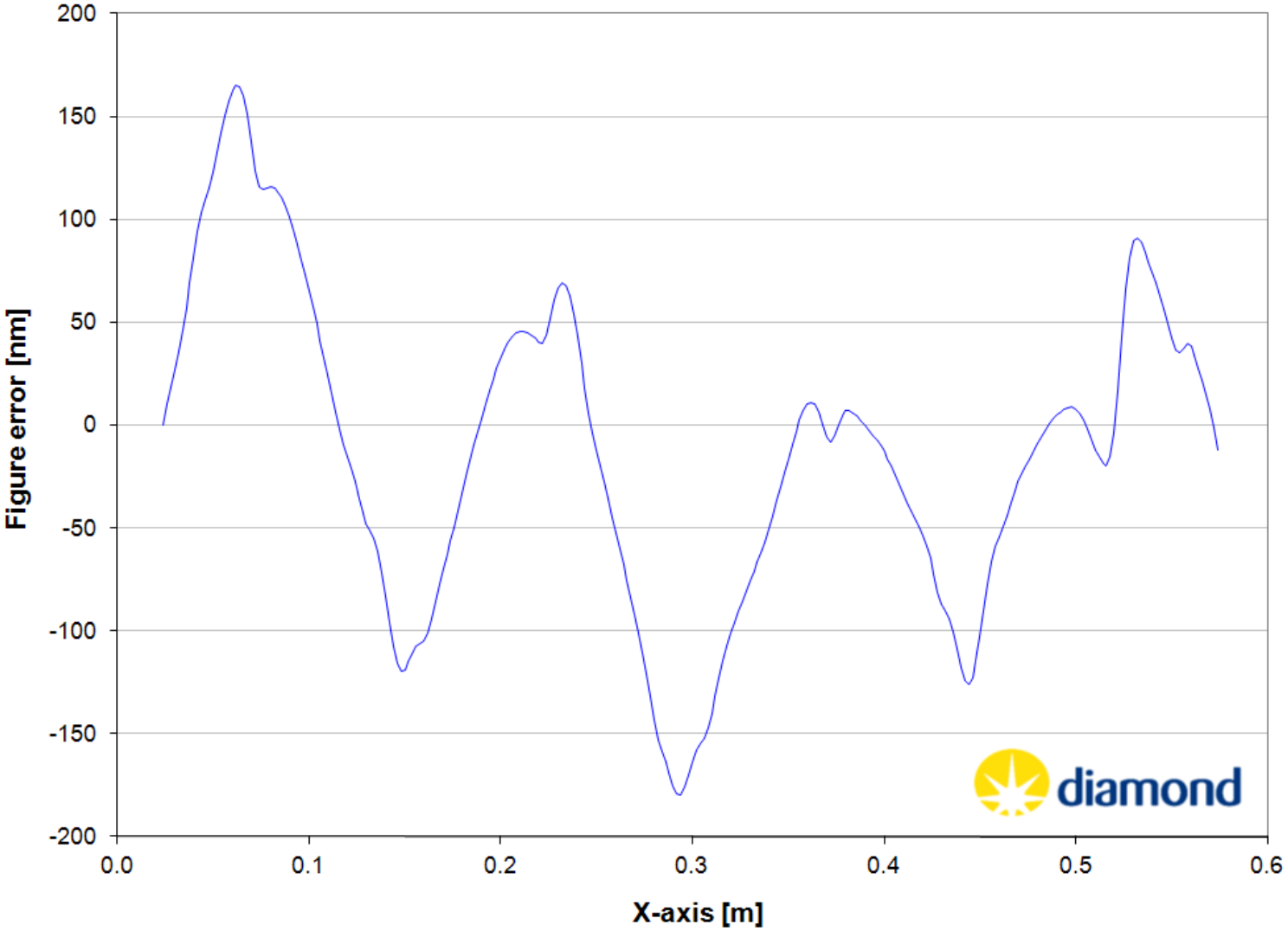


Junction effect: corrugation of surface



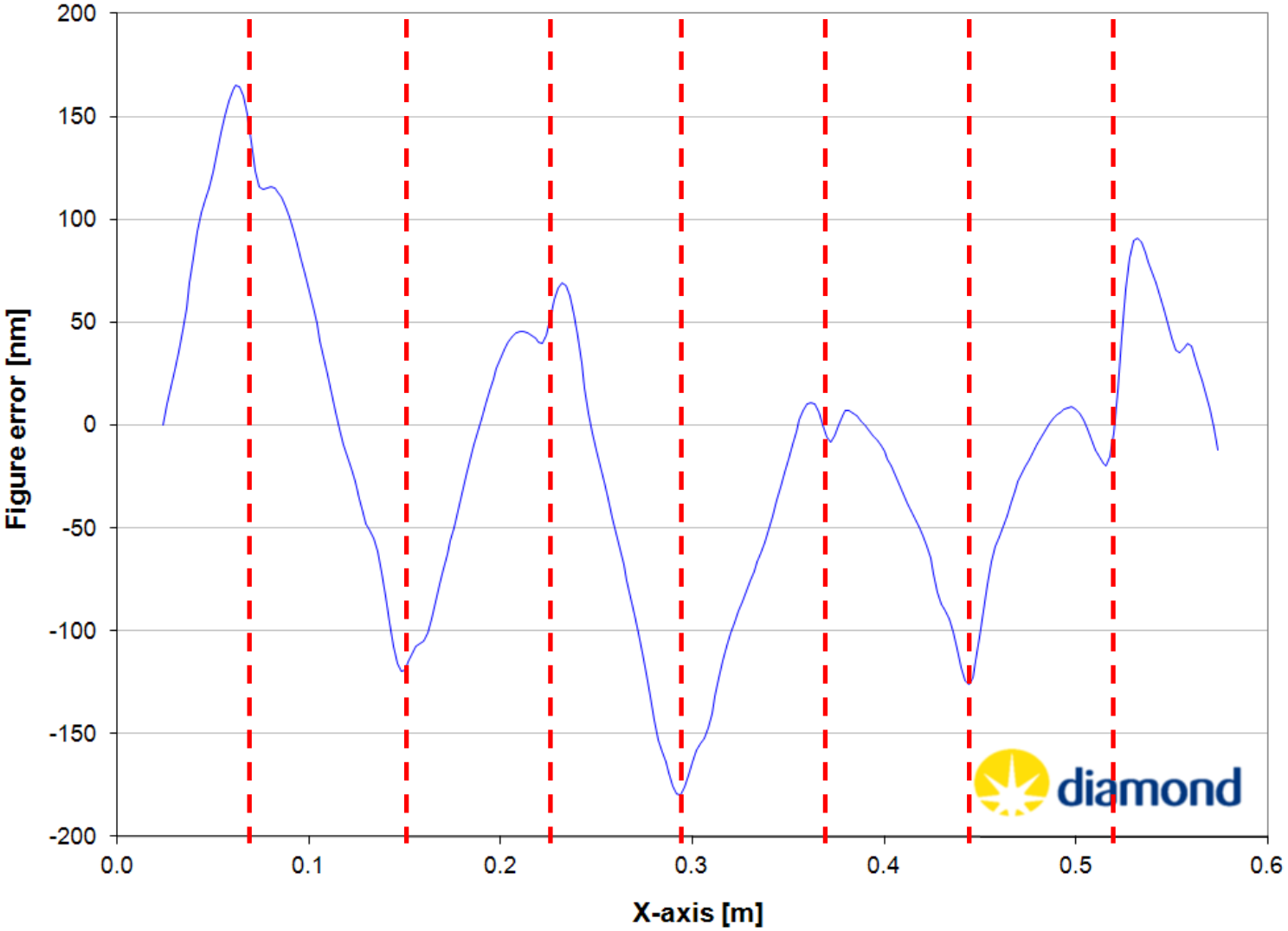
Junction effect: corrugation

- MX (I04) VFM before repolishing



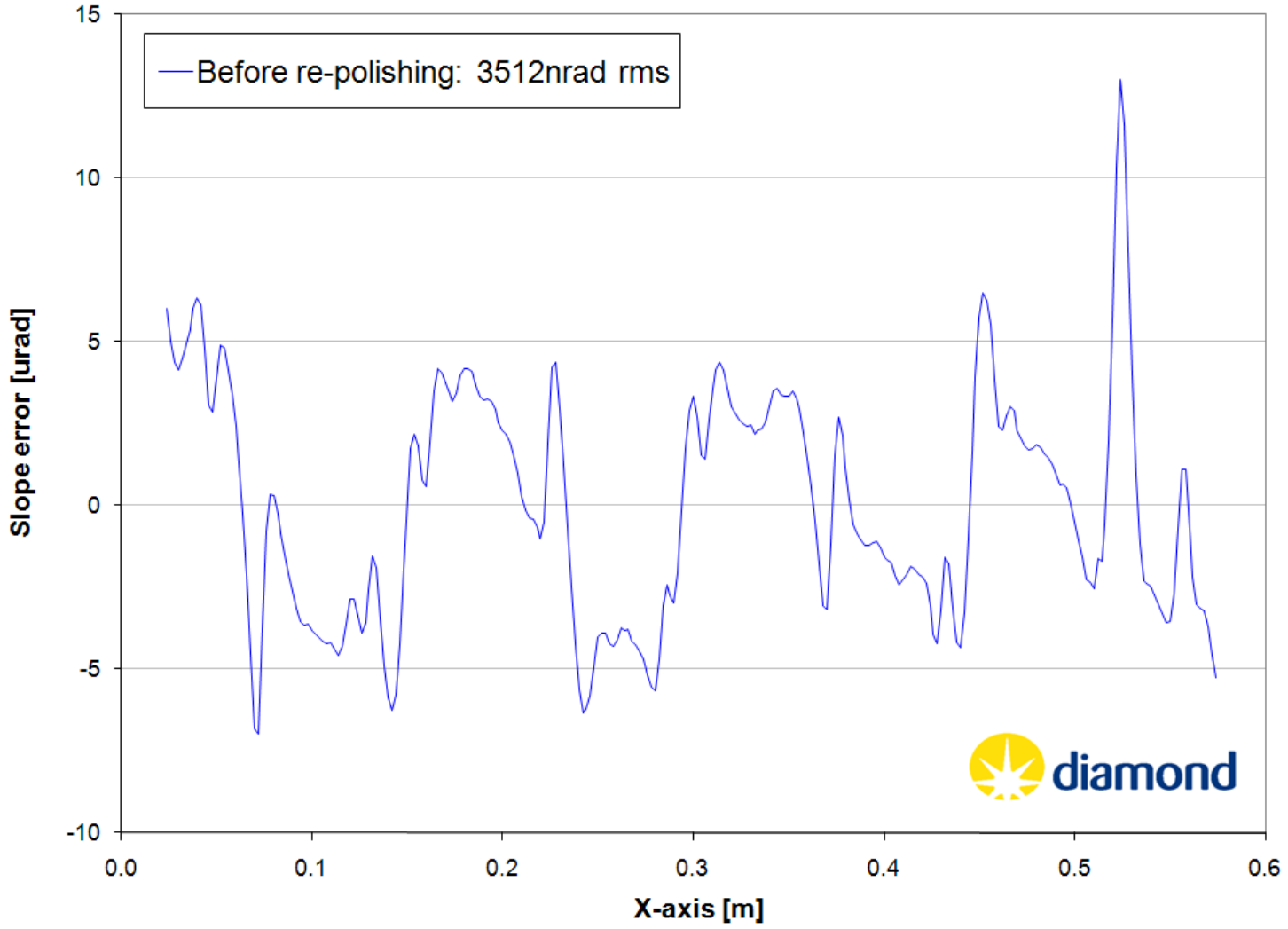
Junction effect

- Corrugations appear at interface between piezos



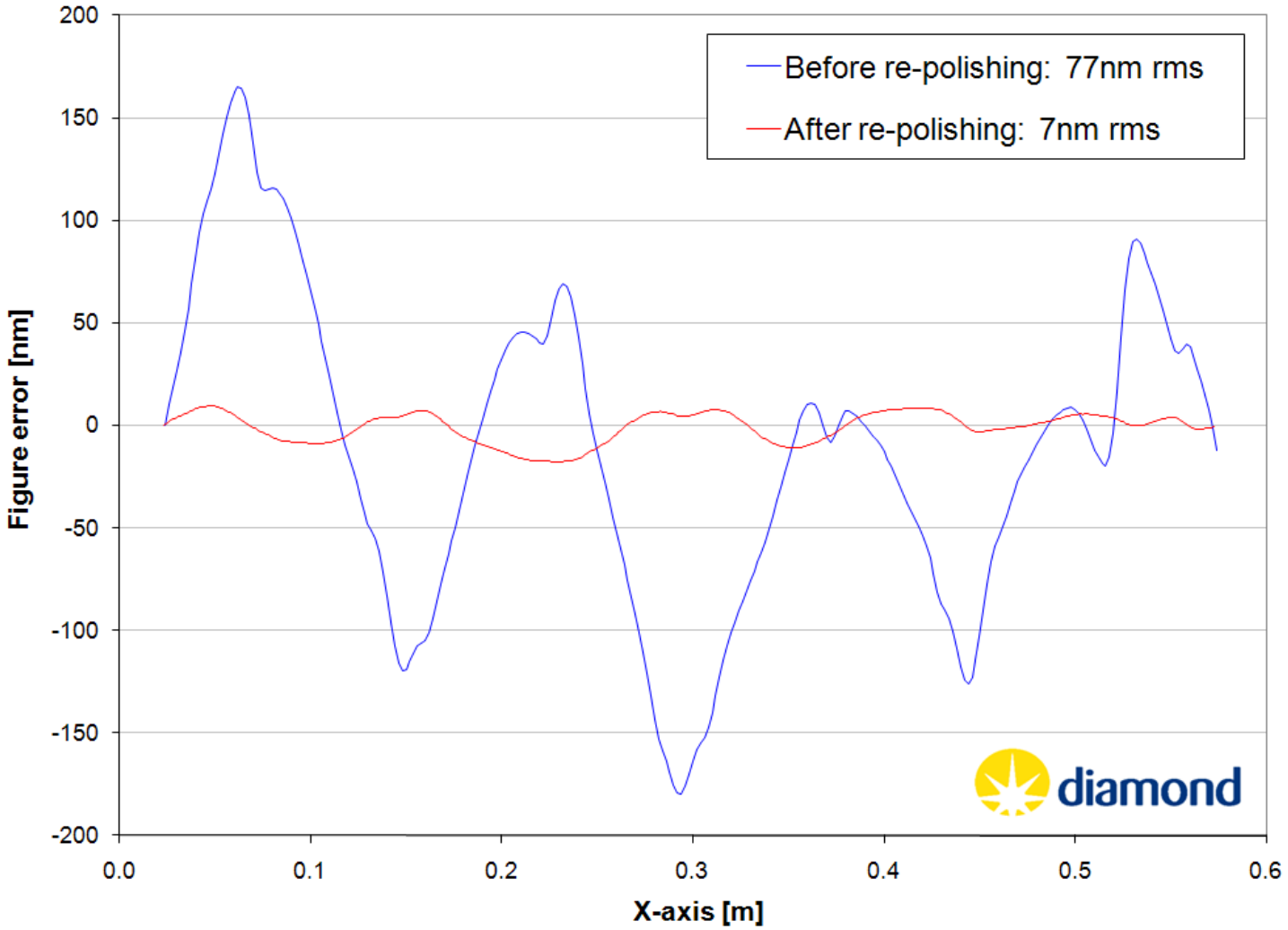
Junction effect: slope “spikes”

- Large slope “spikes” (>10urad PV) at interface between piezos



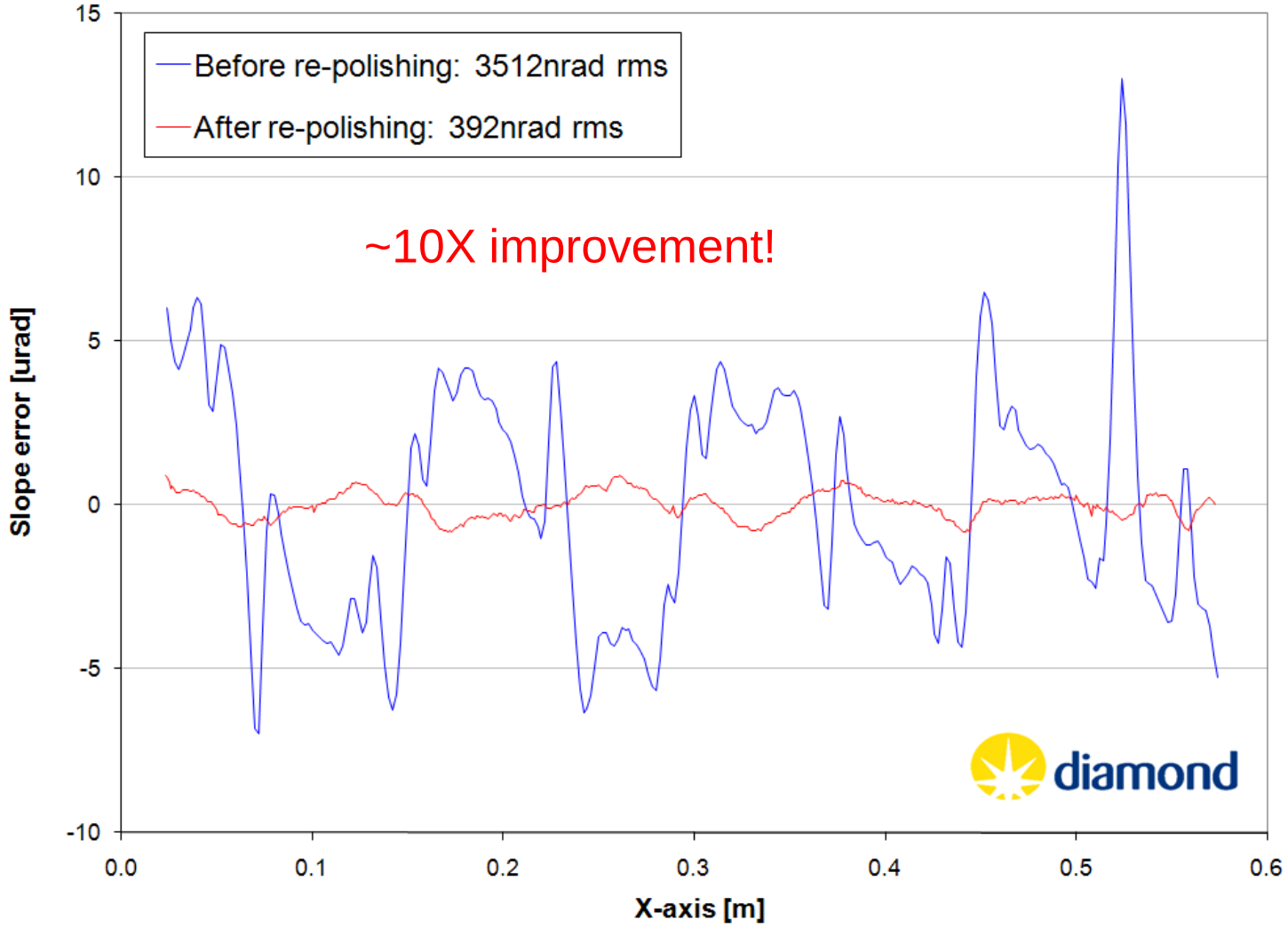
Repolished bimorph mirror

- "Saw tooth" figure errors removed by repolishing at SESO



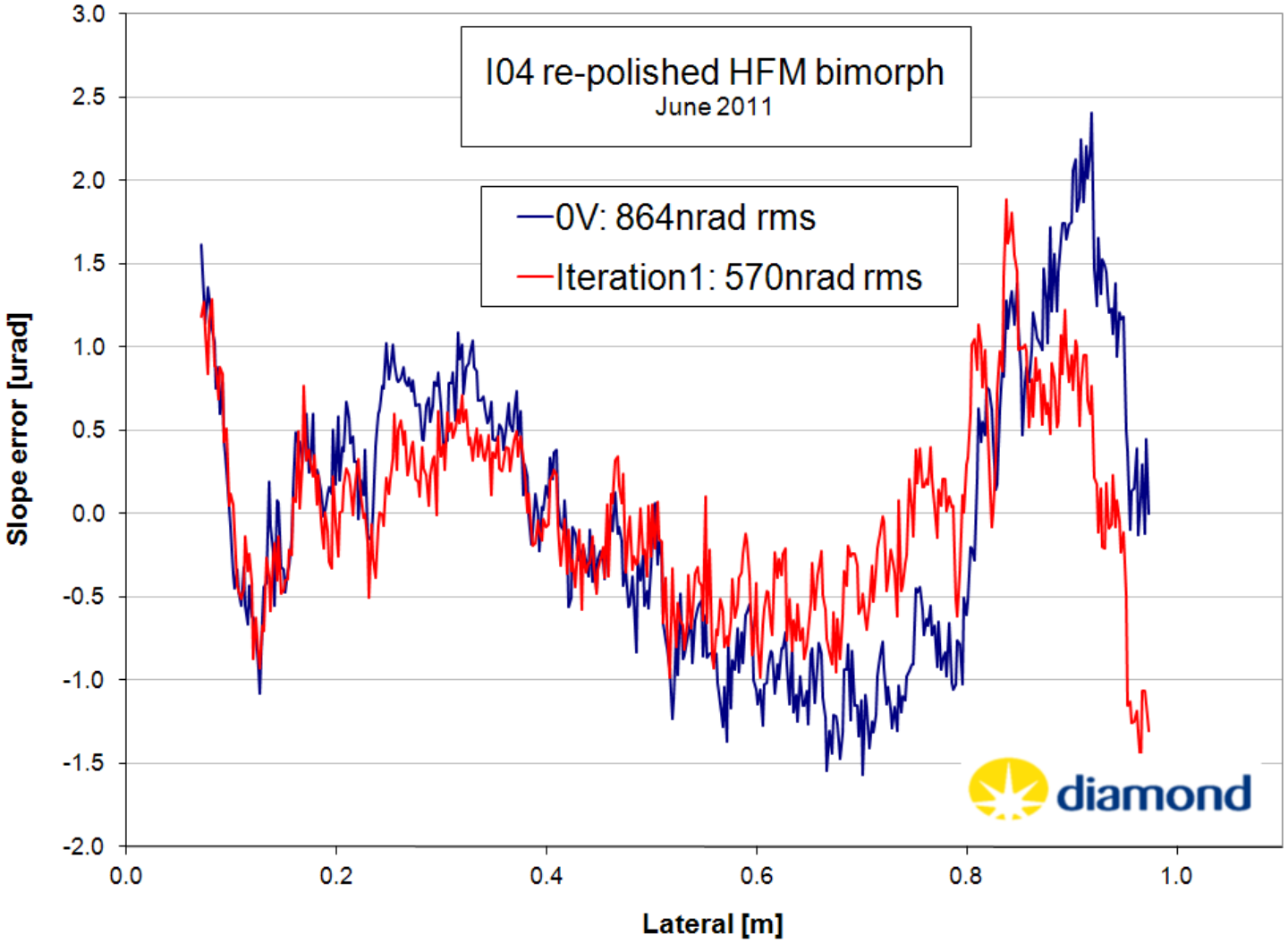
Repolished bimorph mirror

- After repolishing at SESO, slope error = 3512nrad → 392nrad rms



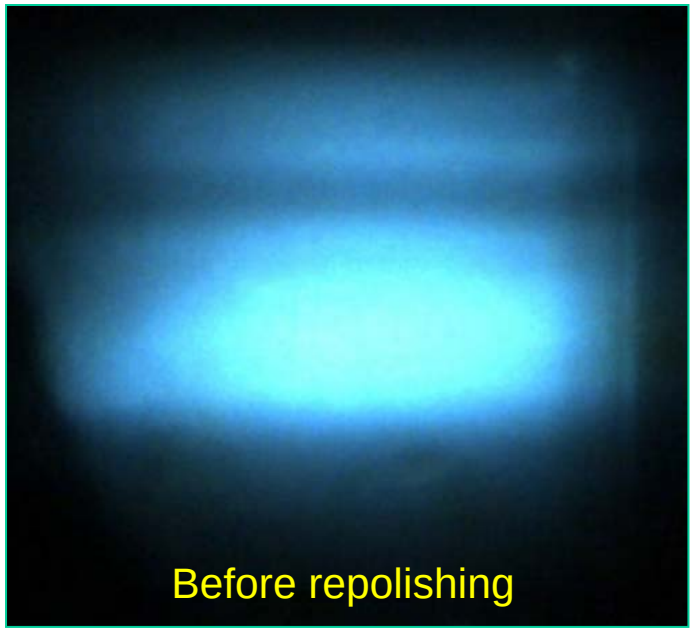
Repolished HFM bimorph

- After repolishing & voltage optimisation, slope error ~570nrad rms

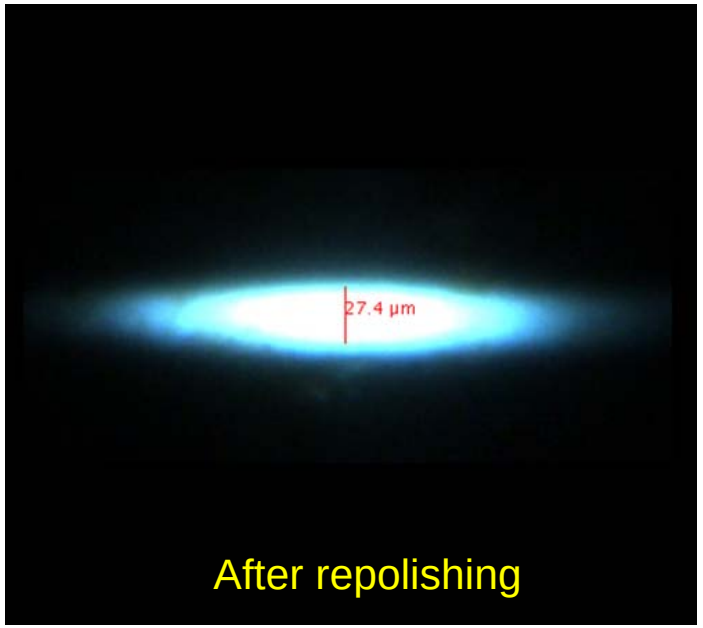


Beamline performance

MX beamline (I03): image of beam on BGO scintillator at sample position



Repolishing

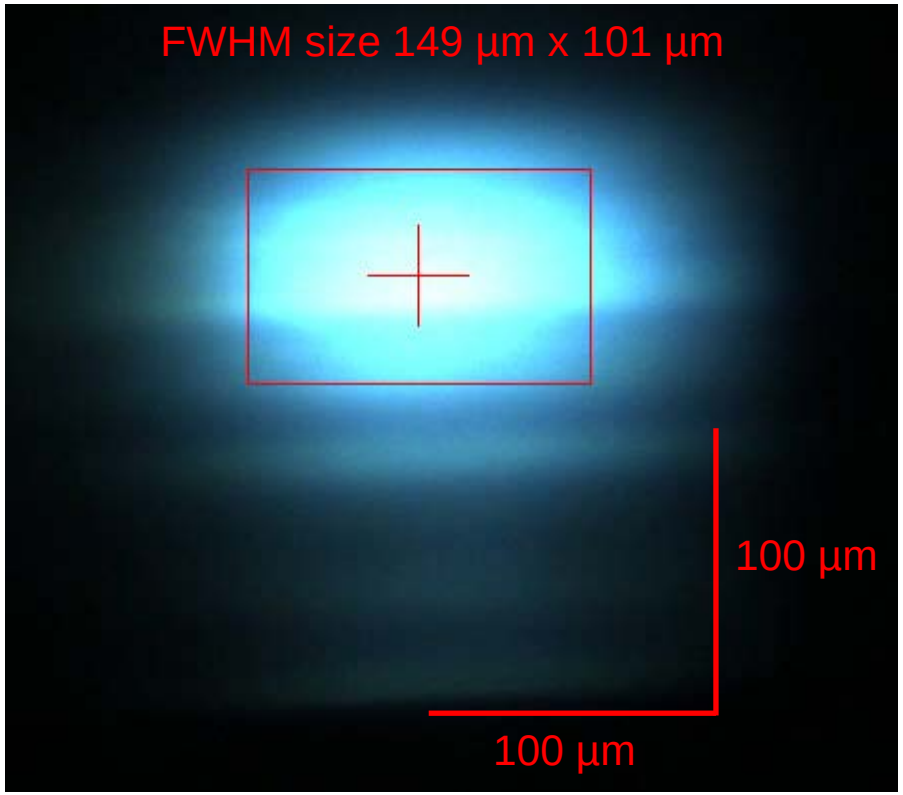


Horizontal FWHM: 120µm → **70µm** (theoretical 65µm)

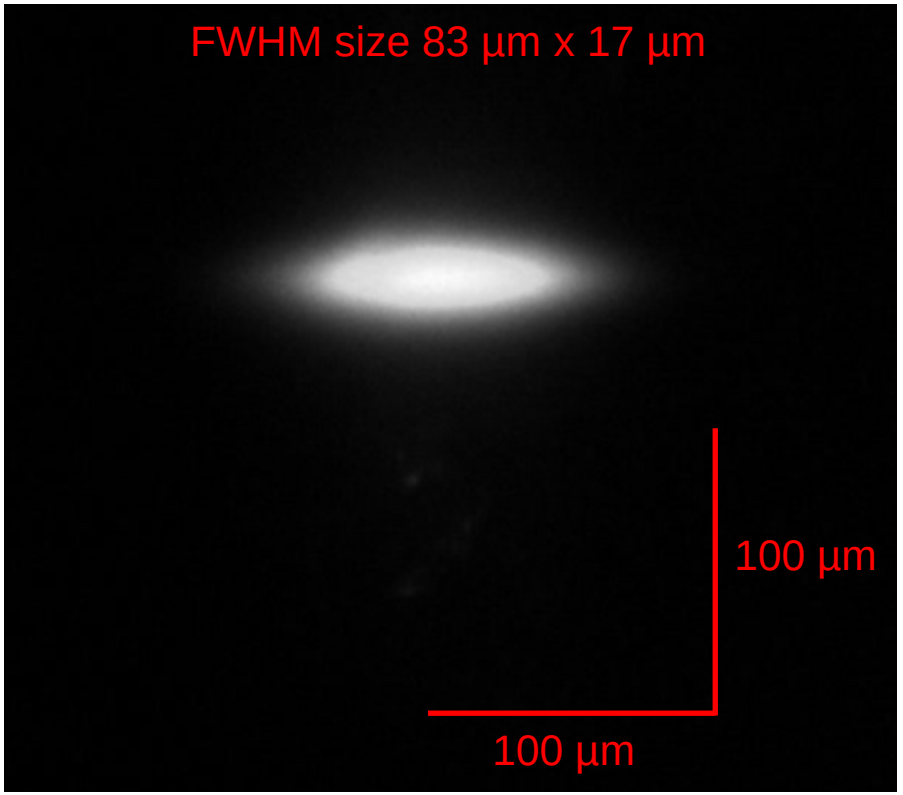
Vertical FWHM: >80µm → **18µm**

+++ Retained performance for >1 year ☺

2nd pair of repolished bimorphs (I02)



Oct 2011: Before repolishing



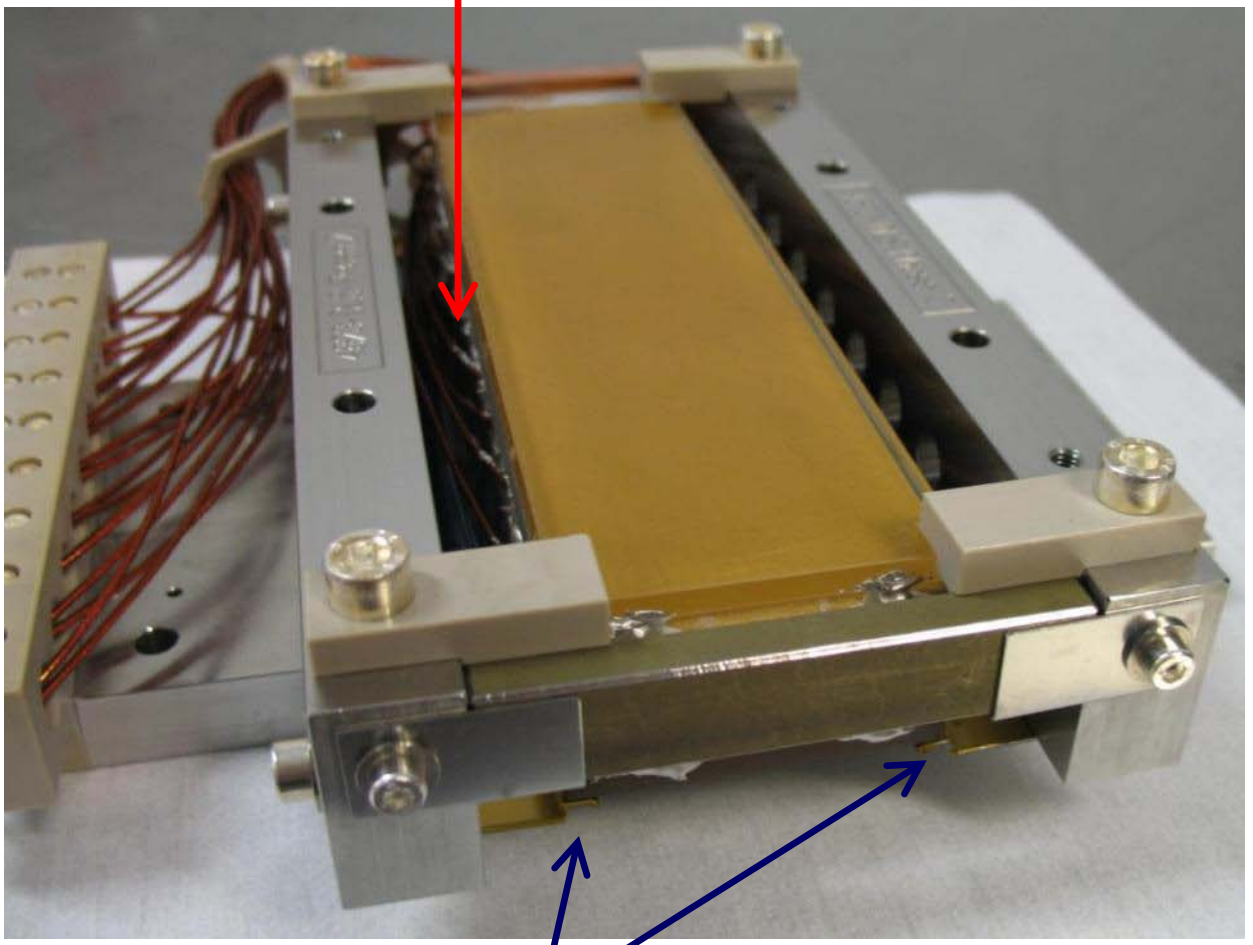
Mar 2012: After repolishing

Mirror distortions???

Several facilities reported problems with mounted (bimorph) mirrors

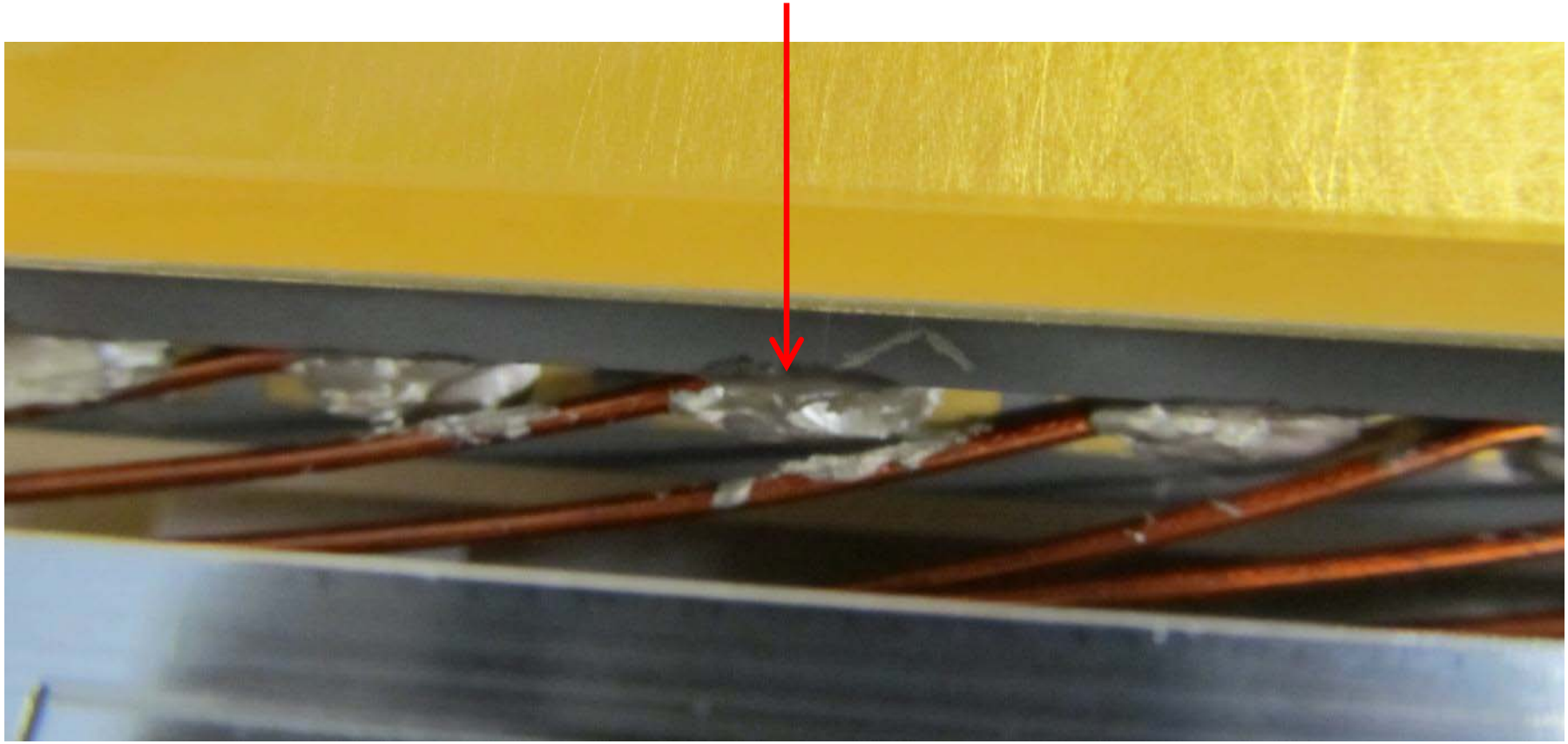
- Clamps / supports
  - ☹ Static distortions (over-constrained / clamping)
  - ☹ Changes with time (flexing)
- Electrical connectors
  - ☹ Stiff connectors act as springs

All electrical wires soldered to piezo ceramics

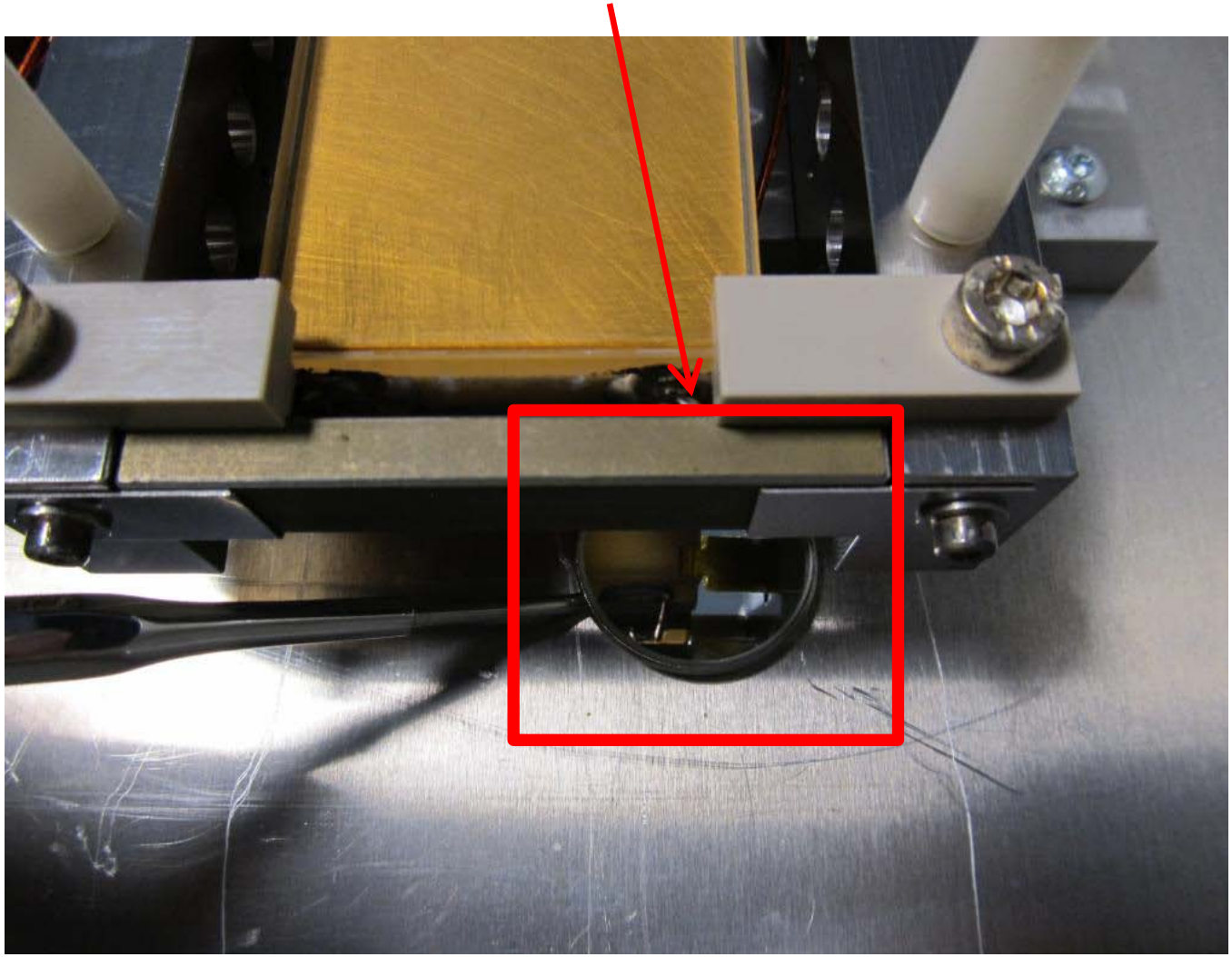


4 x clamps / supports

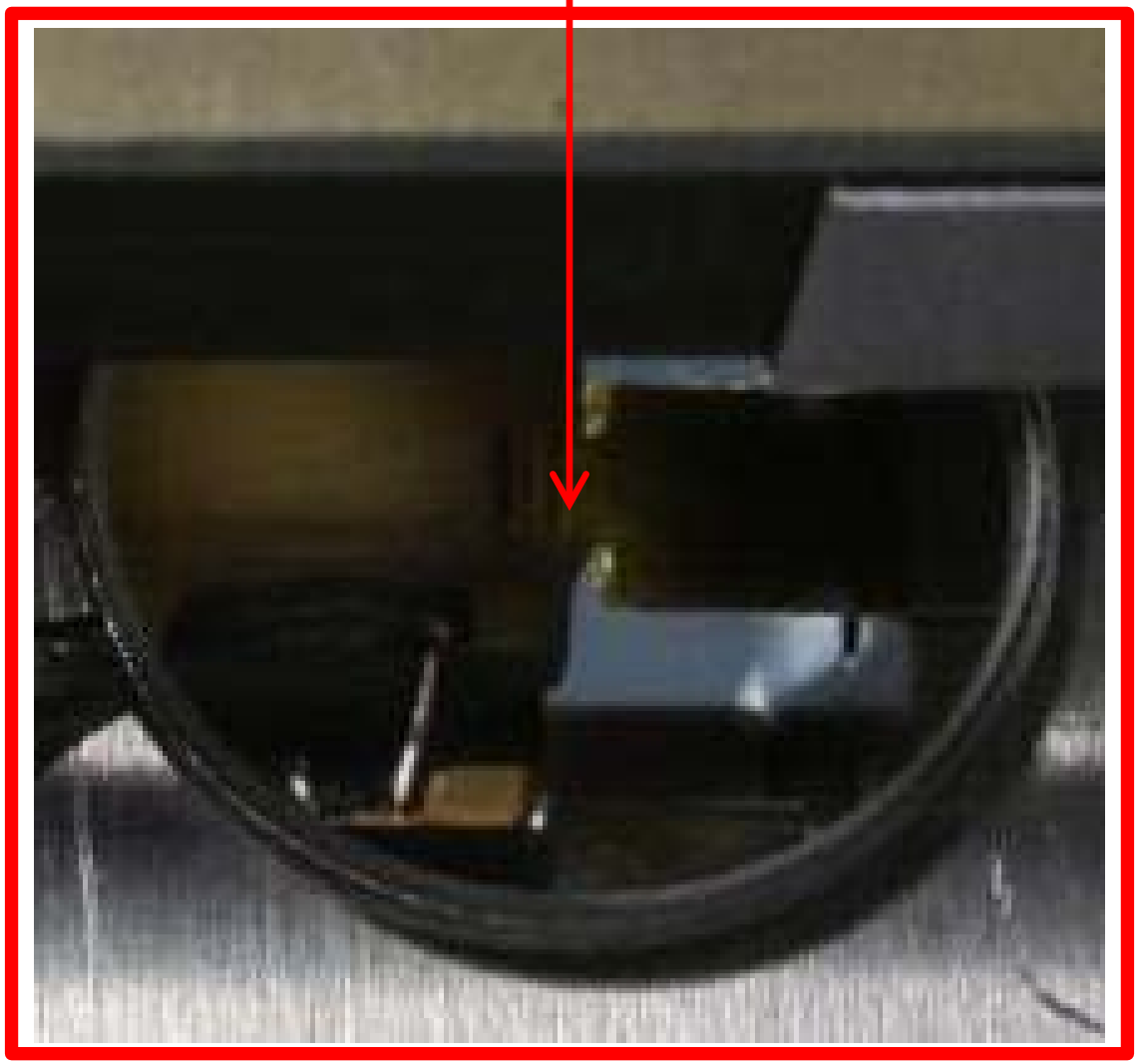
All electrical wires soldered to piezo ceramics



View of underside of mirror



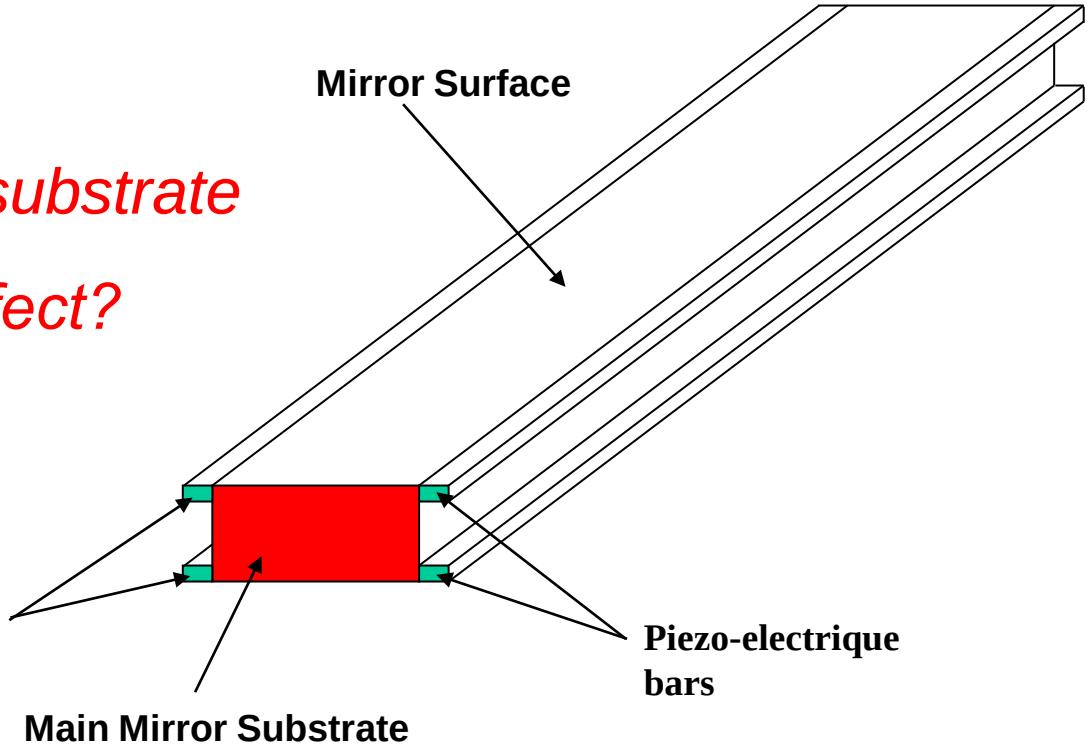
“Cantilever” type mount

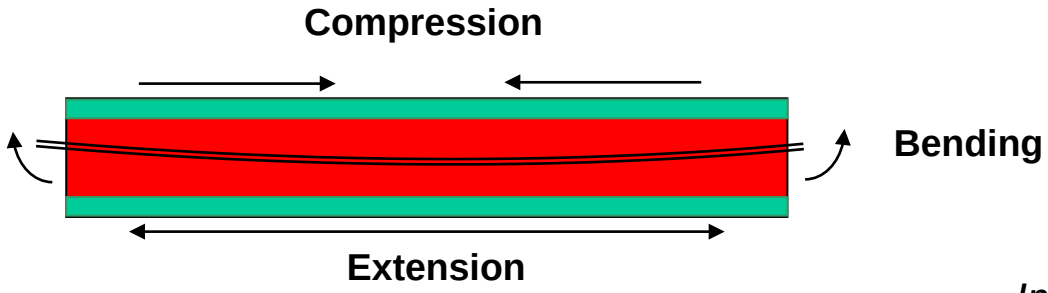


The Future: next generation bimorphs

Piezos on side face of substrate

→ eliminate junction effect?





Patent 1000471-05/02/2010

Images used with permission from SESO

Next generation bimorphs

+ Eliminate junction effect?

+ Much simpler construction (cheaper, quicker fabrication?)

+ Higher density of piezo contacts? More degrees of freedom (correct MSFR???)

+ Multiple, pre-ground figure “channels”?

- Reduced bending range?

- Unproven technology??? Behaviour of glue?

Crystal ball time…

- Combine bimorph technology with super-polishing:

Next generation bimorphs (LSFR) **+** ion beam, EEM (MSFR & HSRF)

→ "Ultimate" mirror???

- Multiple polishing "channels" per substrate? Overcome reduced bending range of next generation bimorphs?

Summary

☺ Comprehensive ex-situ & in-situ investigation of active optics

☹ Many 1st generation bimorphs suffer from junction effect → limits beamline performance

☹ Initial changes to structure of glue / piezo interfaces???

☺ Repolishing leads to significant beamline improvement

☹ …but repolishing expensive & time consuming (+ damage)

☺ Improvements are stable for at least 1 year

☺ Next generation bimorph designed not to exhibit junction effect?

Who wins the bimorph “shoot-out”?

The Good, The Bad or The Ugly?

You decide!

Acknowledgements

- Colleagues at Diamond Light Source
- Collaborators at other SR facilities
- Riccardo Signorato (Bruker)
- SESO-Thales
- Elettra (HV power supply & software)

Thank you for your attention! ☺