Development of a High Resolution Bimorph Deformable Mirror for Free-Space Optical Communications

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- Motivations

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- Bimorph mirror technology

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- Mirror assembly and characterisation

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Motivations

- Low Earth Orbit Satellite to Ground Optical Comms (250-1000km)

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- Effectiveness of binary phase shift keying (BPSK) modulation scheme limited by atmospheric turbulence
- Solution : high speed wavefront correction

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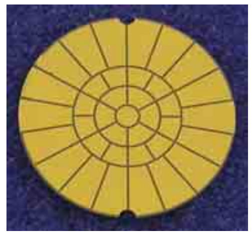
Preliminary requirements

- Operating wavelength : 1064 nm
- Illuminated diameter : 10 mm
- Lowest resonance : 10 kHz
- Stroke : 10 μm
- Number of actuators : >36

Bimorph Deformable Mirrors

- Integrated flexi-circuit technology developed at ATC enables:
    - Very thin structures without print-through issues
    - Large stroke with curvatures in excess of 2 Dioptres
    - High density of actuators
    - Compatible with dual-stage assemblies
    - Potential for low cost, robust and compact systems

Previously assembled BDMs

Device #1- 37 Element BDM with a 10mm Pupil	
	
Electrode pattern	Image of the assembled mirror
Lowest resonance	5.7kHz
PV stroke over the 10mm pupil	8.8µm
Coating Type	Chrome-Gold
Device #2 - 35 Element BDM with a 7mm Pupil	
	
Electrode pattern	Image of the assembled mirror
Lowest Resonance	9.6kHz
PV Stroke over the 7mm pupil	4µm
Coating Type	Sputtered HR coating.

Modelling analysis

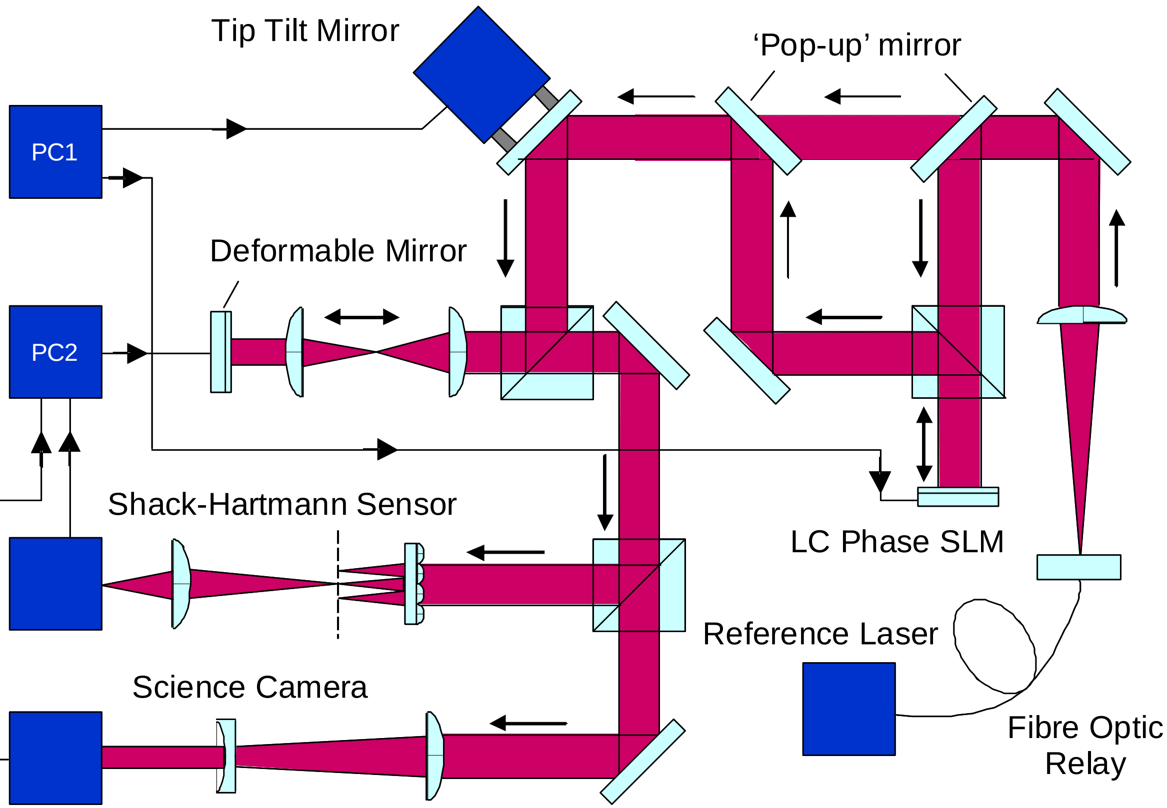
Option 1: Meets Stroke	
Modelled Lowest Resonance	6kHz
Modelled Stroke	10µm
Option 2: Meets Lowest Resonance	
Modelled Lowest Resonance	10kHz
Modelled Stroke	6µm
Option 3: Trade-Off Design	
Modelled Lowest Resonance	8kHz
Modelled Stroke	8µm

Integration on commercial tip-tilt stage

- Integration of mirror onto tip-tilt stage was major design aim
- Experiments undertaken:
  - Base of mirror #1 redesigned
  - 23 grams initial base weight - reduced down to 9 grams

		
BDM with a standard base	BDM with the light-weight base	Light-weight BDM mounted on Tip-Tilt stage

Integrated device evaluation in ATC test bed



Integrated device evaluation in ATC test bed

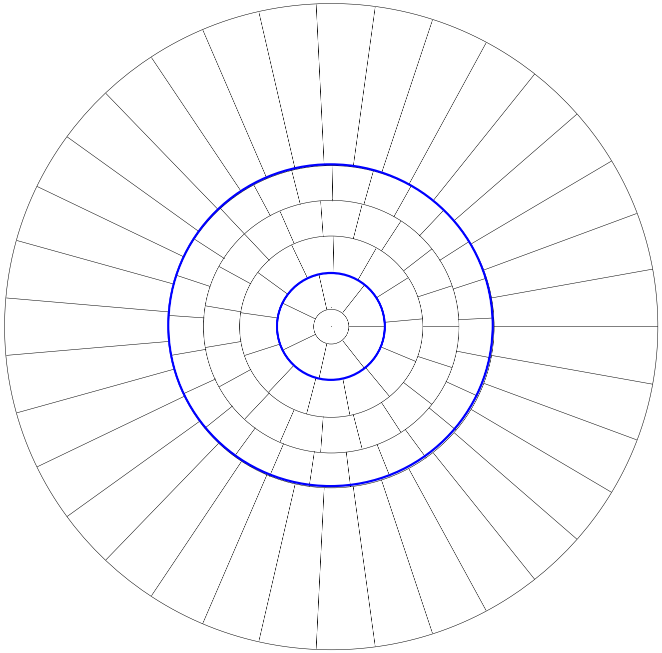
	Standard base with separate tip-tilt stage	Light-weight base integrated onto the tip-tilt stage
Lowest resonance	5.7 kHz	5.4 kHz
PV stroke	8.8µm	9.2µm
Flattened Strehl ratio (relative to a perfect mirror)	0.88	0.89
Lowest resonance for the tip-tilt stage (specification is 2.4 kHz ±20% for a 8mm thick glass mirror)	2.6 kHz	2.2 kHz

Refined requirements

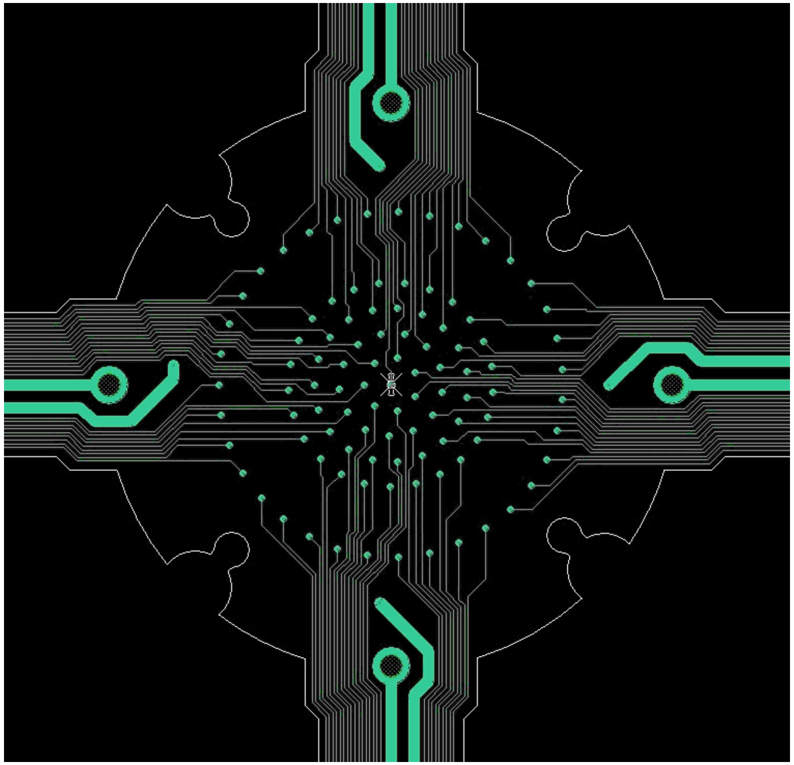
- Following this analysis, the design aims for the mirror were refined in terms of performance and integration capability:
  - Total number of actuators: 100
  - Active (illuminated) diameter: 10mm
  - Number of actuators within illuminated diameter: 65
  - High reflectivity at both 633nm (test) and 1064nm (operational)
  - Lowest resonance of device with a 0.5mm mirror substrate: 6kHz
  - Curvature of device with a 0.5mm mirror substrate: +/-2m
  - Lowest resonance of device with a 1mm mirror substrate: 10kHz
  - Curvature of device with a 1mm mirror substrate: +/-5m

Mirror assembly

- Design exploited high density flexi-circuit interconnect

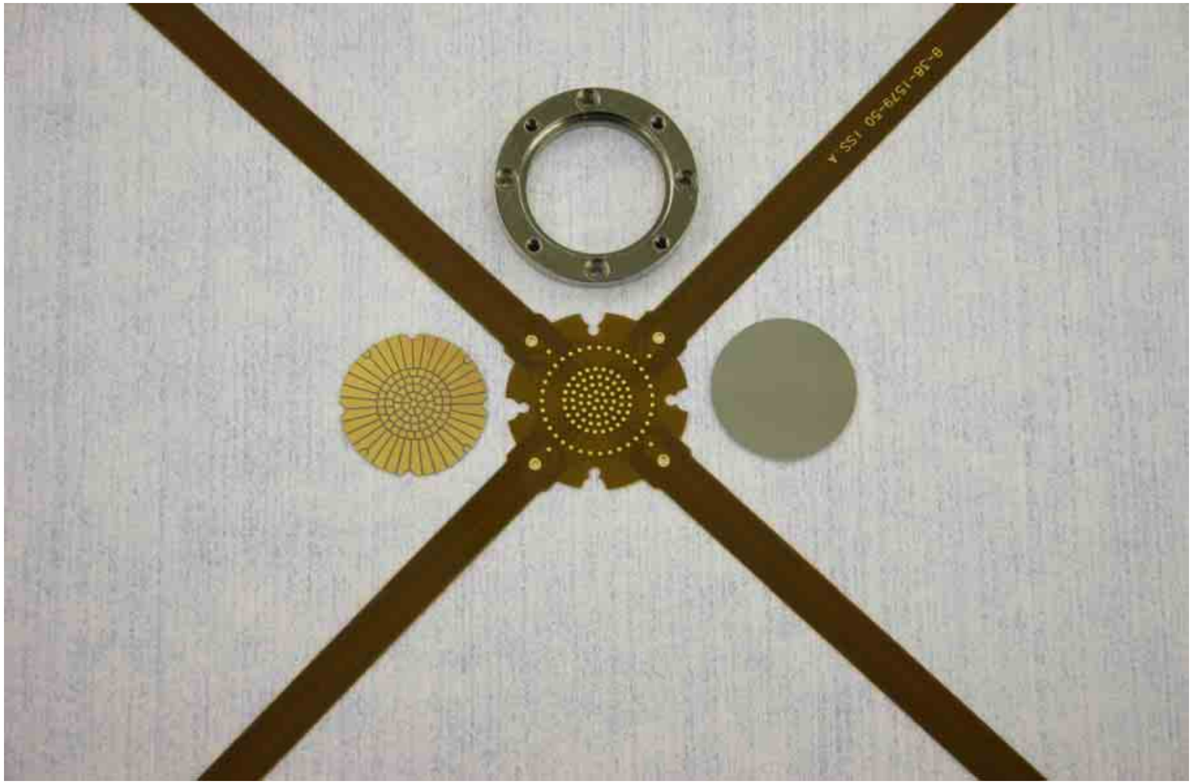


Electrode Pattern



Routing via Flexi-Circuit

Mirror assembly



Main Component Parts

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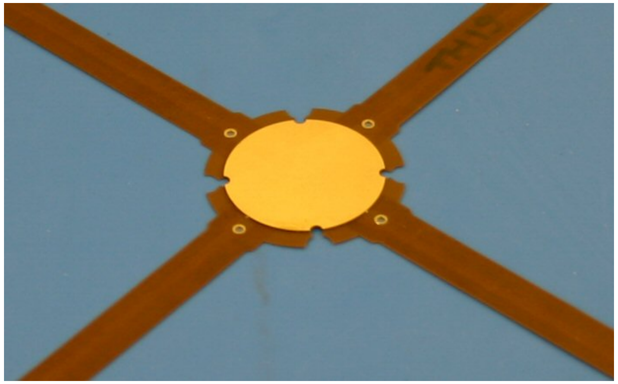
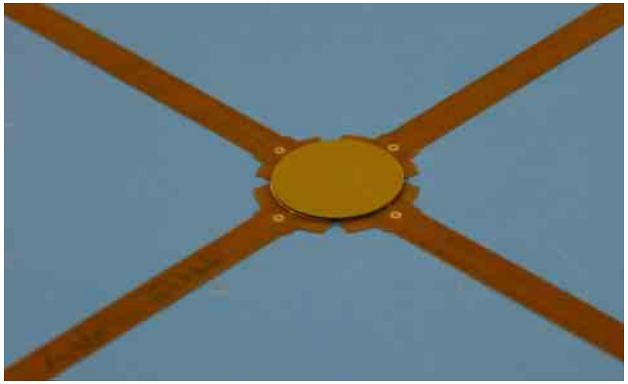
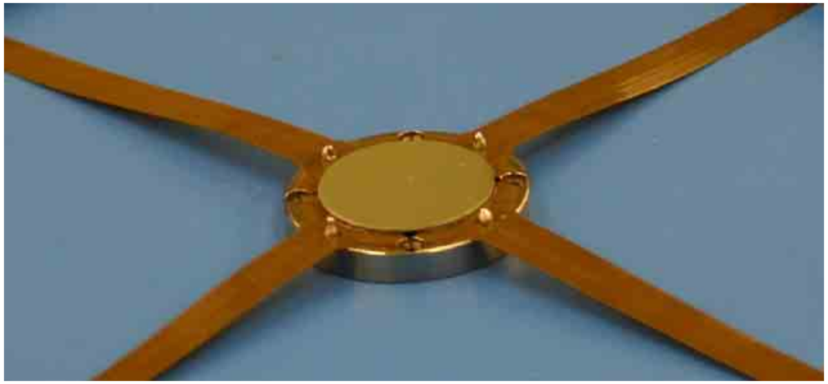
Assembly sequence



Stage 1: Assembly of the
PZT disc onto the flexi-circuit



Stage 2: Assembly of the passive
mirror substrate onto the PZT



Stage 3 : Assembled BDM showing the protruding pins used to earth
the base through the flexi-circuit

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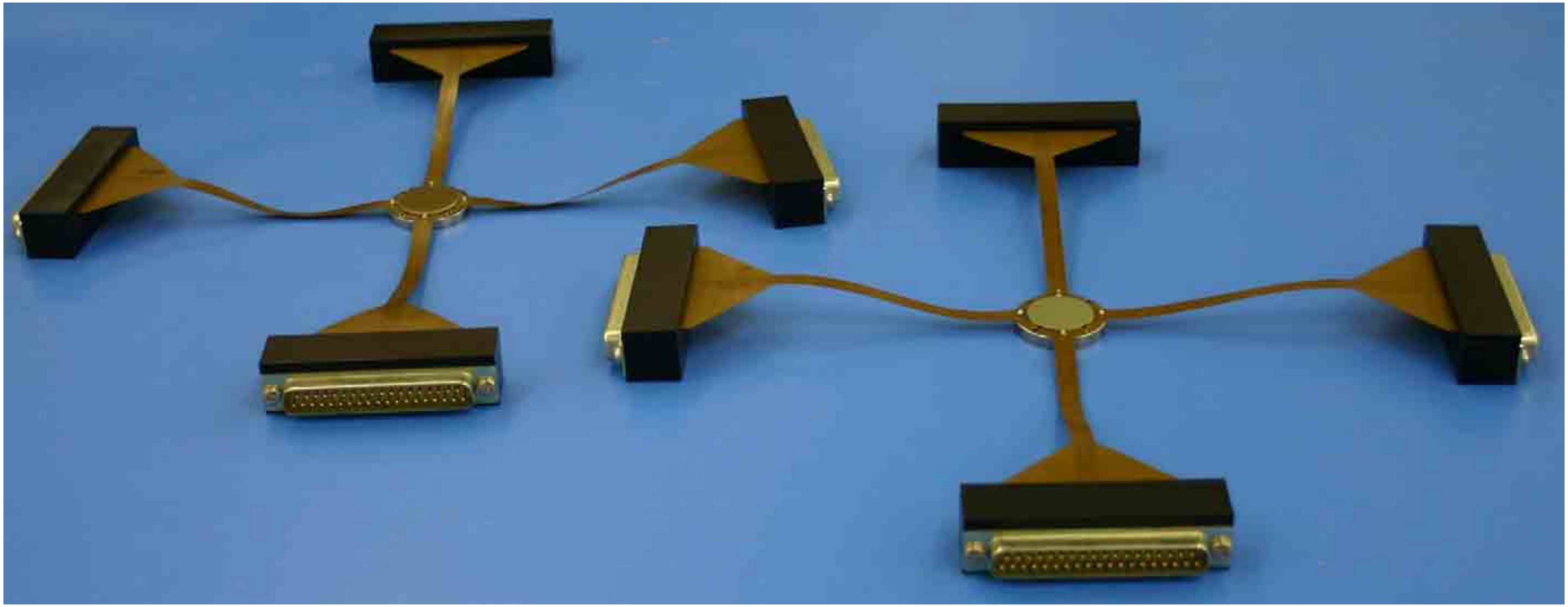
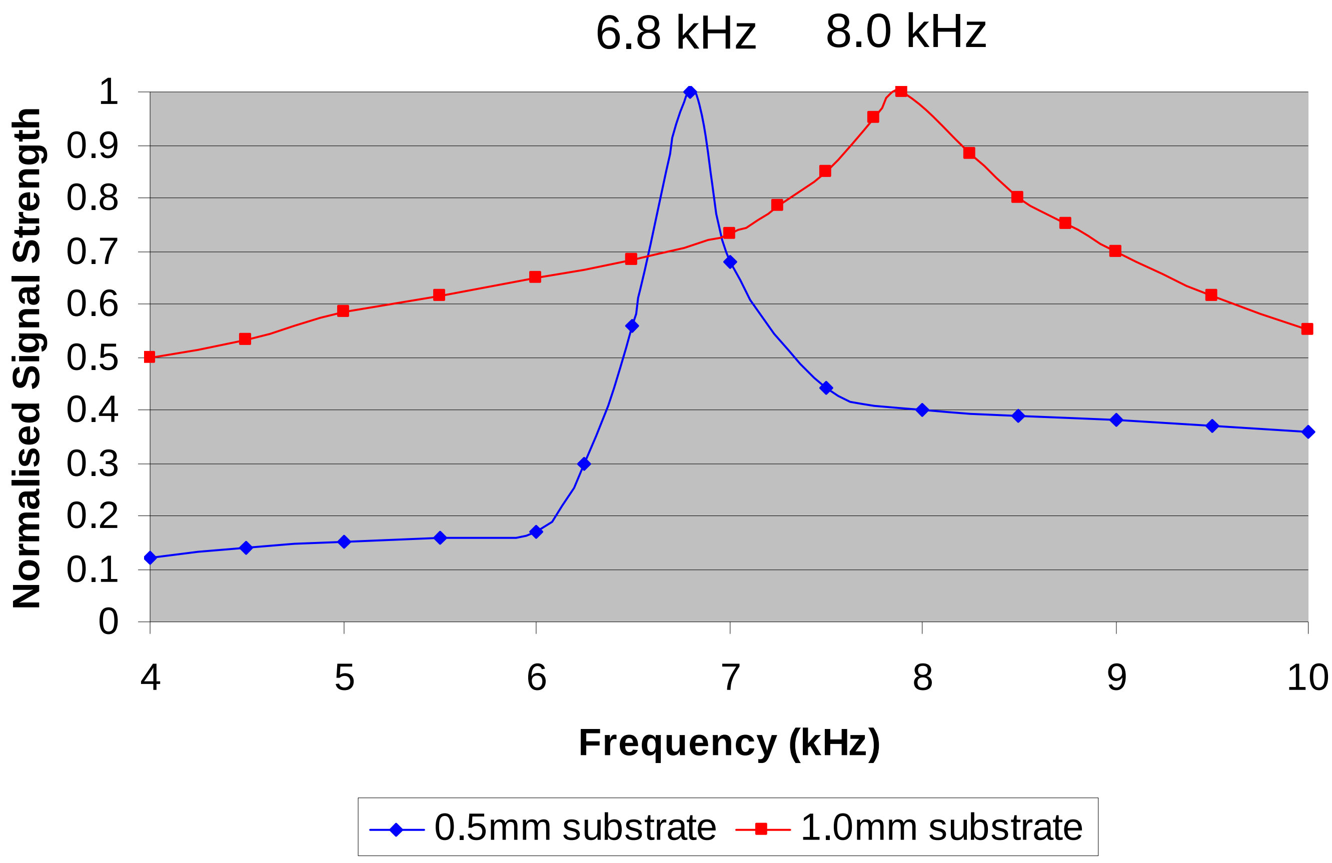
Final assembly



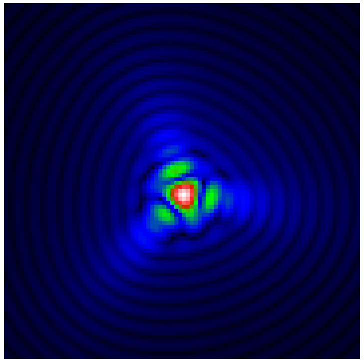
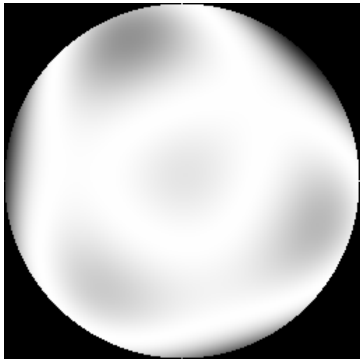
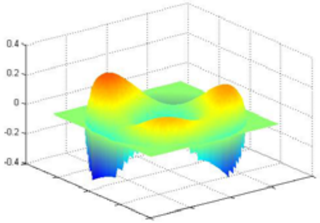
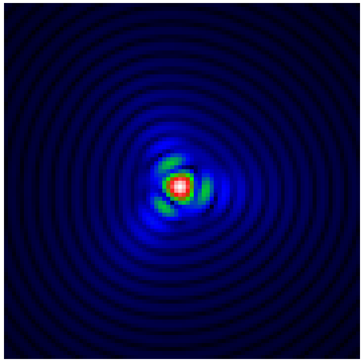
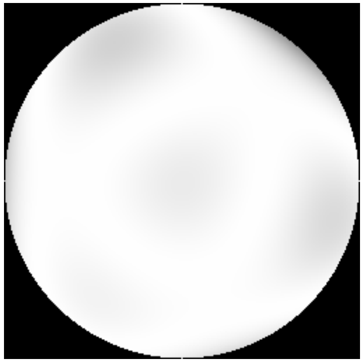
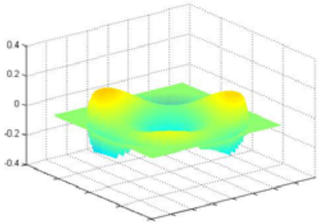
Fully assembled devices

Mirror characterisation



Lowest Resonance Results

Mirror characterisation

	Far-Field Intensity	Interferogram	Wavefront Surface	Phase Peak to Valley	Strehl Ratio
Un-flattened				0.61 waves	0.67
Flattened				0.36 waves	0.87

Results summary

Parameter	Design Aim	0.5mm Substrate	1.0mm Substrate
Reflectivity	>90% at 633nm > 94% at 1064nm	97% 98%	97% 98%
Flattened Strehl ratio (using no more than 20% of the available stroke)	0.95	0.86 (@ 633nm)	To be confirmed
Lowest resonance frequency	6 kHz (0.5mm) 10 kHz (1.0mm)	6.8 kHz -	- 8.0 kHz
Curvature (assuming the use of an optical bias)	±2m (0.5mm) ±5m (1.0mm)	±3m -	- ±4m

Conclusions and acknowledgement

- Bimorph mirrors have been realised that offer unparalleled combination of active element number and density.
- Use of flexi-circuit technology enables mirrors to be integrated onto a tip-tilt stage without size or weight penalty.
- Next step will be to evaluate mirrors in a representative adaptive optics system.
- This work was funded by the European Space Agency through the Innovation Triangle Initiative.