Flextensional Single Crystal Piezoelectric Actuators for Membrane Mirrors

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Acknowledgement:

NASA grant #NNM06AA32C

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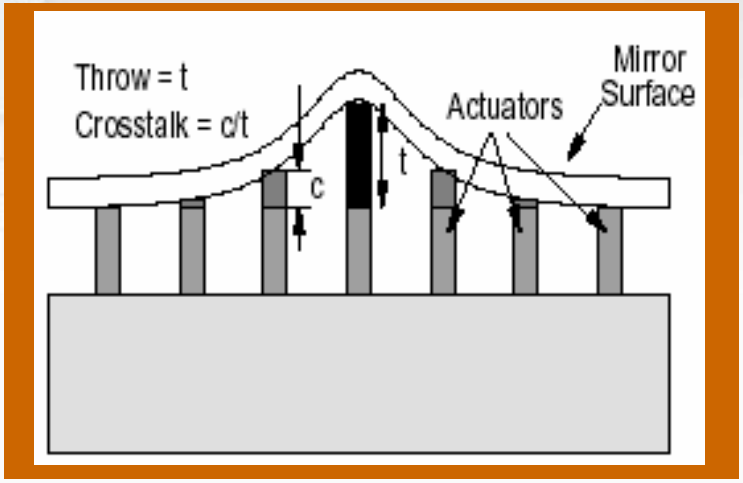
Outline

- **Background**
  - Deformable mirror
  - Cryogenic actuations
  - Single Crystal Piezoelectrics
  - Piezoelectric Actuators
- **Flextensional Actuators Design**
- **Flextensional Actuators Prototyping and Tests**
- **Deformable MM concept Demonstration**
- **Summary**

Currently Available Deformable Mirrors

Characteristic	Ideal DM	PZT or PMN (Xinetics)	Surface MEMS DM (Bifano)	Bulk MEMS DM (OKO)
Throw (μm)	**Large**	**~ 5**	**~ 1**	**~10**
Temperature	Broad	<65K or > 77K	?	?
Spacing (mm)	small	7	~0.4	~2
Cross talk	Low	Low	Low	High
Influence Function	Smooth	Smooth	Smooth	Smooth
Scalable Speed	Yes	Yes	Yes	No
Surface Quality	Great	Good	Poor	OK
Fabrication Complexity	Low	High	Low	Low



Deformable mirrors are employed to improve the quality of the wavefront of a projected beam or source image, which has been distorted by optical disturbance along the optical path. Deformable mirrors have been used extensively in space wavefront corrector, directed energy, auto-focus, etc. DM in the market include: micromachined DM (electrostatic), thermal DM, piezoelectric DM, Electrostrictive DM, liquid crystal, etc.

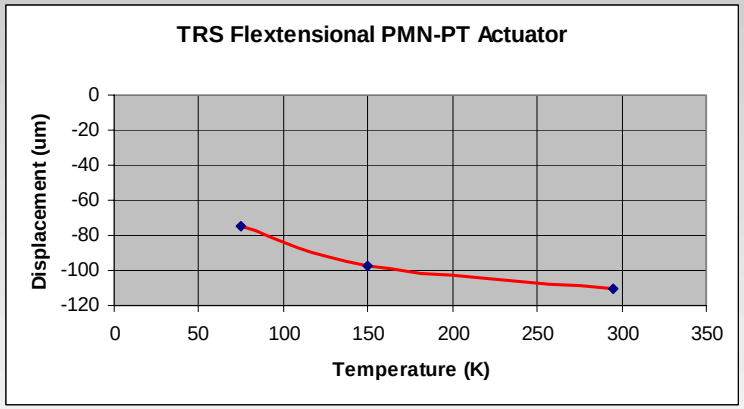
Background

Actuator Type	Shape Control		Position Control		Force Control		Deformable Mirror	
Property	Req.	Goal	Req.	Goal	Req.	Goal	Req.	Goal
Resolution (nm)	**≤20**	**≤ 10**	**≤ 20**	≤ 10	**≤ 4**	**≤ 2**	***≤ 5***	**≤ 3**
Life Cycles	$\geq 10^4$	$\geq 10^5$	$\geq 10^4$	$\geq 10^5$	$\geq 10^4$	$\geq 10^5$	$\boldsymbol{\geq 10^5}$	$\geq 10^6$
Stroke (mm)	**≥ 0.3**	**≥ 0.5**	**≥ 6**	≥ 10			***≥ 0.005***	**≥ 0.05**
Operating temperature range (K)	20-60	20-300	20-60	20-300	20-60	20-300	***20-60***	<20-300
Mass (g)	≤ 40	≤ 20	≤ 40	≤ 20	≤ 100	≤ 50	***≤ 20***	≤ 10
Outside Diameter (cm)	≤ 2	≤ 1	≤ 5	≤ 1	≤ 5	≤ 2		
Creep, OM (nm/Day)	**≤ 0.1**	**≤ 0.01**	**≤ 0.1**	≤ 0.01	**≤ 0.6**	**≤ 0.4**	***≤ 0.6***	**≤ 0.3**
Power Consumption, CM (W)	≤ 1.0	≤ 0.1	≤ 1.0	≤ 0.1	≤ 1.0	≤ 0.1	***≤ 1.0***	≤ 0.1

-- Cryogenic Actuation Requirements for NASA JWST

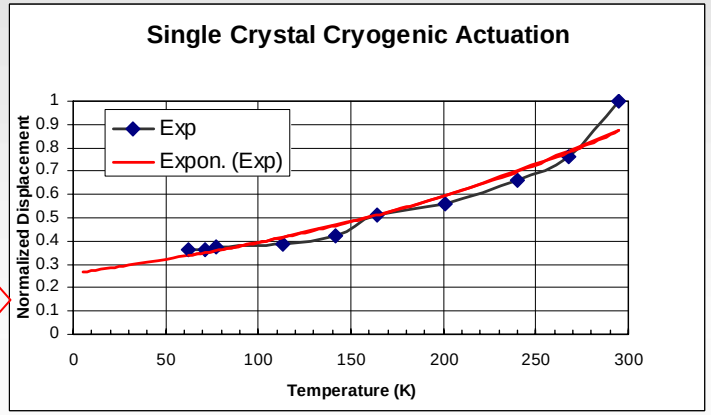
Currently Available Cryogenic Actuations

- Superconducting coil based electromagnetic actuations, e.g. magnetostrictive, EM motor, etc. Temperature range: <77K.
- Compositionally modified piezoelectric and electrostrictive ceramics for electrostrictive and piezoelectric actuations. Temperature range: < 65K.
- Single crystal piezoelectrics. Temperature range: 20K->300K.



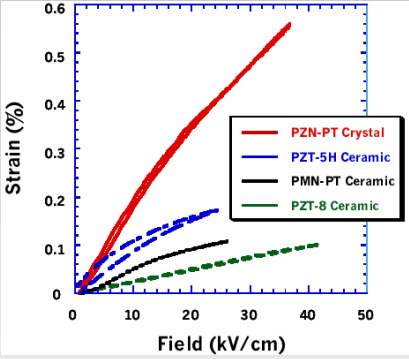
Cryogenic strain test for "33" mode PMN-PT flextensional actuator, stroke >74 um at 75K.

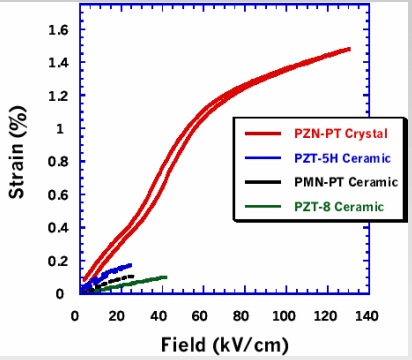
Cryogenic strain test for PMN-PT stack actuator. It is predicted that the stroke ratio (stroke at cryo-temperature/stroke at room temperature) to be 27% at 10K.

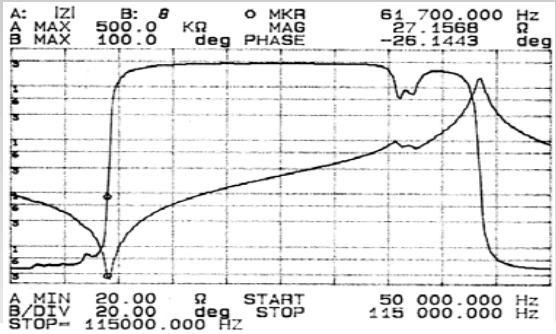


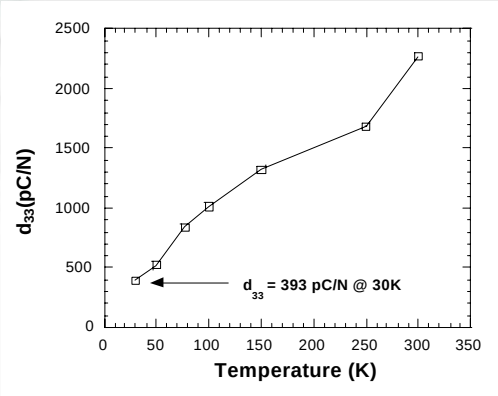
Single Crystal Piezoelectrics

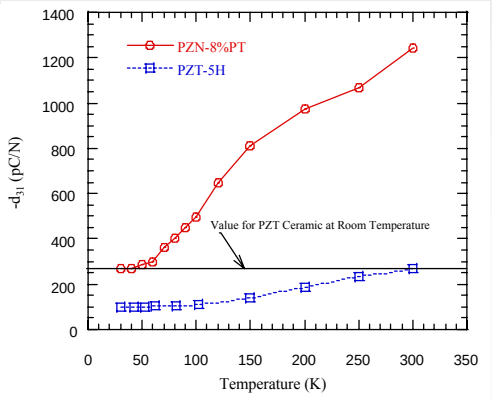
- High electromechanical coupling
- Low hysteresis
- Large piezoelectric coefficient
- Excellent cryogenic property

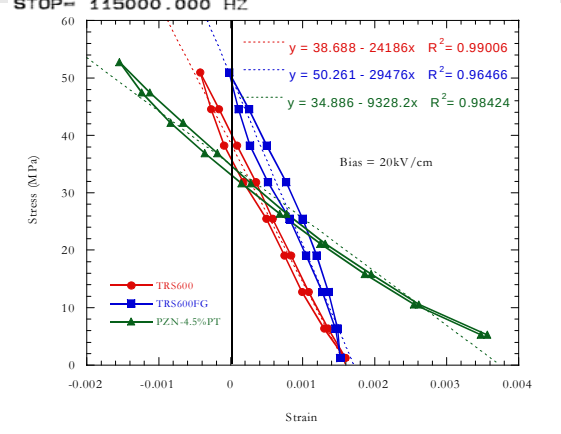










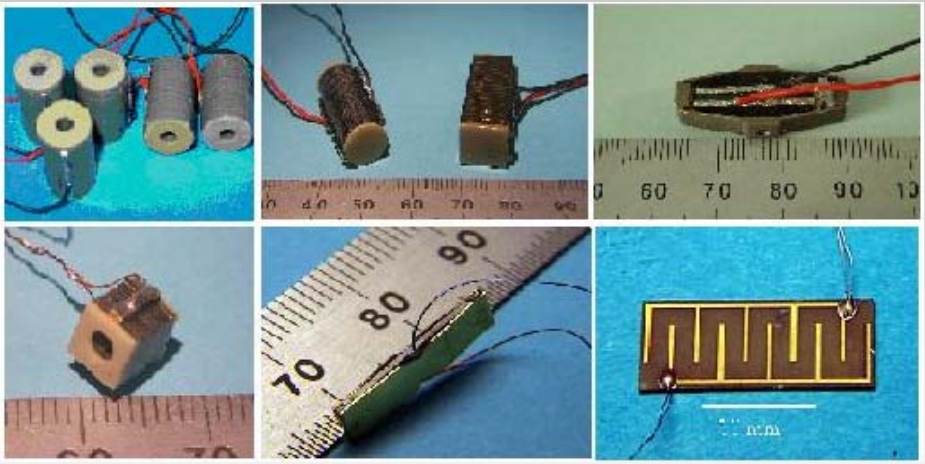


Piezoelectric Actuators

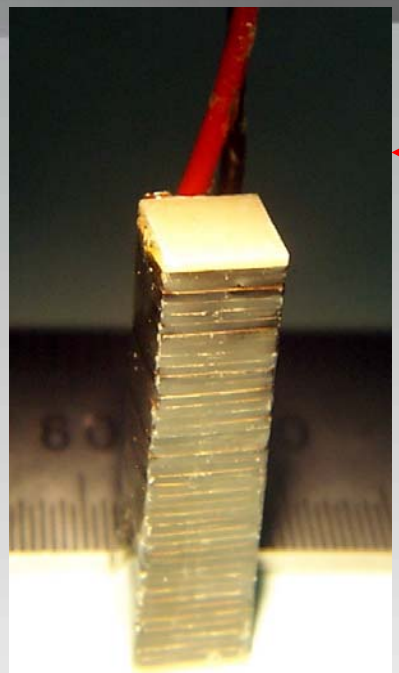
- Stack Actuator
- In-plane actuator ("31", IDE, Shear)
- Unimorph/Bimorph
- Flextensional (moonie, cymbal, Thunder, etc.)
- HYBAS
- Polymer
- Others (compliant amplification mechanism, Motor, etc.)

Stroke ↓ **Force** ↑

TRS Single Crystal Actuators



TRS Stack Actuators

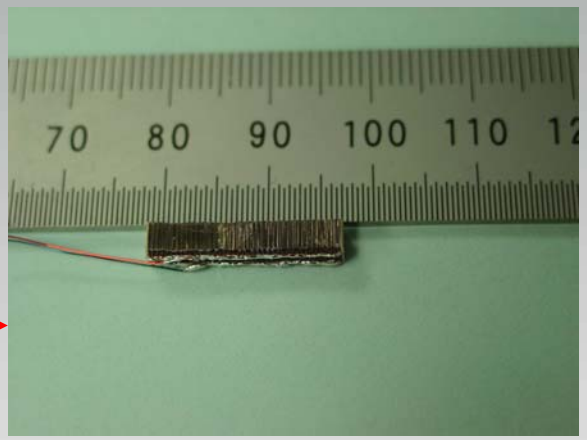


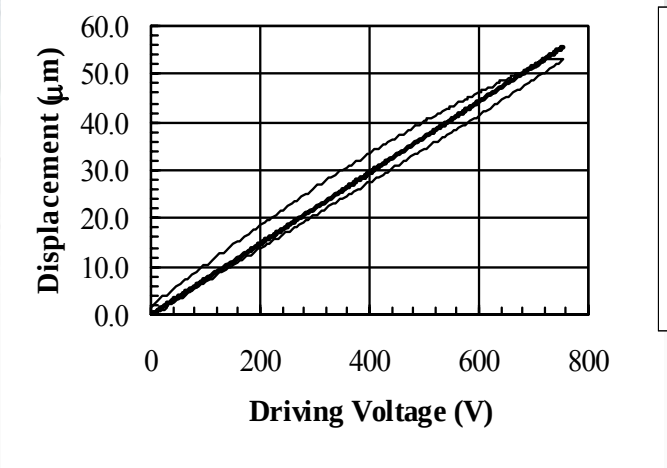
5 mm x 5 mm x 25 mm

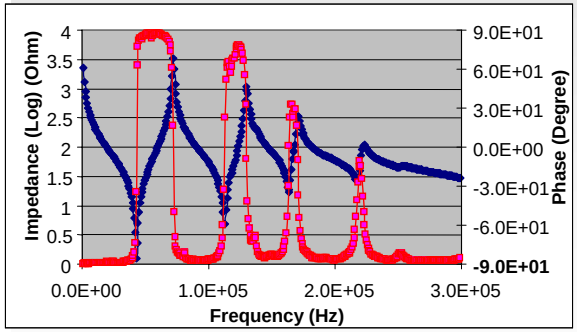
Layer thickness: 0.5 mm

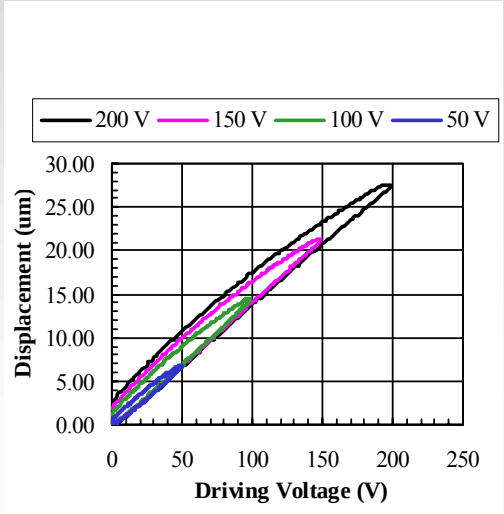
3 mm x 3 mm x 19 mm

Layer thickness: 0.2 mm

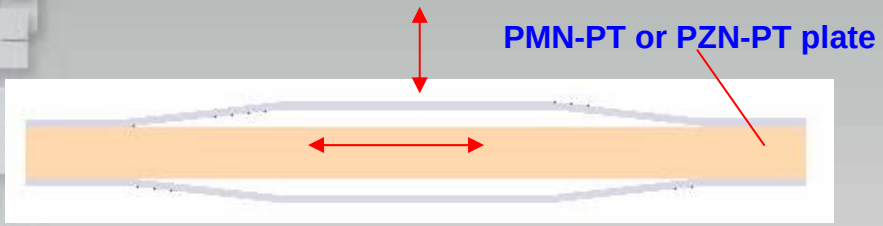


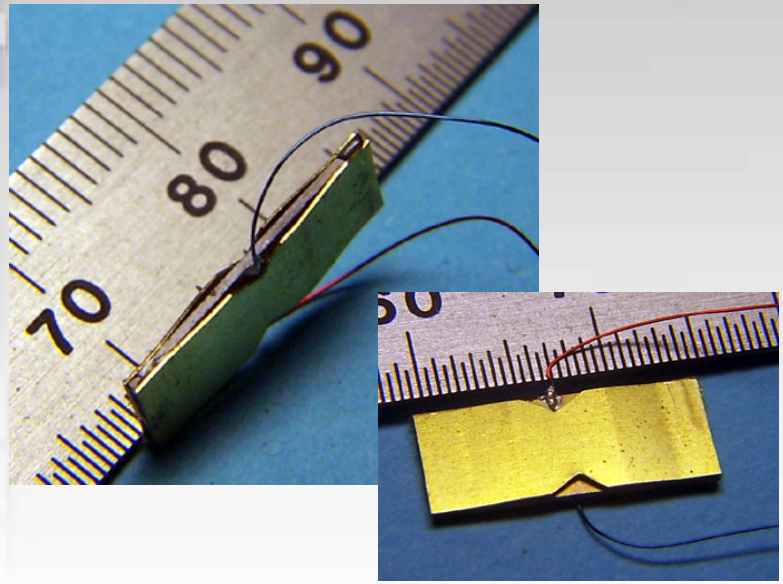




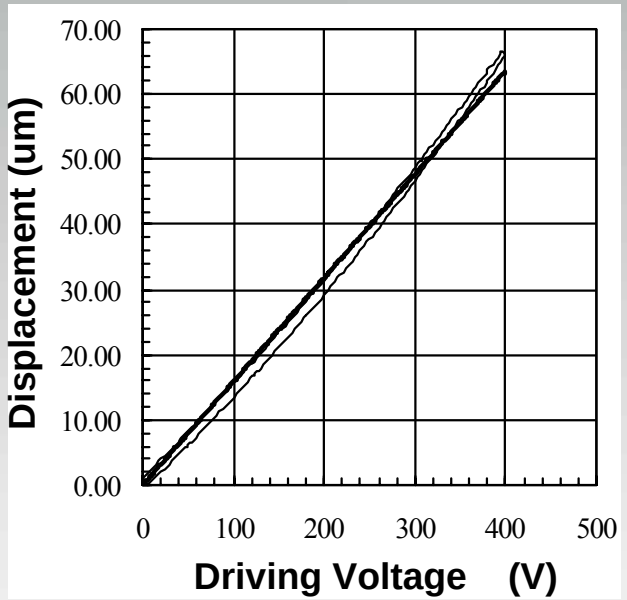


Flextensional Actuator ("31" mode)





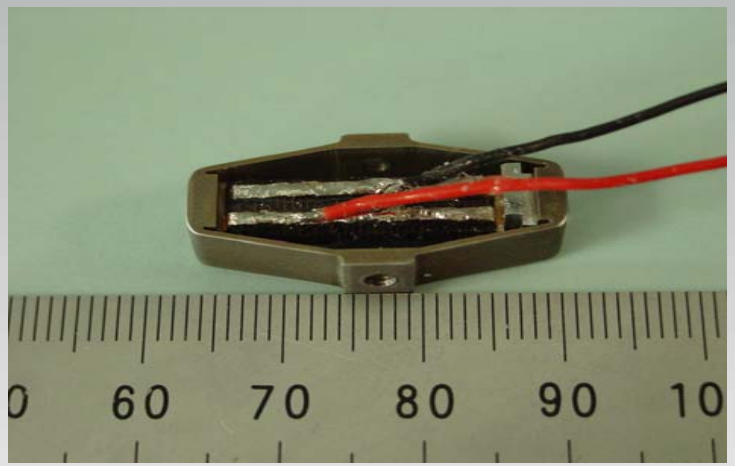
Prototype with 15mmx6mmx0.5mm PMN-PT crystal

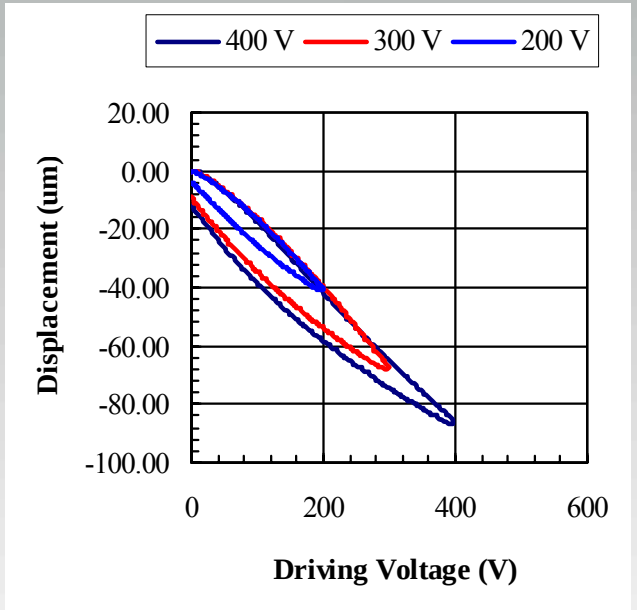


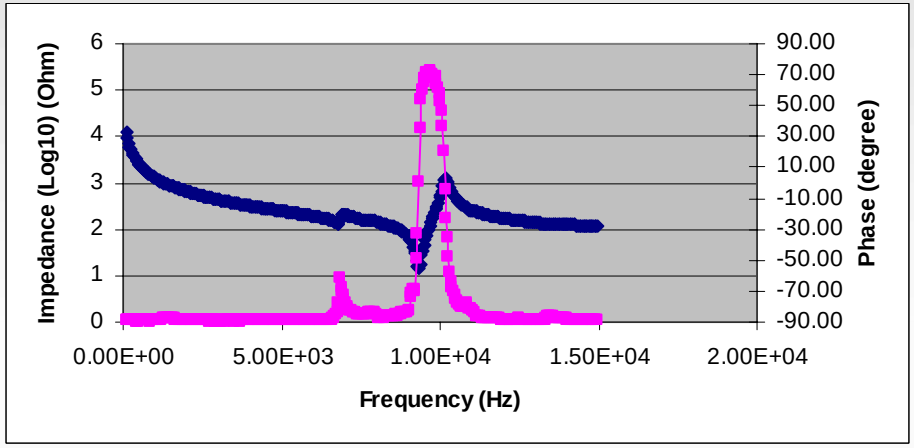
Modeling results:

>100 um with actuator sizes of 15mmx6mmx1.3mm

Flextensional Actuator ("33" mode)

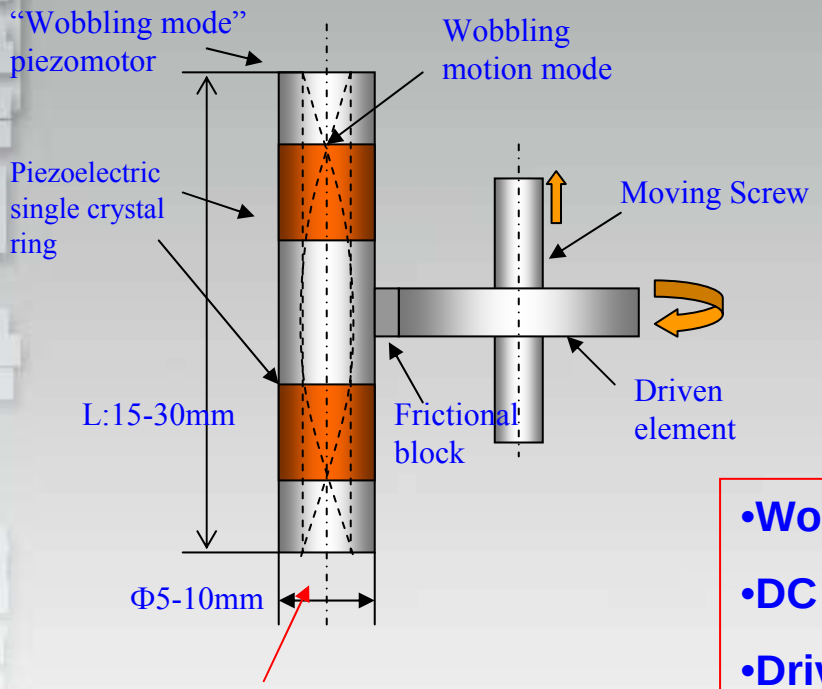




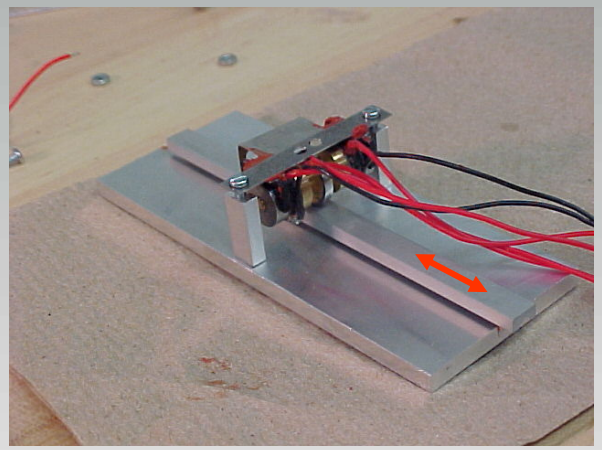


- Stroke >100 um at 500V
- Resonant Frequency ~ 10 KHz

Single Crystal Piezomotor

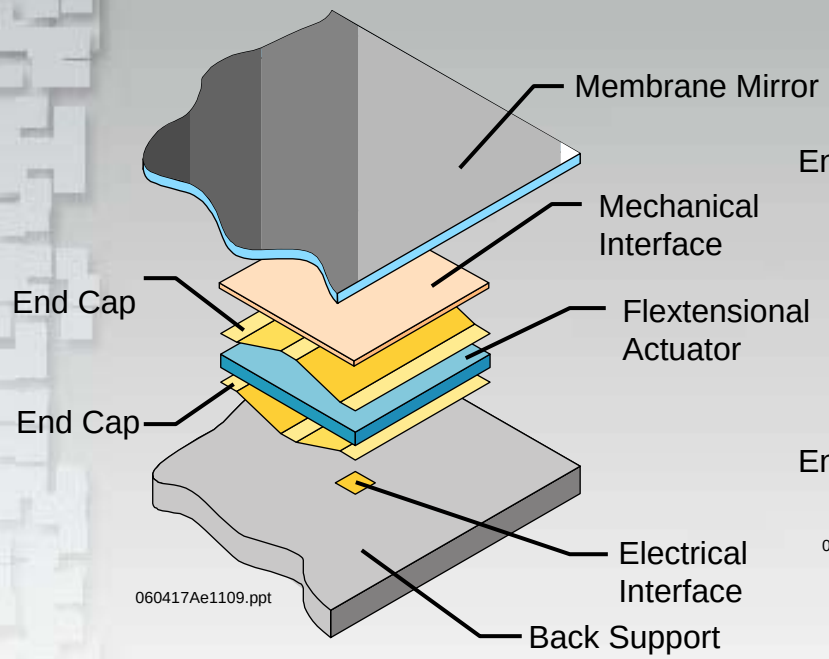


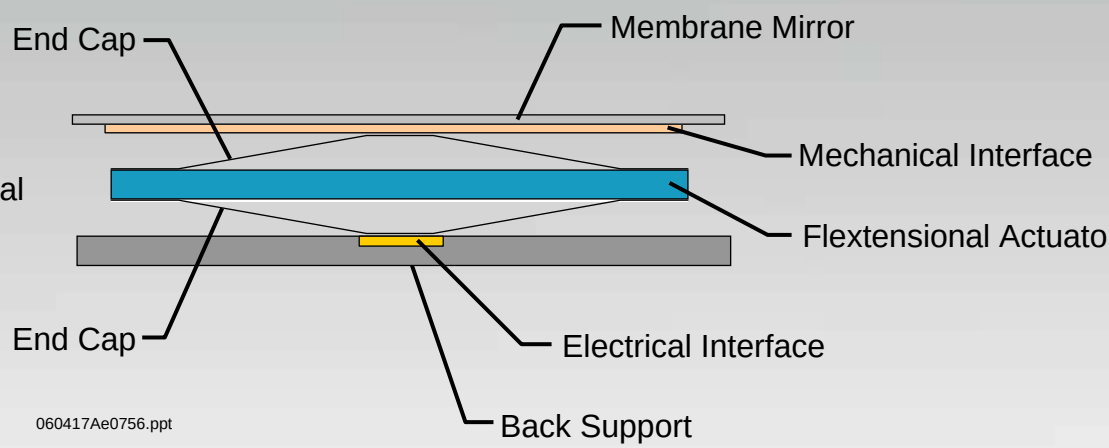
Schematic view of a piezomotor with screw



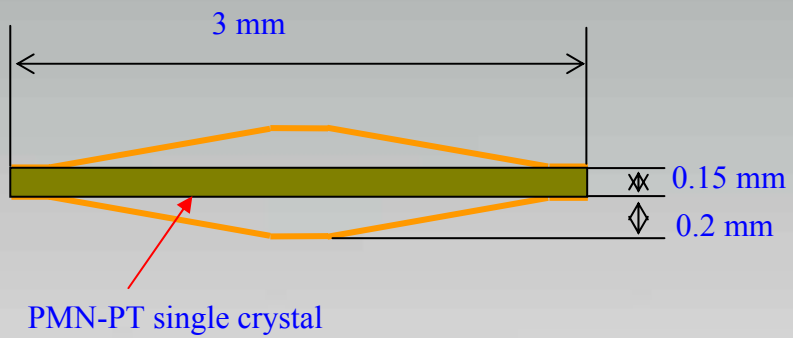
- Working frequency: f_0=41.5kHz
- DC voltage for circuit driver: 6V
- Driving voltage to piezoelectric stator: 60-70Vpp
- Estimated traveling speed: 50-100mm/sec
- Very quick direction reversal
- Estimated maximum driving force: tens of grams.
- Weight Loading: Kgs

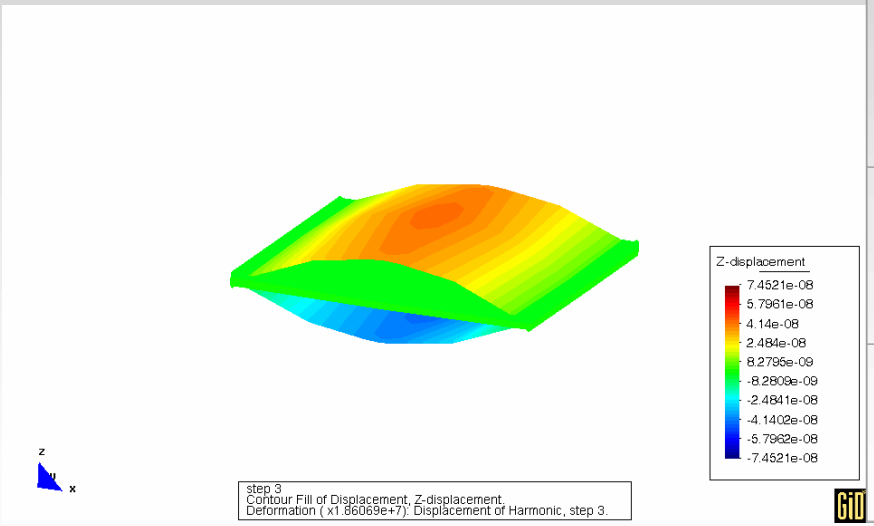
Membrane DM with Flextensional Actuators





Atila FEM Modeling for Flextensional Actuator Design



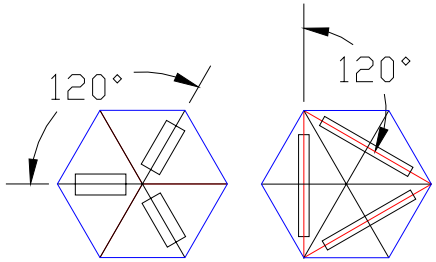


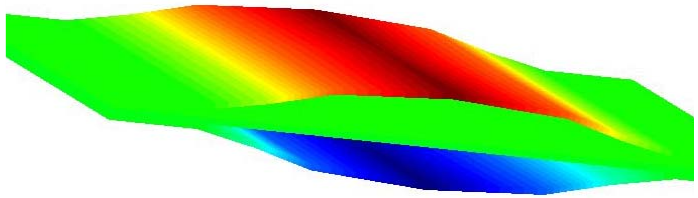
Calculated 3mm actuator stroke comparison

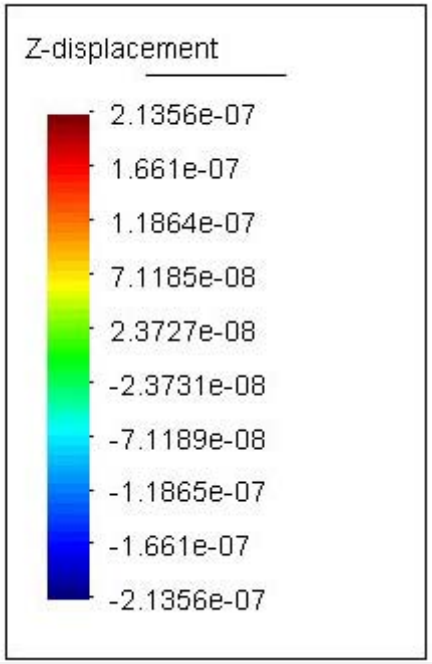
Endcap thickness (mm)	Stroke under 0 N (@ 100V) (μm)	Stroke under 0.1 N (@ 100 V) (μm)
0.025	15	11.5
0.035	14	12
0.050	12	10.7

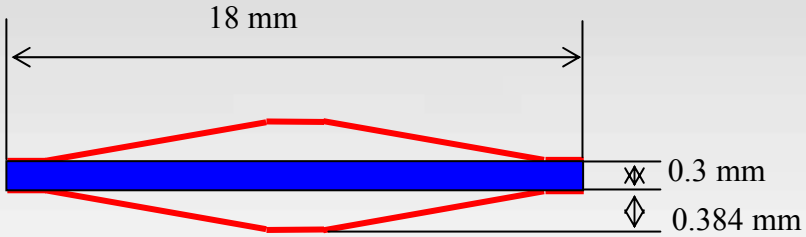
ATILA Modeling for Flextensional Actuator Design

1" MM demo





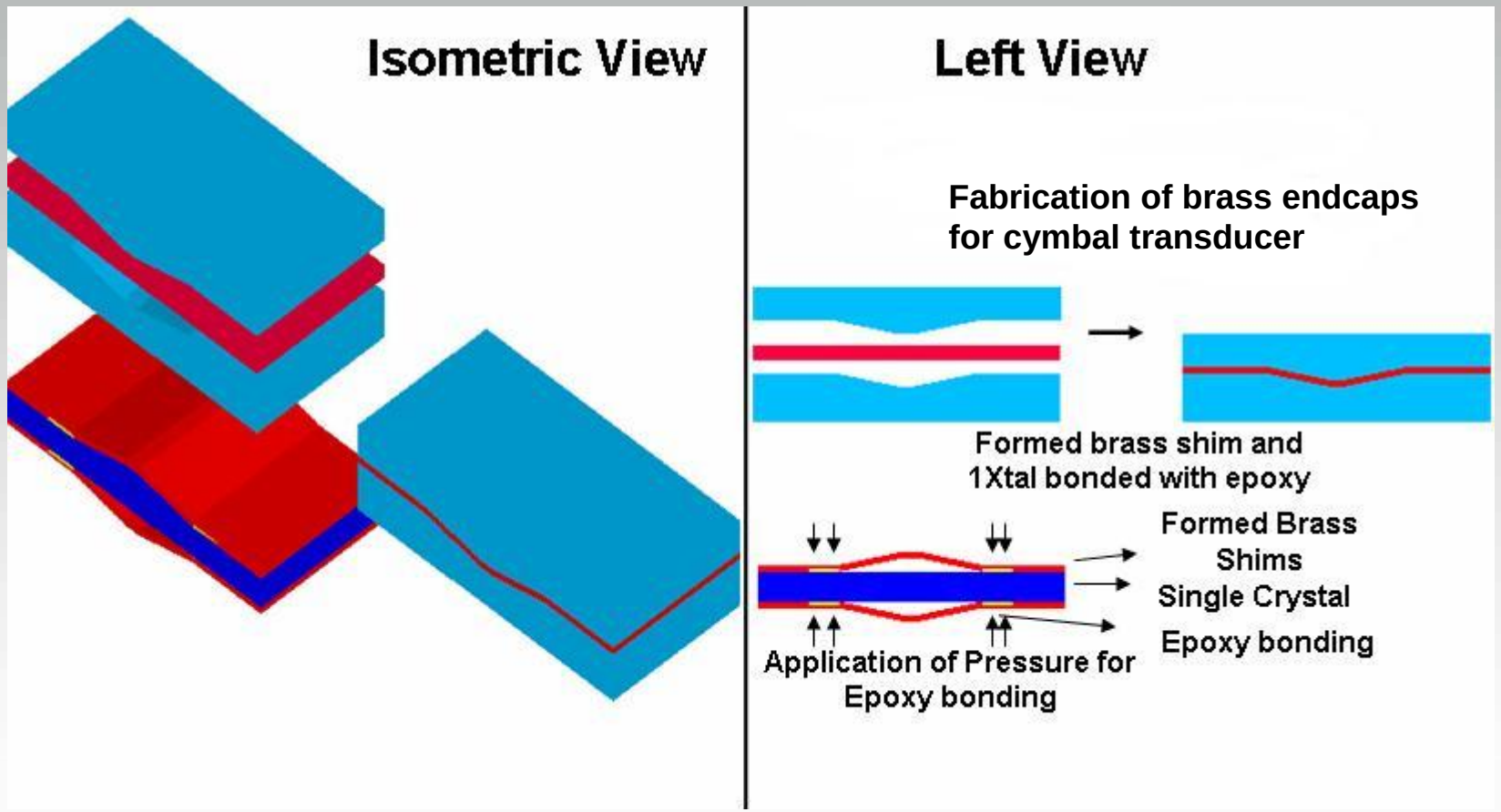




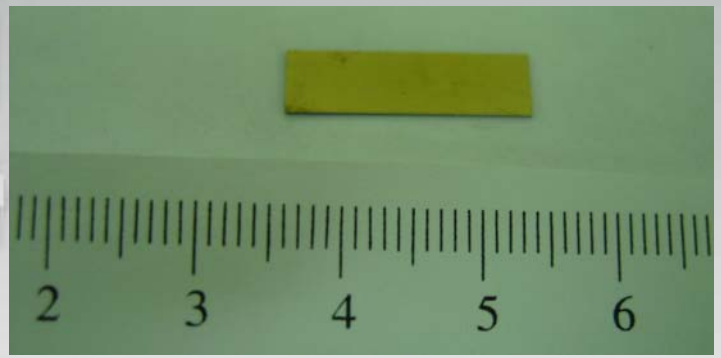
PMN-PT single crystal

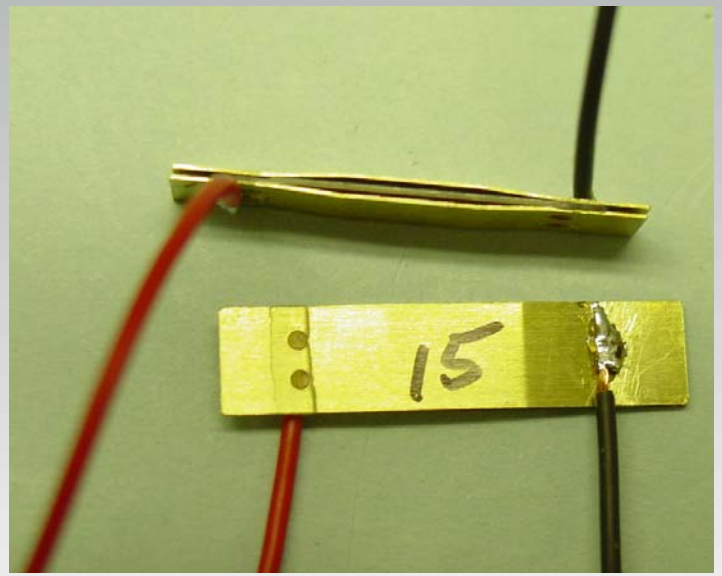
Calculated stroke of this 18 mm flextensional actuator is 128 um under 300 V.

Flextensional Actuator Prototyping



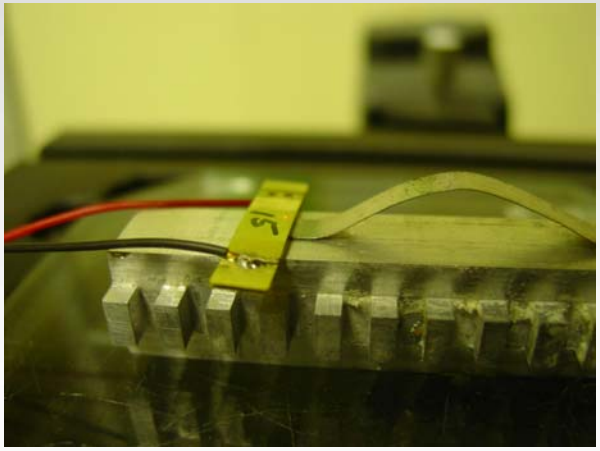
Fabrication of Flextensional Actuators

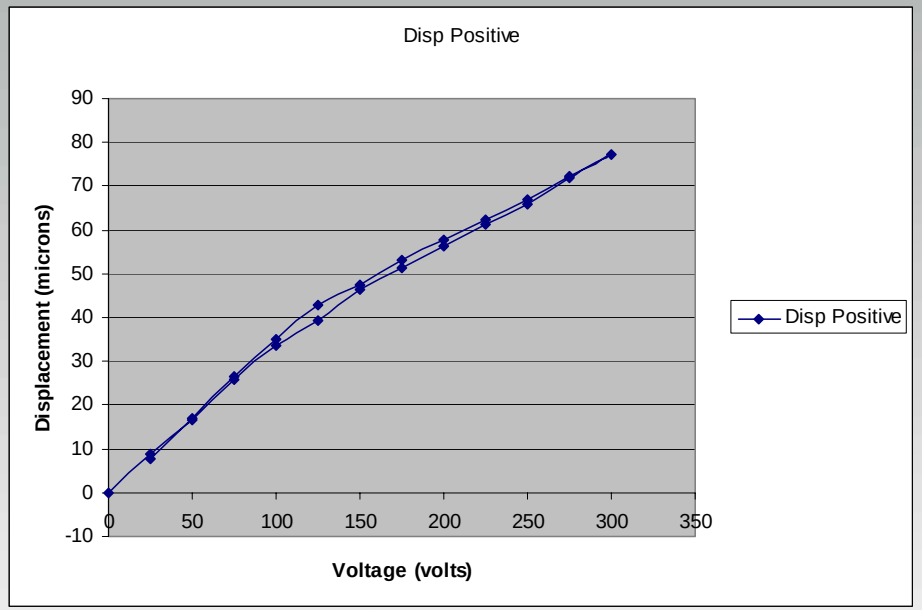




18 x 5 x 0.3 mm flextensional actuators fabricated at TRS. The endcaps are bonded with a cryogenic epoxy to the crystal and leads are attached for actuation and testing.

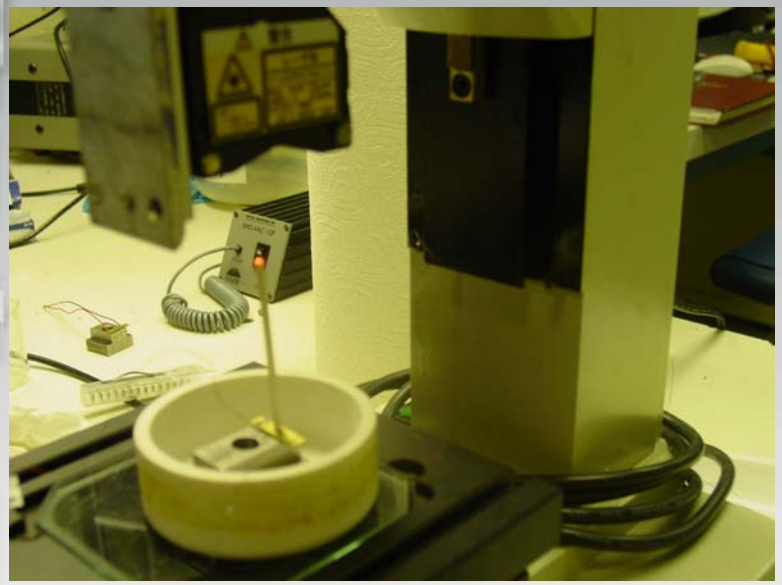
Laser Setup for Non-contact Displacement Measurement

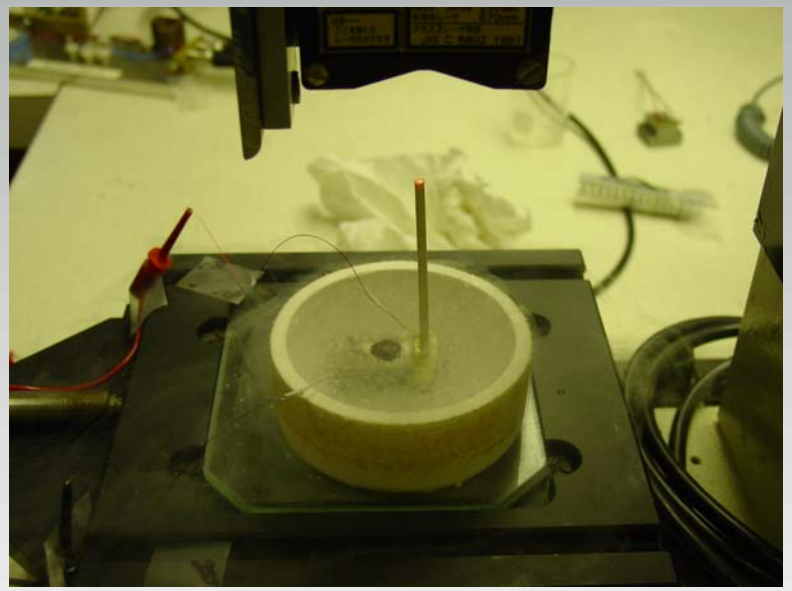




Large strain with low hysteresis was obtained from 18mm flextensional actuators. The maximum stroke is about 95 um.

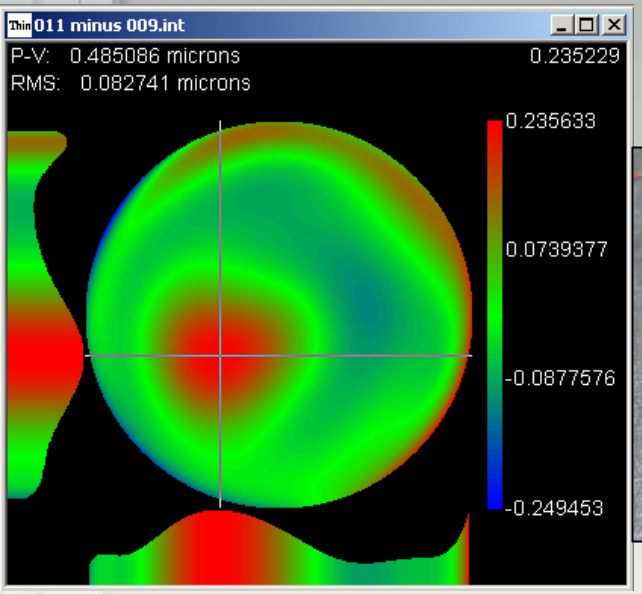
Cryogenic Testing of Flextensional Actuators

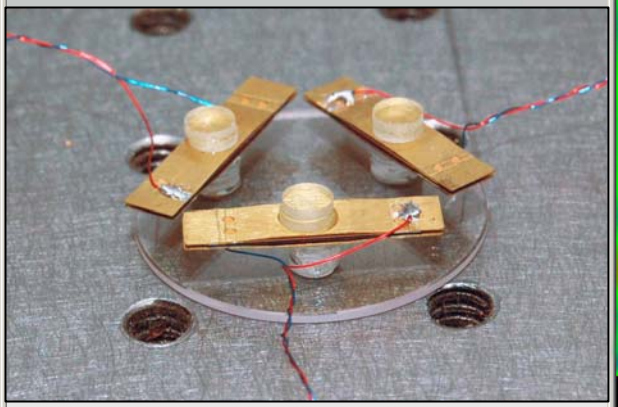


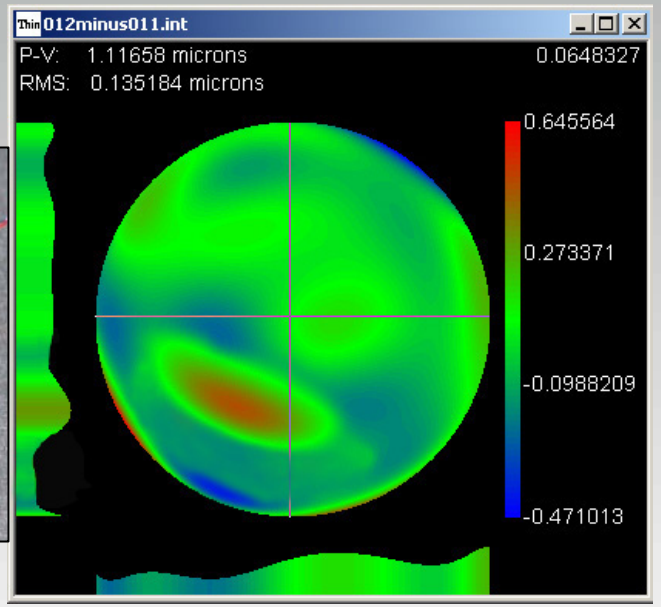


- The flextensional actuator was placed in an alumina boat below the Laser
- LN_2 was poured in the boat and displacement measurements were conducted and compared against room temperature displacement data

Concept Demonstration: Flextensional Membrane







All 3 Flextensional Actuators @ 500V

Flextensional Actuators on a 1” plate

2 Actuators @ 0V
1 Actuator @ 500V

Summary

•Single crystal piezoelectric actuators showed large stroke, low hysteresis, and excellent cryogenic performance.

•Feasibility of deformable membrane mirror using flextensional actuators were demonstrated, which is promising for large aperture, light weight, cryogenic deformable mirrors.

Future work:

•Cryogenic test at temperature of 4K-300K.

•Deliver membrane mirror with up to 61 channel of flextensional actuators.