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ManTech SRS Technologies, Inc.

Initial Development of Deformable Membrane Mirror to correct Large Amplitude Aberrations

Presented by Brian Patrick, MSRS

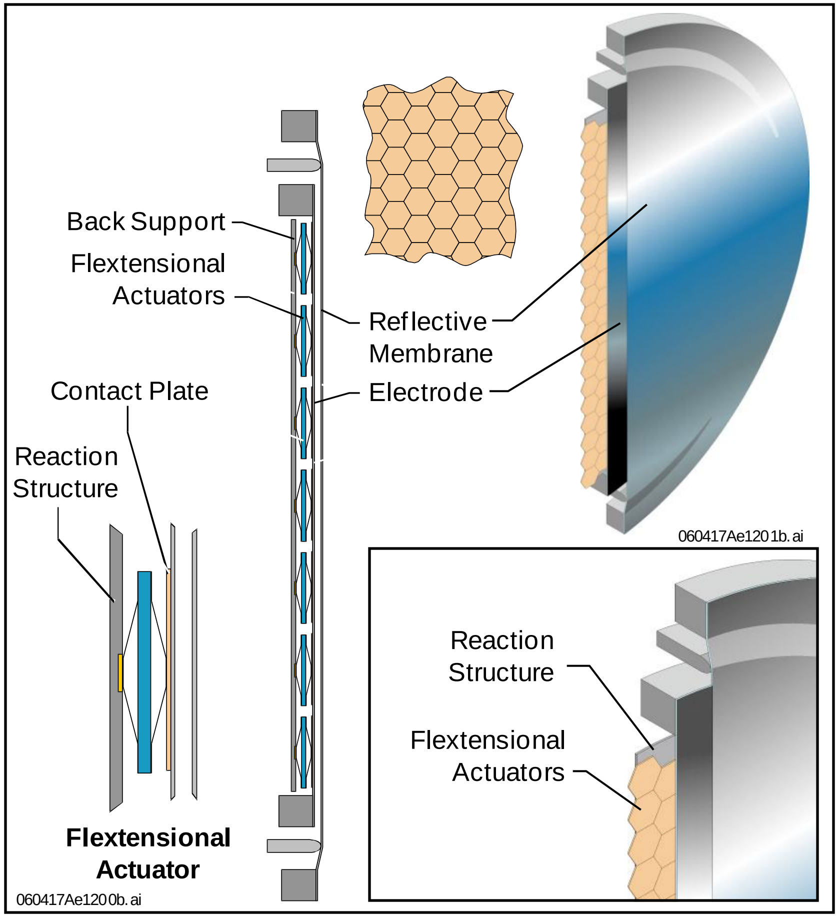
Technology Days 2007

Research Overview

- Membrane Mirror with Flextensional Actuators Concept
- Initial Deformable Mirror Modeling
  - Actuator layout optimization, capability prediction
- Facesheet Material Optimization
- Initial Test Setup/Model Correlation
- Near Term Activities

Background

Hybrid DMM Concept



Combines TRS Technologies' flextensional actuators with SRS Technologies' Membrane Mirror Technology

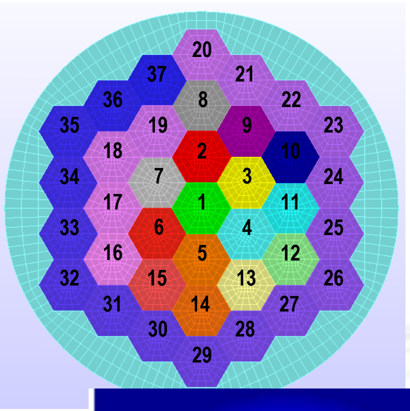
Significance:

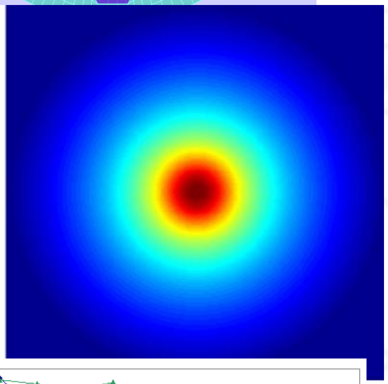
- Correction for low order aberrations with large magnitude
- Large aperture capable
- Light weight
- Broad temperature range
- Low voltage

Approach:

Conduct FEM to optimize the shape control and performance of a 0.25 m mirror with various configurations. Parameters include electrode positioning, stress state, mechanical properties of material, mounting positions, driving conditions, etc.

FEA Modeling



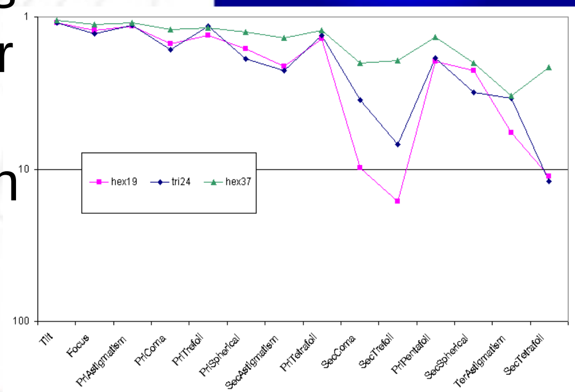


Objective:

To optimize deformable membrane design by selecting electrode shape, configuration, density that will maximize the correctability of the DM within the constraints of the program

Approach:

- Model DM with hexagonal and triangular electrode pads.
- Simulate actuators by applying displacements to the electrodes based on theoretical data for film displacement range.
- Perform studies with either 1 or 3 actuators on each electrode pad.



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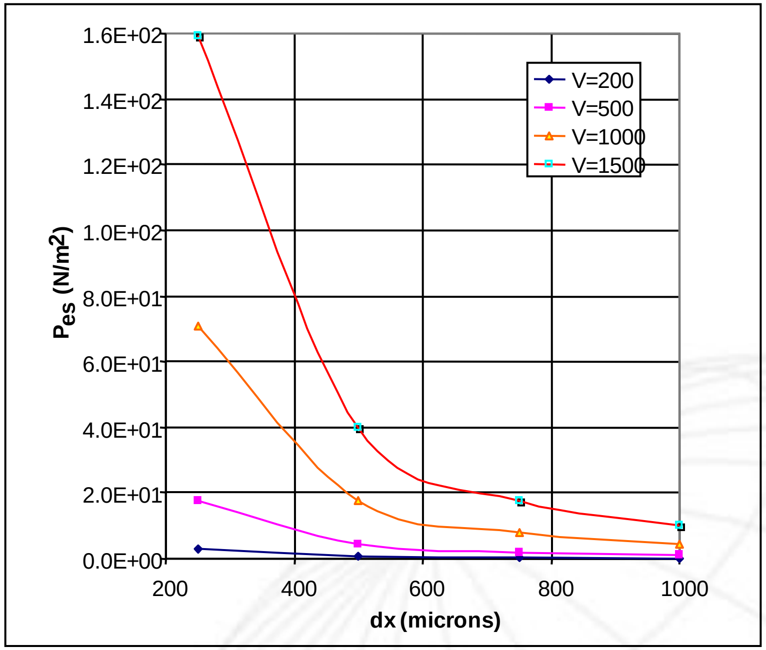
Analysis Method

- **Simulated actuation by applying pressure to electrode pad**
  - **Max deflection at 1500V is 300microns**

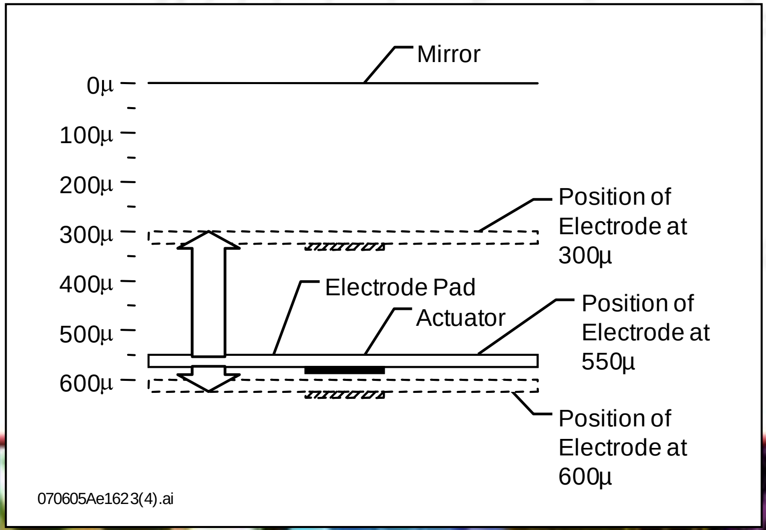
- **Set initial electrode pad position at distance of 550µ away from DM**
  - **Electrostatic pressure at 550µ is 30N/m^2 which was applied to entire mirror surface to create reference shape**

- **Influence functions were created by energizing each electrode pad individually**
  - **36N/m^2 pressure was applied to energized electrodes (Pressure was chosen as 20% higher than reference pressure)**

- **Membrane pre-stress was simulated by applying a negative thermal load to entire membrane**
  - **Used initial membrane pre-stress of 2582psi (based on previous experience)**



Electronic Pressure Control Response to Actuator Deflection



FEA Cases

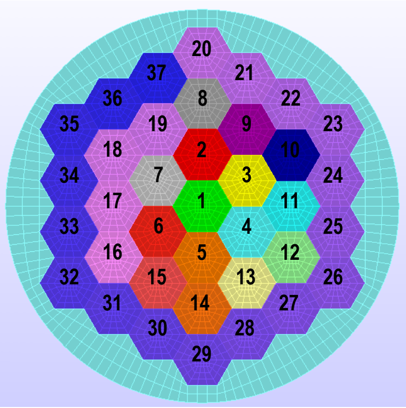
- **Created and analyzed 6 different cases with varying electrode geometry, membrane pre-stress, and electrode pressure load**
- **Determined influence functions for each actuated electrode pad**

Current FEA Models

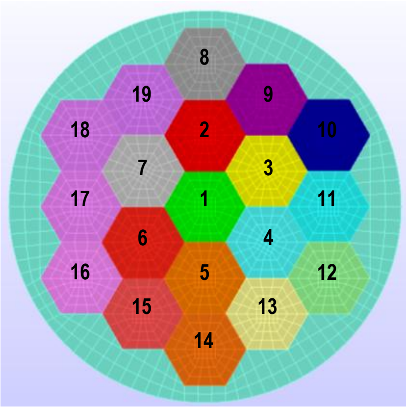
Case	Electrode Geometry	Electrode Number	Film Stress (psi)	Pressure Load on Actuated Electrode ‡
1	**Hexagonal**	**19**	**2580**	**1x**
2	**Triangular**	**24**	**2580**	**1x**
3	**Hexagonal**	**19**	**1000**	**1x**
4	**Hexagonal**	**19**	**2580**	**7x**
5	**Hexagonal**	**37**	**2580**	**1x**
6	**Triangular**	**59**	**2580**	**1x**

‡ 1x Load = 0.052psi, 7x Load = 0.104psi

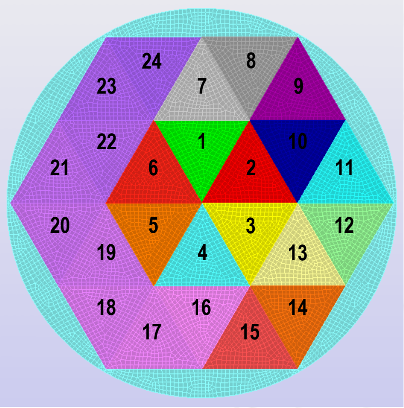
Hex 37



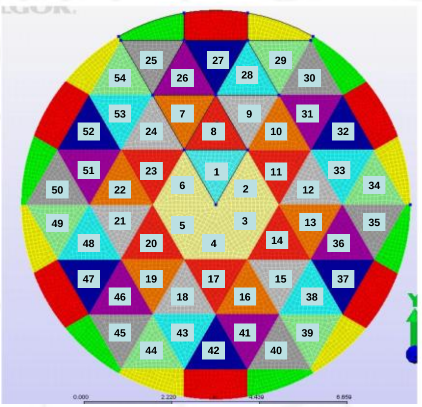
Hex 19



Tri 24



Tri 59



Correctability Study

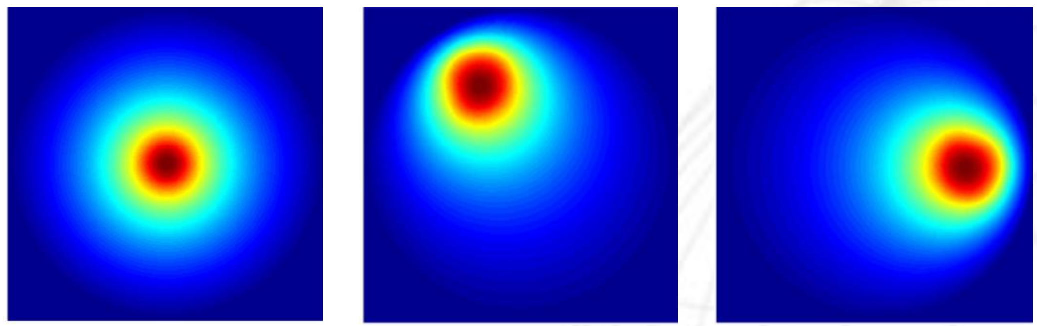
- **Theoretical correction is calculated using the influence functions from the FEM**

$$Correctability = \frac{\sigma_{starting}}{\sigma_{starting} - \sigma_{residual}}$$

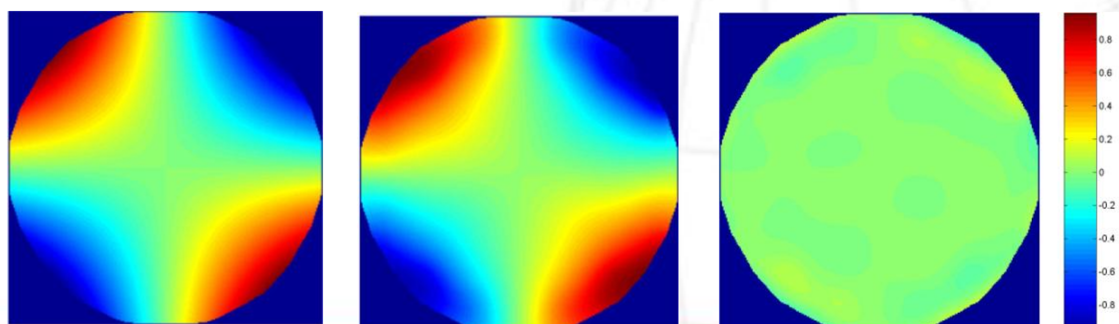
$\sigma_{starting}$ = RMS of the starting error

$\sigma_{residual}$ = RMS of the residual error after correction has been applied

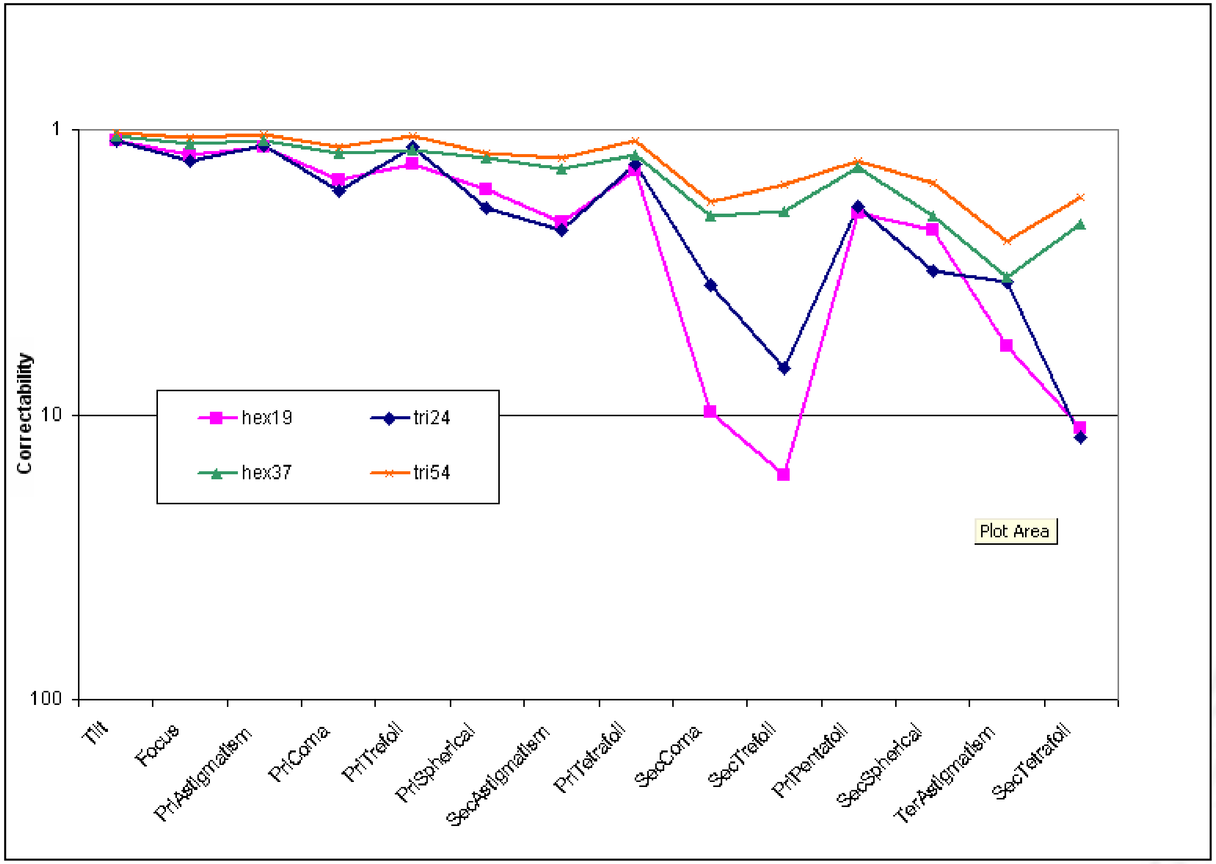
Examples of influence functions from Hex37 case.



Example calculated starting error, actuator induced error, residual error after correction.



Design Analysis



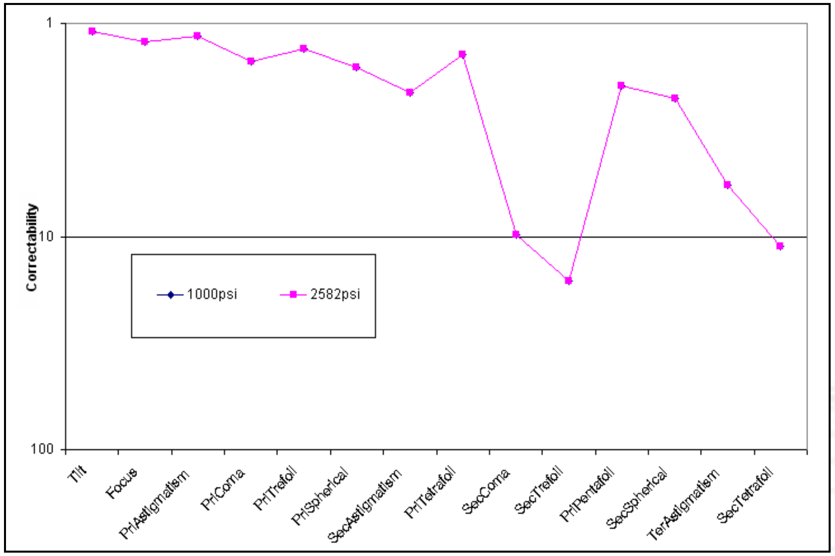
- Compared correctability results for four designs
  - 19 Hexagonal cells, 24 triangular cells, 37 hexagonal cells, 54 triangular cells.
- Hex37 performs better than other designs
- Tri24 performs better overall than Hex19

Design Analysis

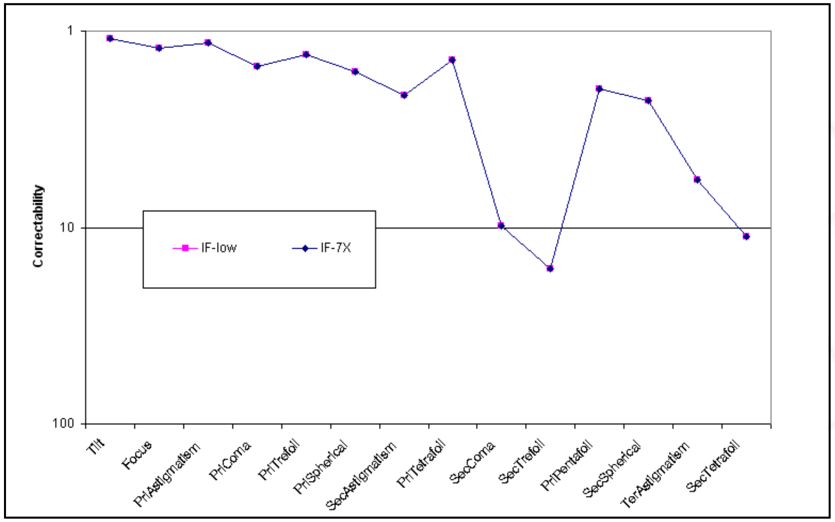
Linearity Study

Varied film pre-stress and magnitude of activated electrode in Hex19 case to determine linearity of correctability study

- Case 1 –Actuated electrode pressure set at seven times the initial magnitude
- Case 2 – Varied membrane pre-stress (1000psi and 2582psi)
- In both cases the shape of the influence functions varies slightly; Correctability results are virtually the same
- Study shows that the influence functions can be considered linear for the purpose of comparing potential designs
  - Issue will be further explored when developing control algorithm

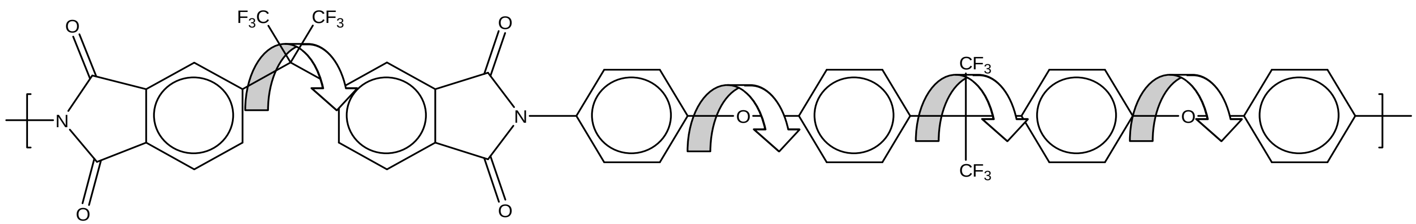


Case 1 – Varied Membrane Pre-stress

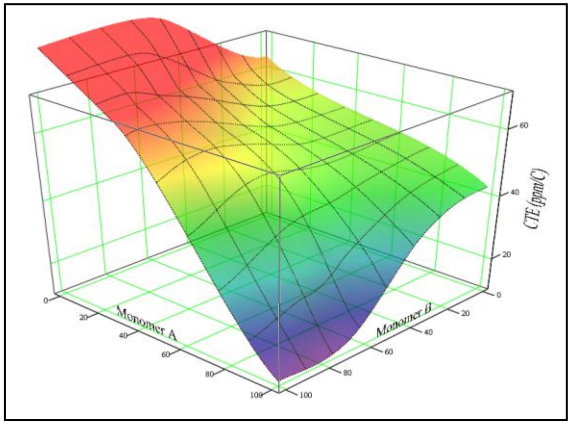


Case 2 – Varied Actuated Electrode Magnitude

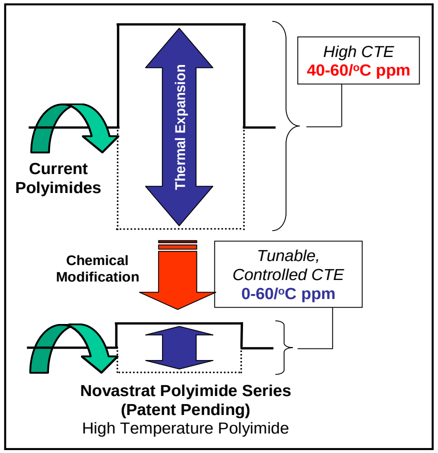
LOW CTE Polymer Face Sheet



Typical polyimides contain flexible bonds resulting in a high (50 ppm/°C range) CTE value.



Observed CTE as a function of rigid monomer incorporation.



Crankshaft Mobility Model of thermal expansion.

Goal: membrane with CTE < 20 ppm/°C

Approach:

Modification of polymer at molecular level to reduce thermal-induced dimensional instability.

Polymer Design Toolkit

Material Classes: These classes of SRS-designed polymers are typically used by our Aerospace customers.							
Material	**Description**	**CTE (ppm/°C)**	**Temp. Stability**	**Modulus**	**Wrinkle Resist.**	**UV Resist.**	**AO Resist.**
CP1-DE	Optical-quality CP1 Polyimide	Moderate: 60	Excellent > 300 °C	Moderate 315 ksi	Moderate	Good: Space Rated	Poor
Novastrat Series	A series of low CTE polyimides designed to match substrate CTEs	Controlled: -12 to 40	Excellent > 300 °C	High 500-1500 ksi	Moderate	Good	Poor
CTP Series	Polyimides toughened to produce good tear and impact resistance	High: >100	Moderate >150 °C	Controlled Low 30-100 ksi	Good	Good	Moderate
EP Series	Polyimides modified to exhibit rubbery behavior	High: >100	Excellent >280 °C	Controlled Low 1-50 ksi	Excellent	Good	Moderate
Polymeric Modification: The above polymer classes can be designed with the following inherent properties.							
CORIN	Polyimide with enhanced AO resistance	Controlled 4 to >100	Controlled	Controlled	Controlled	Good	Excellent
MANTIN	Polyimides with enhanced electrical conductivity	Controlled 4 to >100	Controlled	Controlled	Controlled	Good	Controlled

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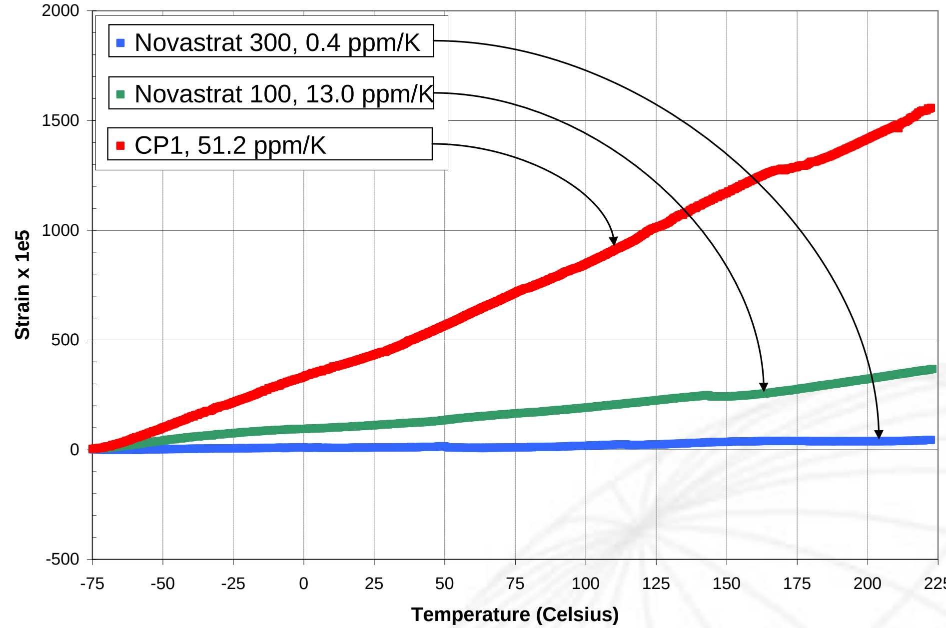
Novastrat Dimensionally Stable Polyimides

Novastrat History and Overview

- The Novastrat series is a polymer family with controlled CTE.
- Novastrat was designed for interlayer dielectrics, and exhibit good adhesion to silicon substrates.
- All Novastrats are high temperature polyimide materials.
- Novastrat 300 was designed to exhibit near-zero CTE at mils thickness.
- Currently fabricated in 2’ x 2’ panels.
- Readily scalable to 6’ x 6’ panels or larger.



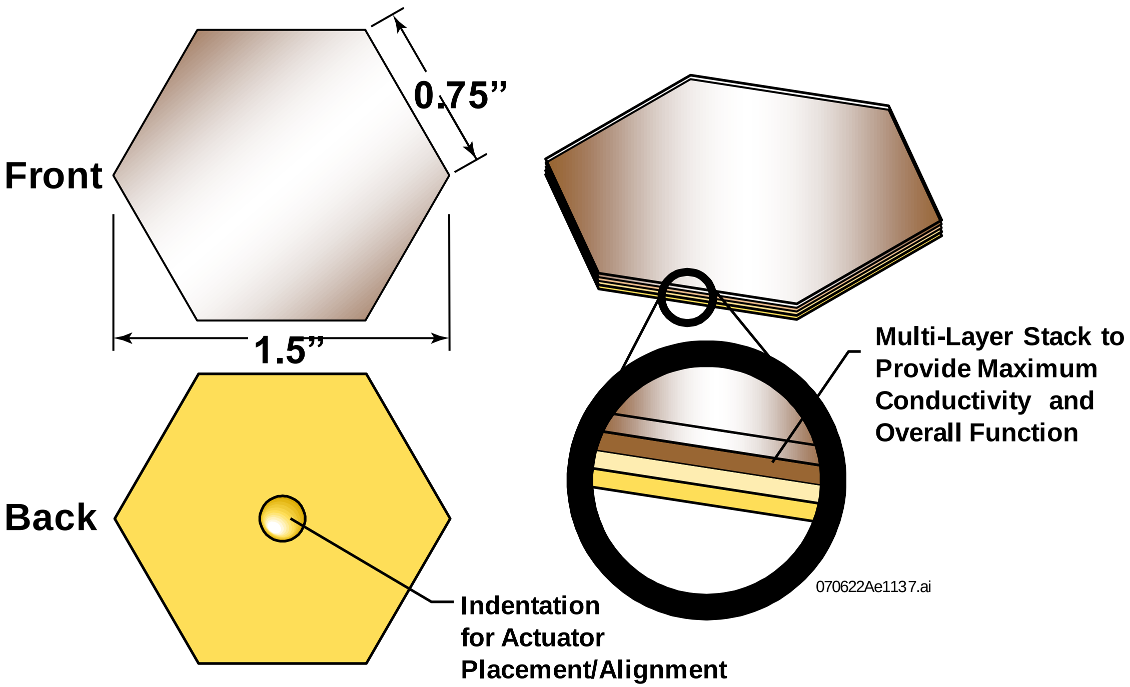
Property*	Novastrat 300	Novastrat 100	Kapton HN	CP1
In Plane CTE (ppm/^{o}C)	0.4	13.0	20.0	51.2
Tg (^{o}C)	>300	>300	>300	263
Tensile Strength (ksi)	23.8	30.1	33.5	14.5
Tensile Strength (MPa)	164	208	231	100
Youngs Modulus (ksi)	600	880	370	315
Youngs Modulus (GPa)	4.1	6.0	2.6	2.2
Solvent Resistance	Excellent	Excellent	Excellent	Poor
Color	Yellow	Yellow	Orange	Slight Yellow
Dielectric Constant (10 GHz)	3.1**	3.0**	3.4	2.5

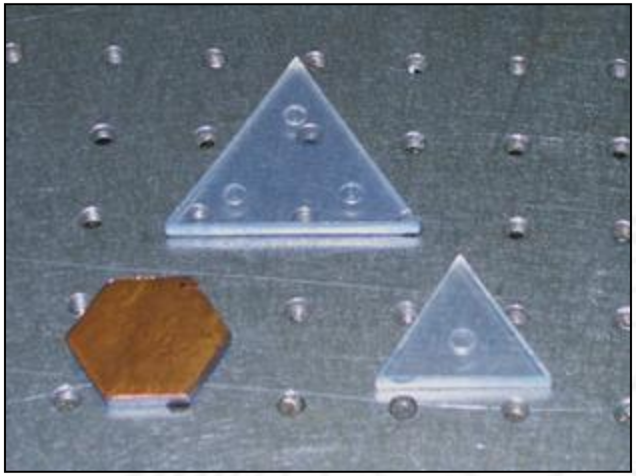
* All properties measured at 23 ^{o}C

** Estimates from circuitry tests.

2 mil Novastrat 300 Zero CTE Polyimide

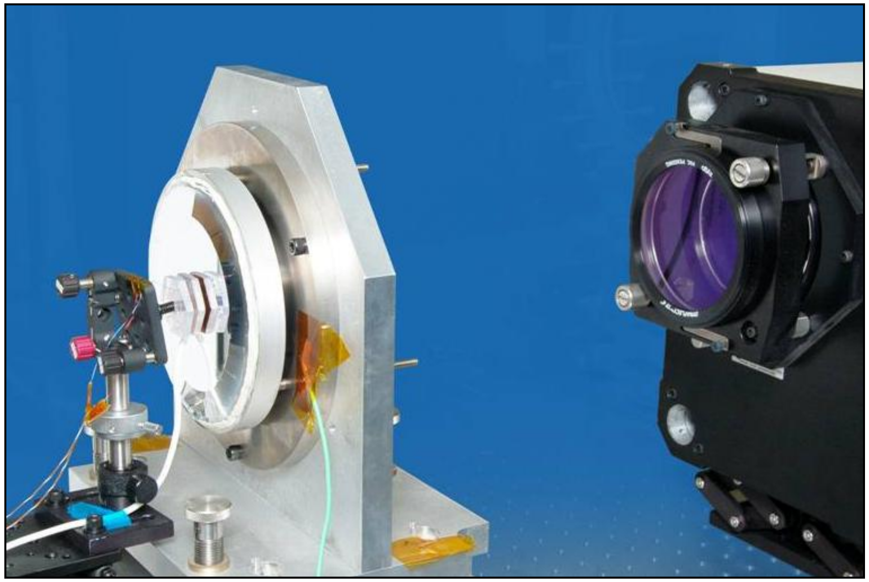
Electrode Assembly





- Electrode pad consists of a conductive layer with a polymer overcoat.
- Custom adhesive used to affix stack to the substrate base.
- Substrate base is nonconductive material.
- Setup and testing currently underway.

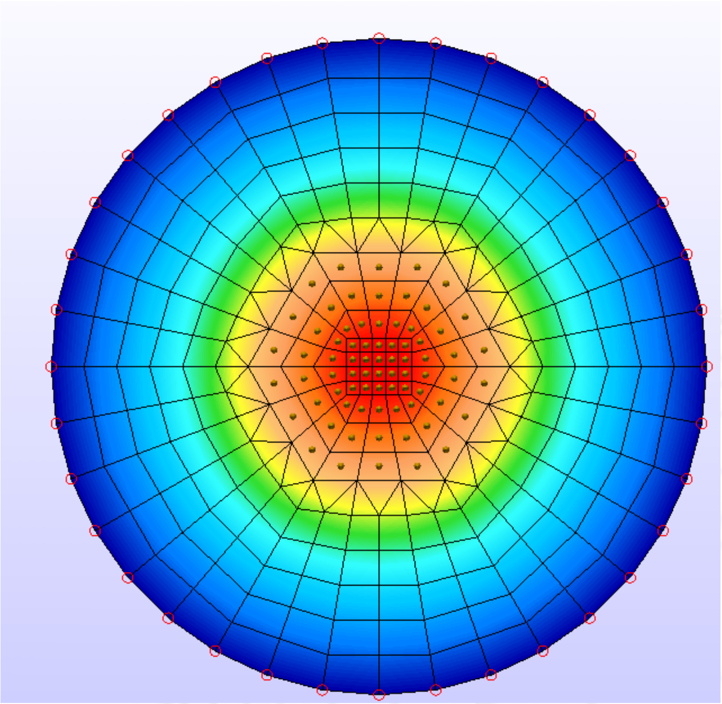
Initial Testing of Electrostatic Control



- Initial test setup using 10cm diameter membrane mirror complete
- Test data will be used for FEM correlation
- Initial data taken for single hexagonal electrode with one TRS flextensional actuator
- Triangular electrode testing in process
- Seven electrode setup currently being fabricated

FEM Comparison to Test Data

- Created FEA model to simulate test setup with 10cm diameter CP1 film and single hexagonal electrode
- Distance between film and electrode = 1.65mm
- Electrode set at 500V
- 2500psi film prestress



FEA model

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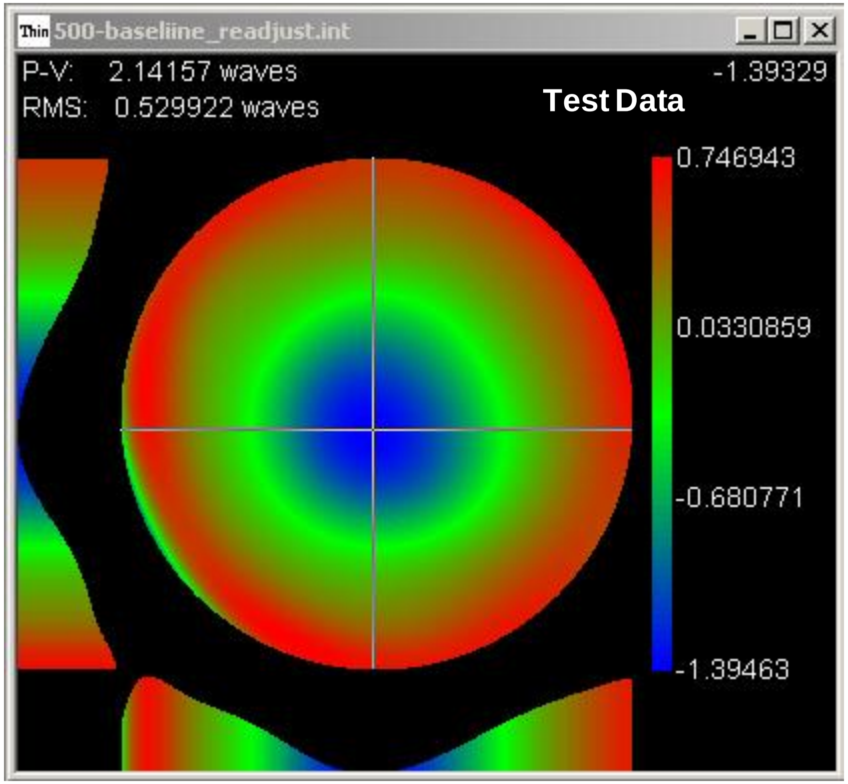
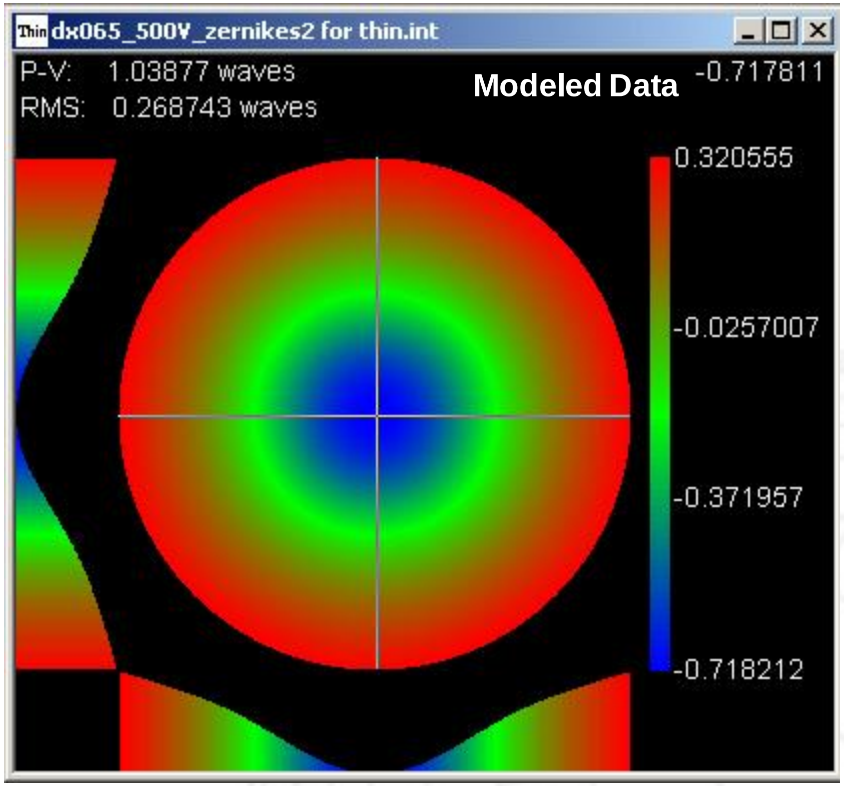
FEM Comparison to Test Data





- Test and modeled data differ by half in magnitude
- Further testing will allow for adjustments in model to provide better results (main variable is film prestress)
- Initial testing will measure only small amplitude actuation due to interferometer limitations with current setup. Shack-Hartmann sensor will be used for testing after further development.

Near Term Activities

- Additional single actuator testing and model correlation
- Include 3 actuators on each electrode in model to allow for tip/tilt capabilities
    - Determine improvement on final mirror shape
- Incorporate low CTE facesheet material into design
- Finalize actuator layout design and correlate model to test data
- Begin initial control algorithm development