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Micromirror arrays for light field manipulations

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Advanced Photonics Research

Bell Laboratories, Lucent Technologies

Contents

- Capabilities
- low fill factor two tilt axes arrays
  - -beam steering
- Spatial Light Modulator will large tilt capability (CCIT)
  - -beam steering
  - -programmable optical element
  - -phase front manipulation
  - -tracking
- High resolution pure phase SLM

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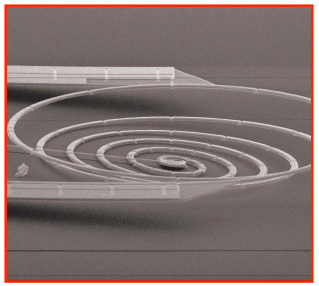
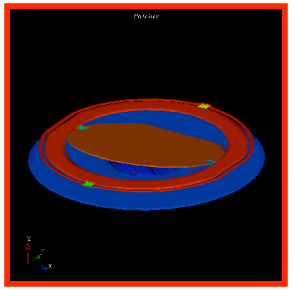
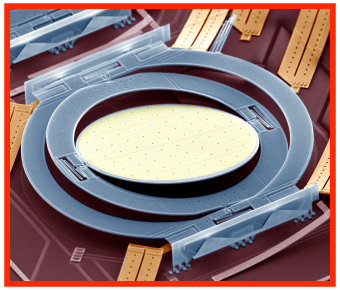
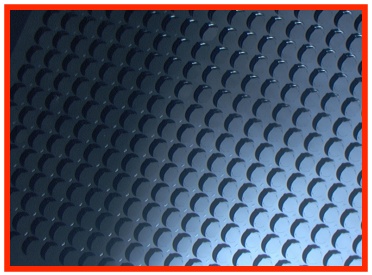
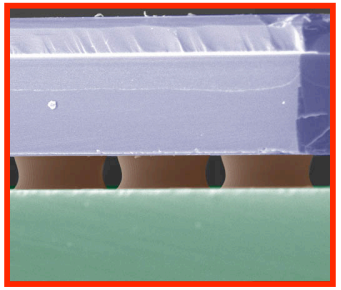
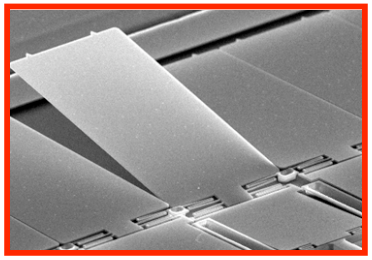
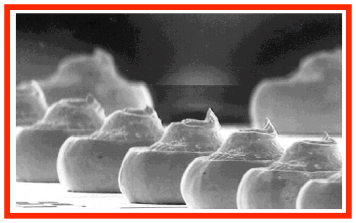
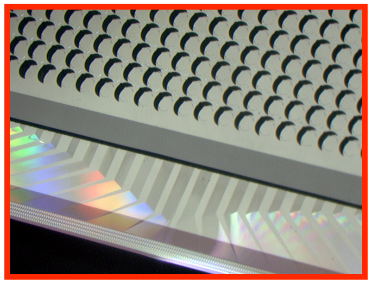
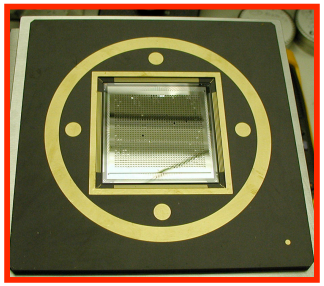
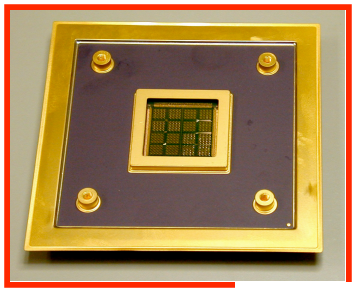
NJNC - Bell Labs: Unique capabilities in MEMS/NEMS

Design

Fabrication

Microsystem Integration

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MEMS MicroMirror Technical Capabilities

- Number of devices on a single die: one device to 10 million
- Types of motion: piston (0-5 microns) and/or tip-tilt (+/- 20°)
- Speeds: 1 microsecond to 10 milliseconds
- Sizes: 1-1000 microns in diameter
- Drive electronics: integrated or discrete
- Mirror flatness: less than 5 nm
- Metals: Aluminum or Gold
- Drive voltages: 1-100 volts
- Optical Power: 2-10 watts per pixel
- Vibration: NEBS zone four earthquake compliant (most rigorous NEBS spec)
- Power dissipation: less than a nanowatt per mirror
- Packages: hermetic or free space, optical windows available
- World class design, processing and packaging teams are “in house”
- Time to deliver a custom packaged design: three to six months
- Design team experience: Designed and delivered industry leading LambdaRouter optical switch-Only MEMS switch currently in commercial service.

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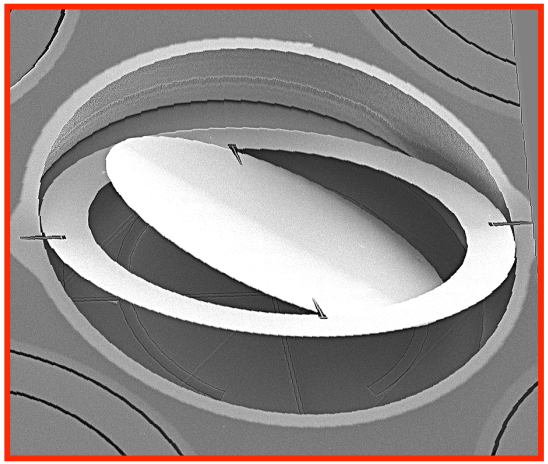
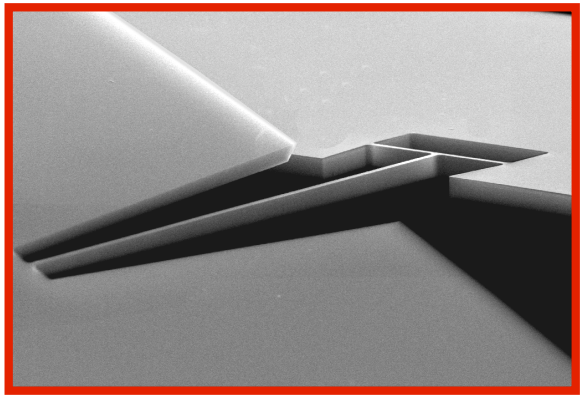
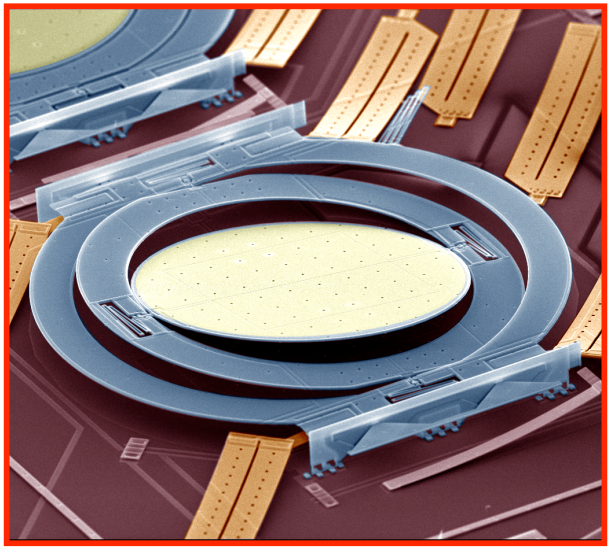
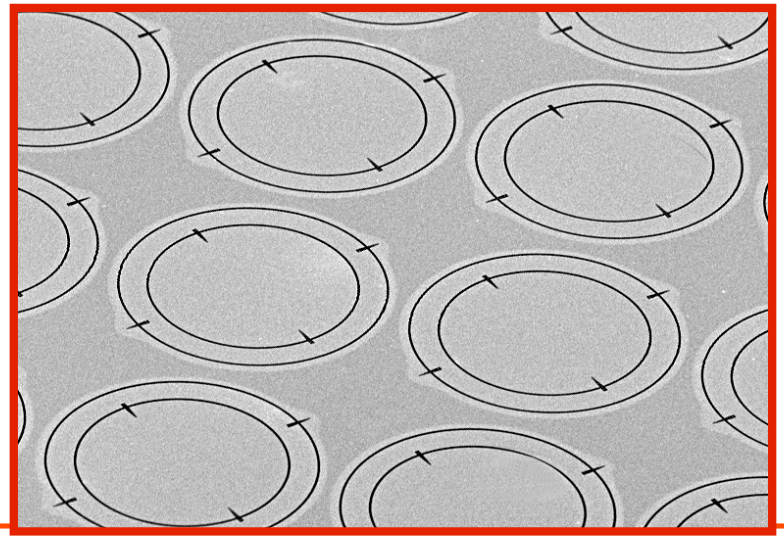
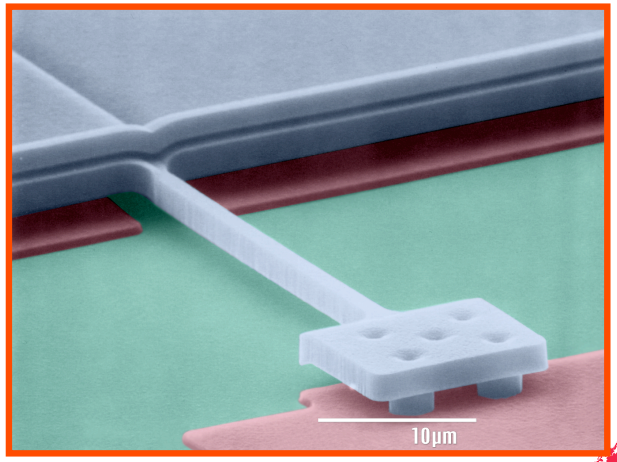
Some Sample Devices











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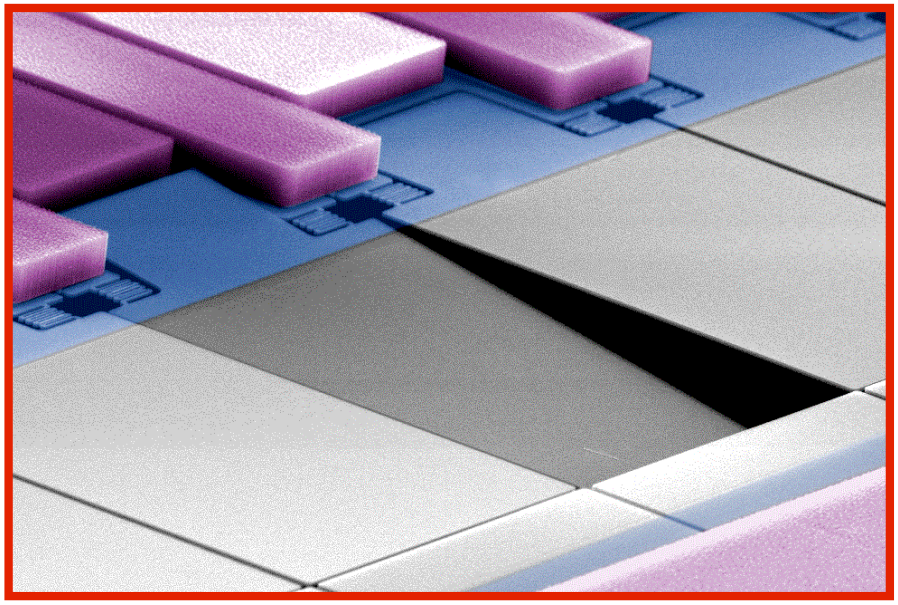
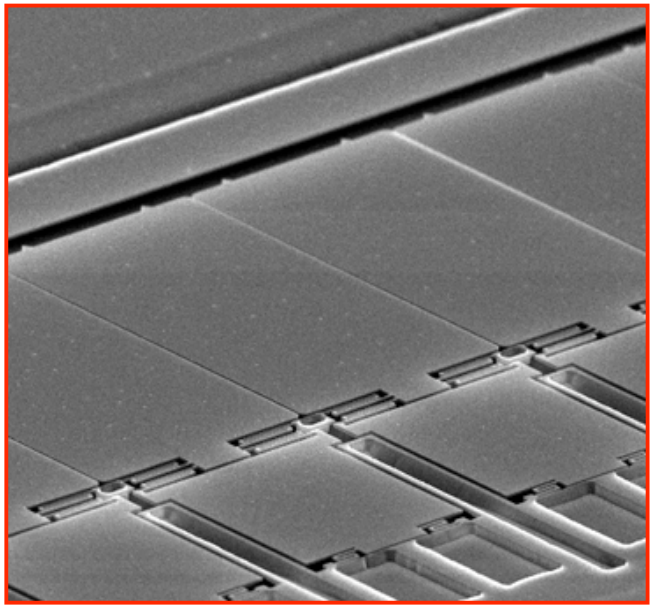
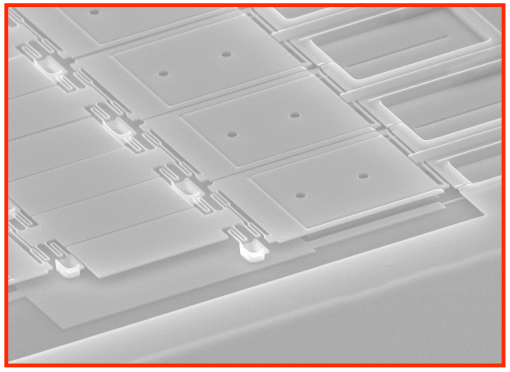
More MicroMirror linear arrays

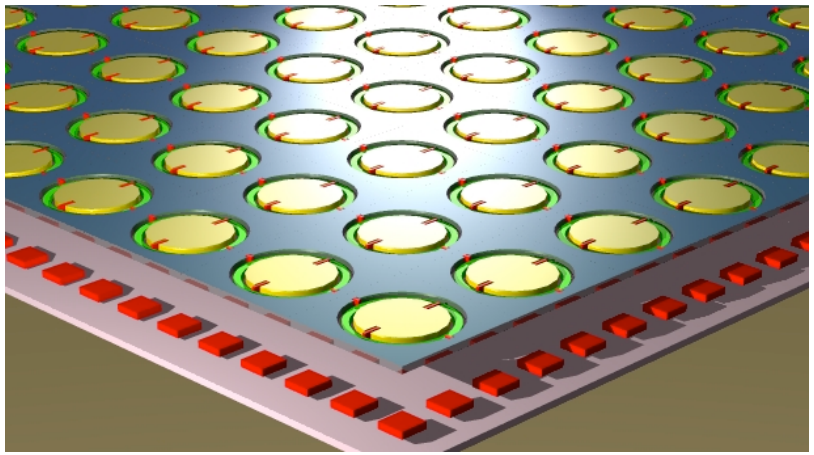




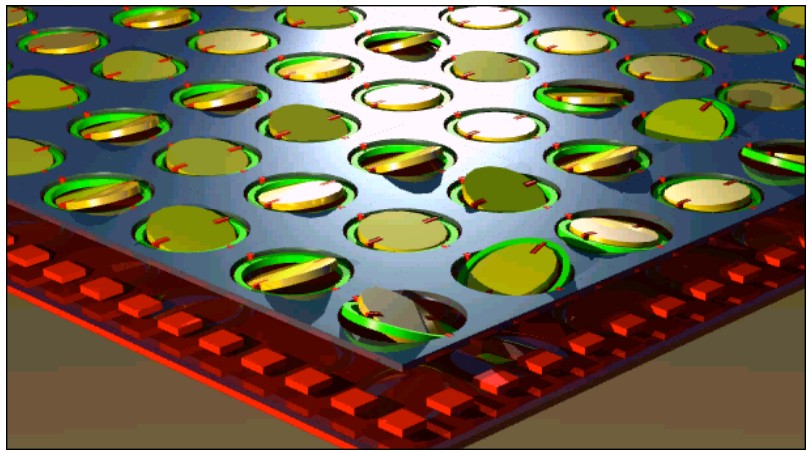


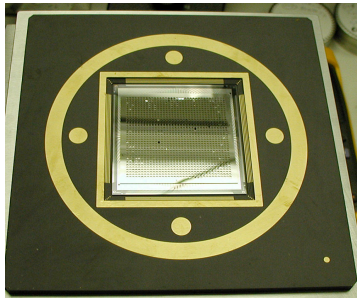
Beam steering arrays with 1296 mirrors

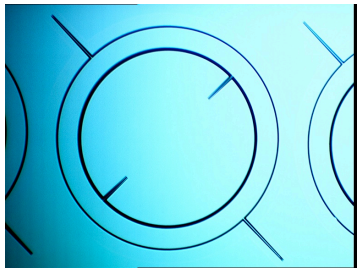
Zero voltage

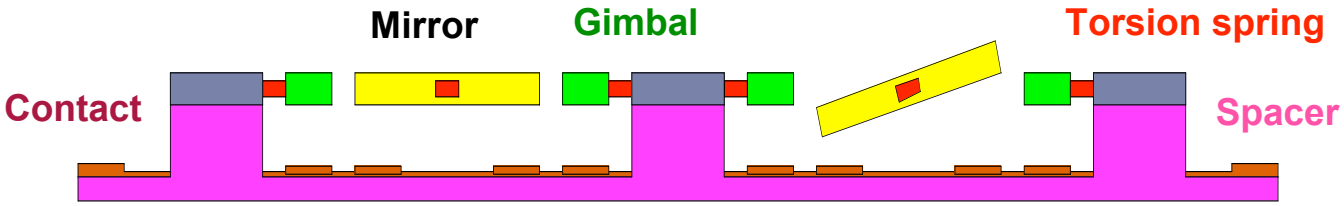


Voltage-actuated mirror deflection



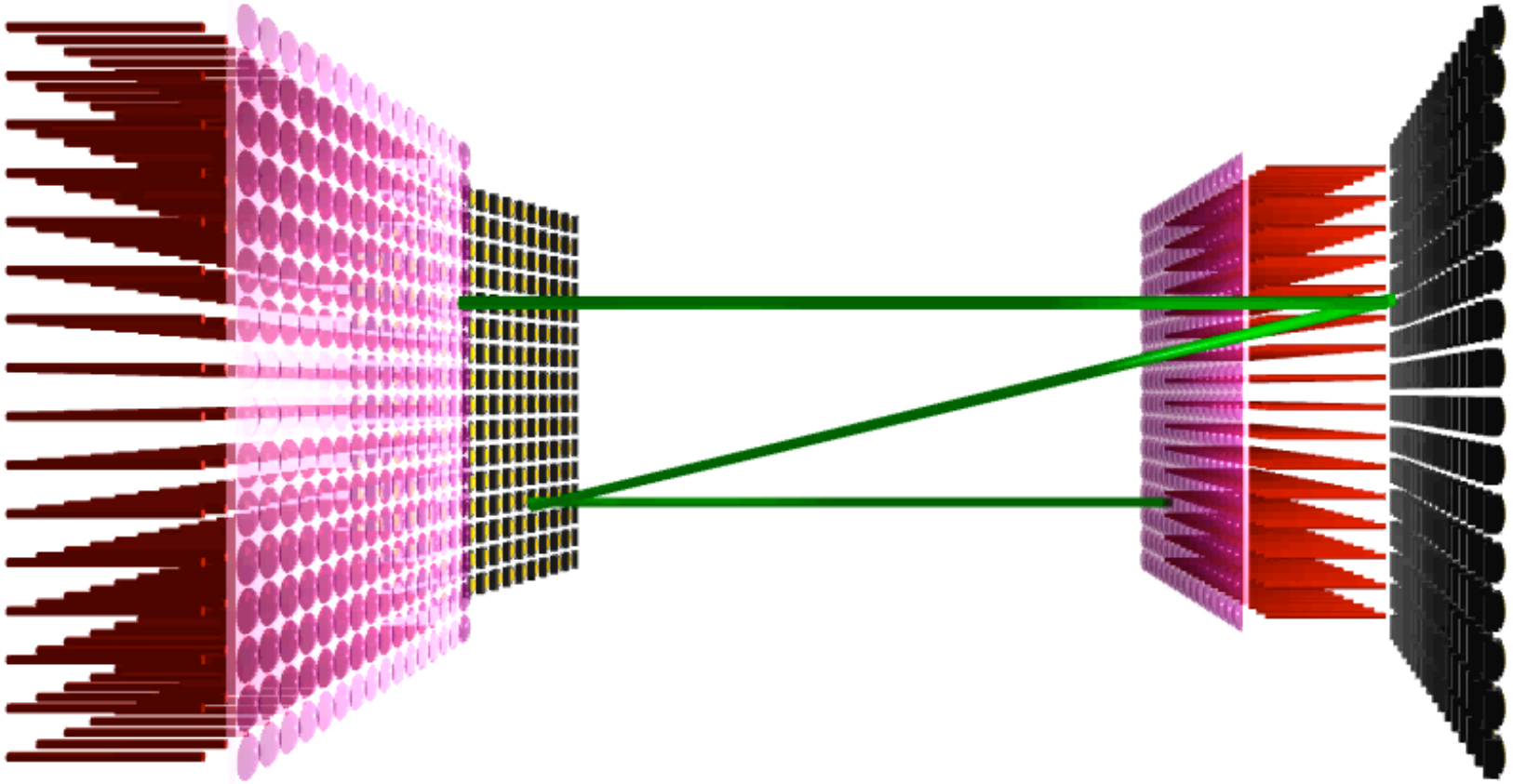






1296 mirror array (36x36)
850μm mirror diameter
1.25mm spacing
±7° tilt, activation voltage <200V
20ms response time

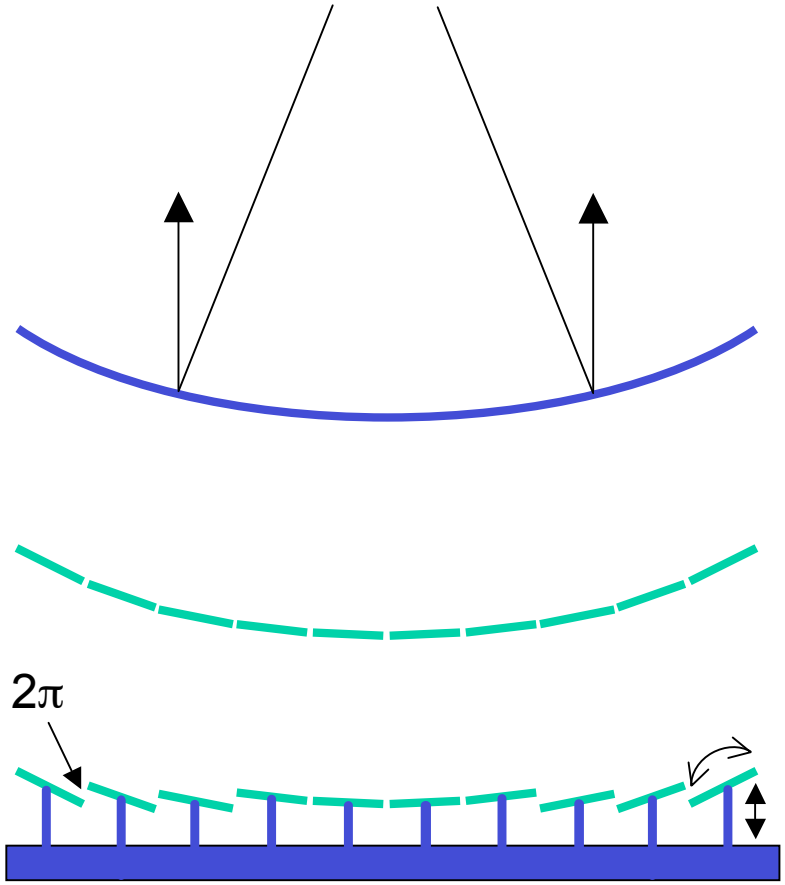
2-Axis Tilt Micro-Mirrors for beam steering



CCIT: Overall SLM Goals

- 2D Array with 256x256 tip-tilt-piston pixels (for base program)
- Individual pixel characteristics
  - Fill factor 98%
  - Response time 10 μs
  - Flatness λ/50
  - Roughness 2nm
  - Piston range on the order 5μm
  - Tip-tilt range +/- 10°
  - 8-bit resolution for tip-tilt and piston
- Integrated electronics addressing each pixel

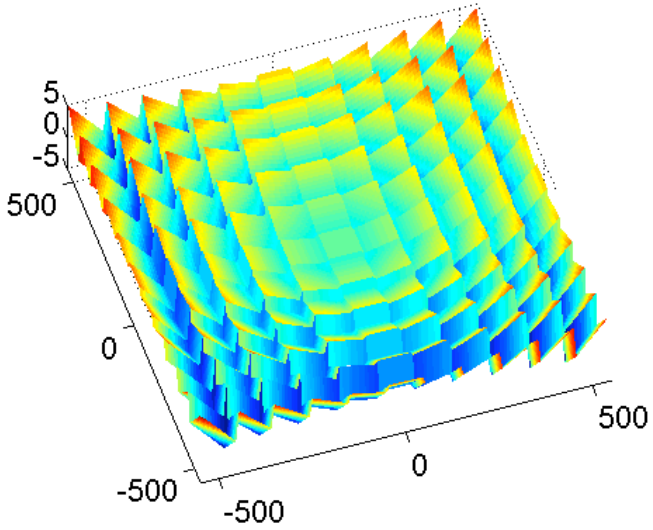
Creating Lenses with the SLM



Curved mirror microlens

Stepwise linear approximation

SLM reconfigurable microlens

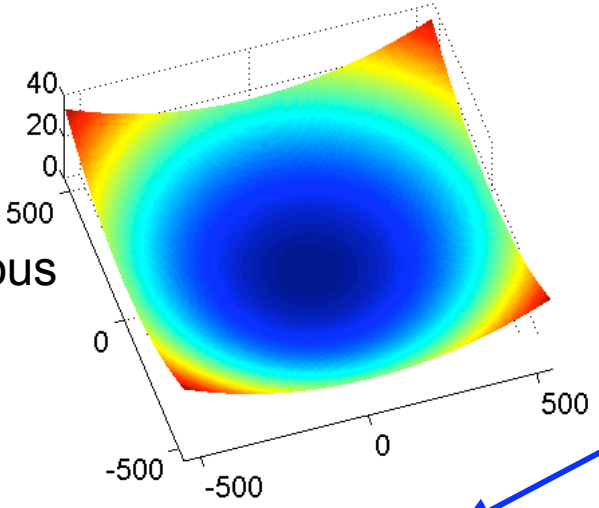


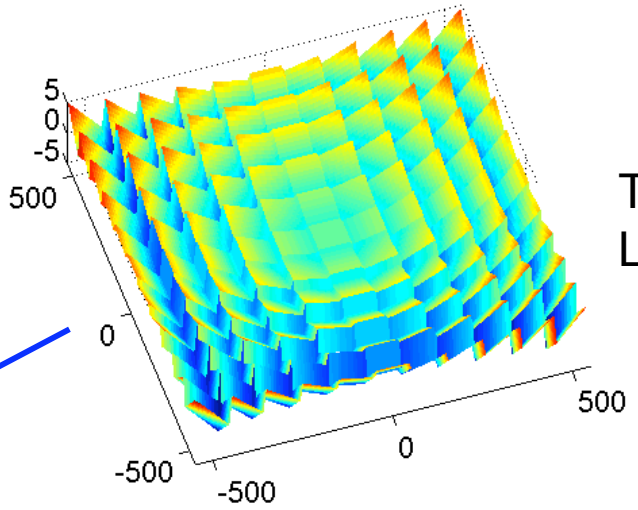
Independent control of tilt and piston motion enables microlens formation

Lens Approximation by SLM

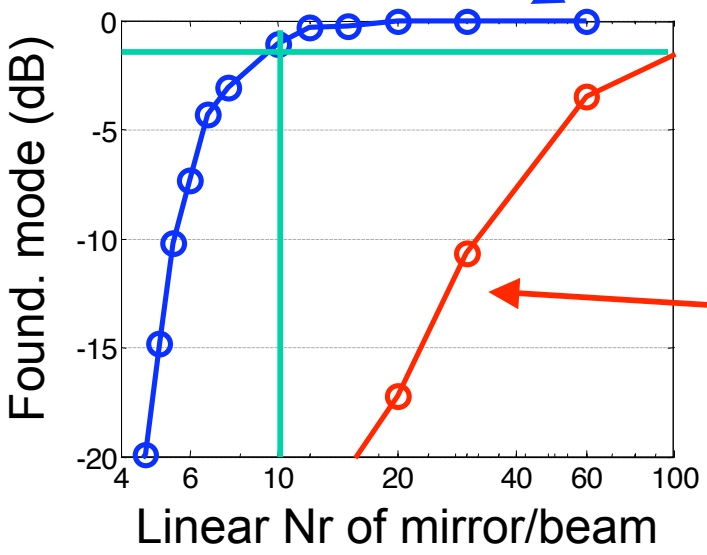
NxN Pixel Approximation

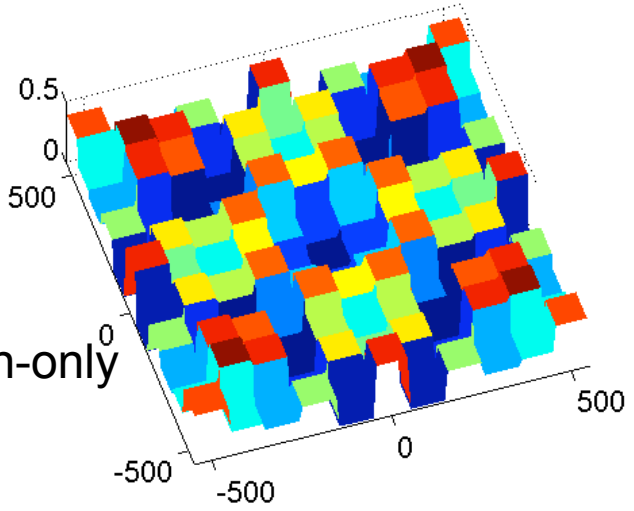
Continuous Lens





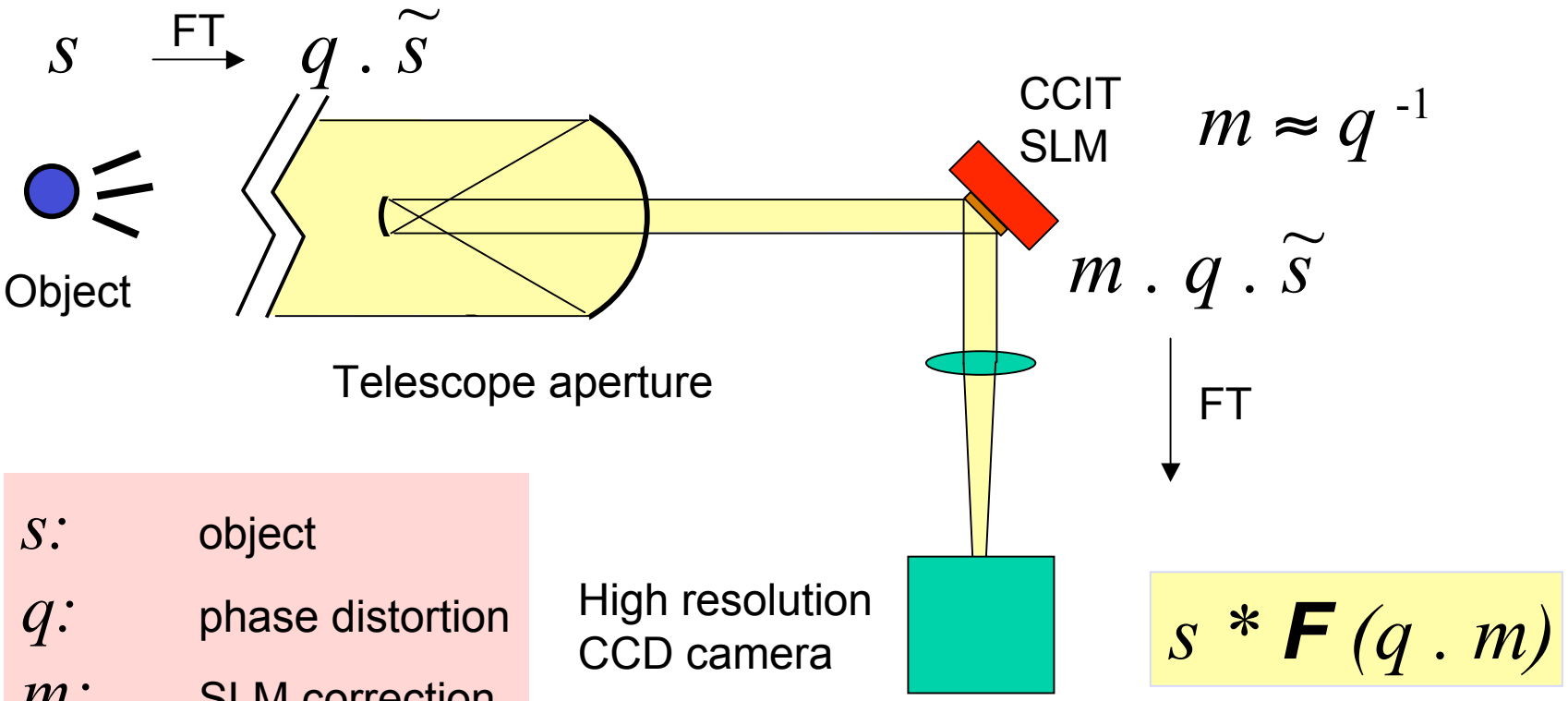
Tilt-Piston Lens





Piston-only Lens

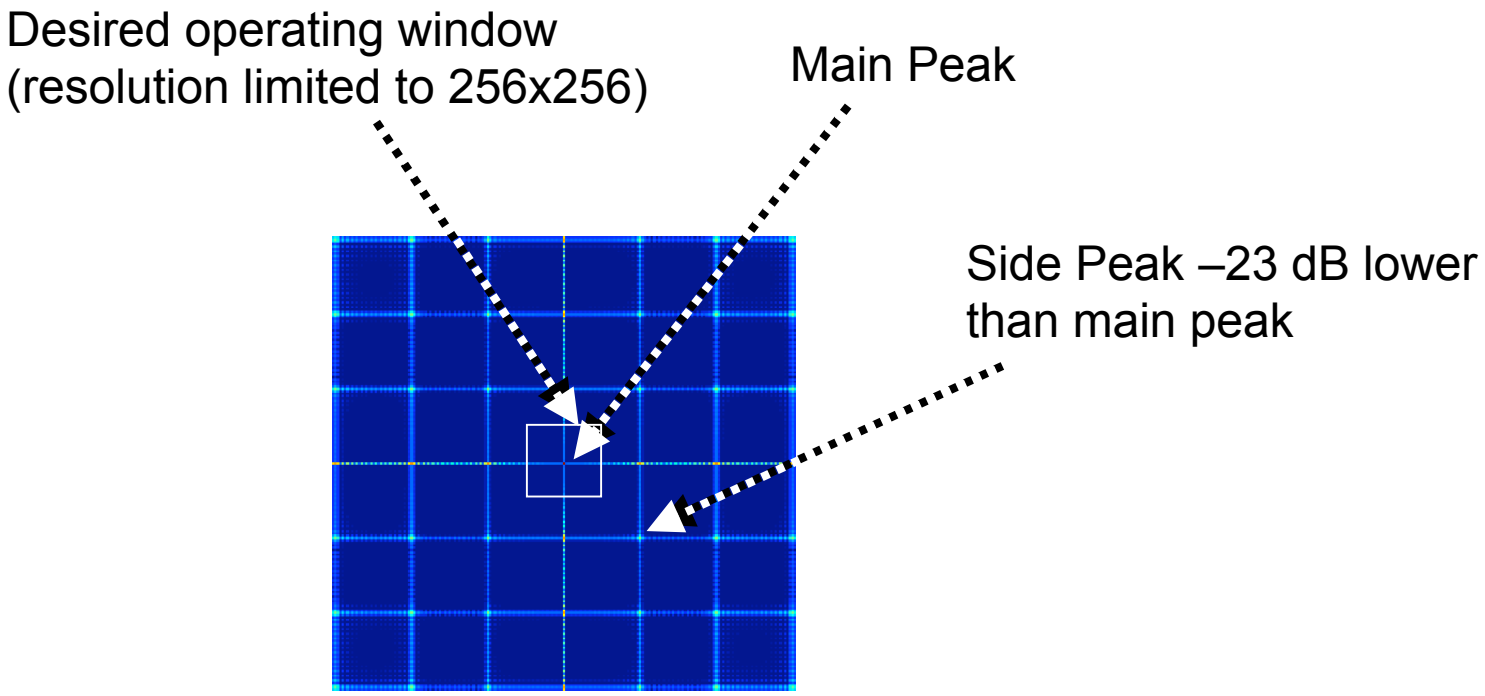
SLM Inside Telescope



s:	object
q:	phase distortion
m:	SLM correction

The image is the convolution of the object with the diffraction pattern of the SLM

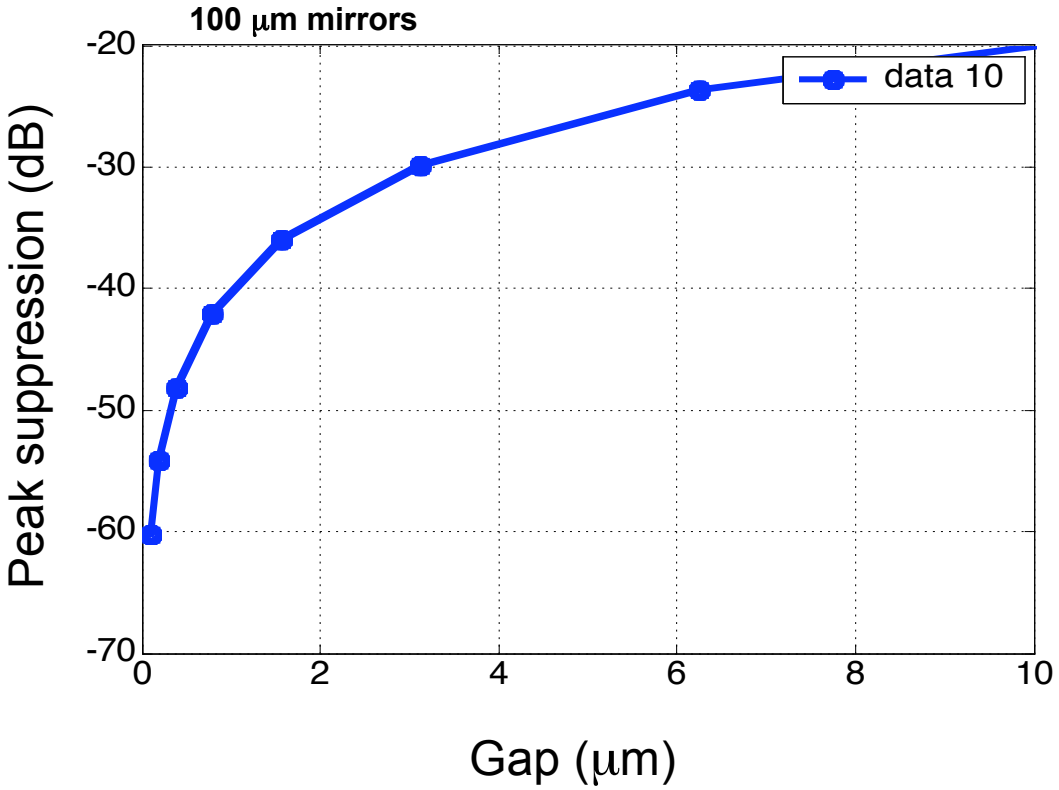
SLM Diffraction Pattern



If the detector camera has a higher resolution than the SLM, side peak produced by SLM matrix must be kept low.

Origin of the SLM Diffraction Pattern

1. Gap between the mirrors



$$\eta \approx \left(\frac{\Delta d}{d} \right)^2$$

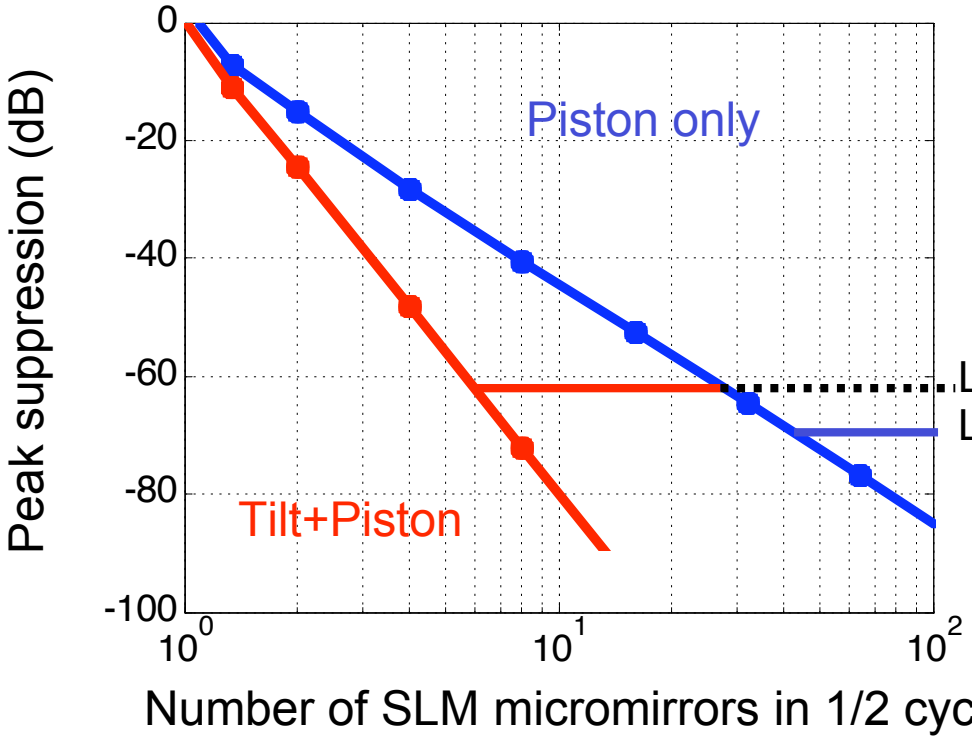
Δd : Gap

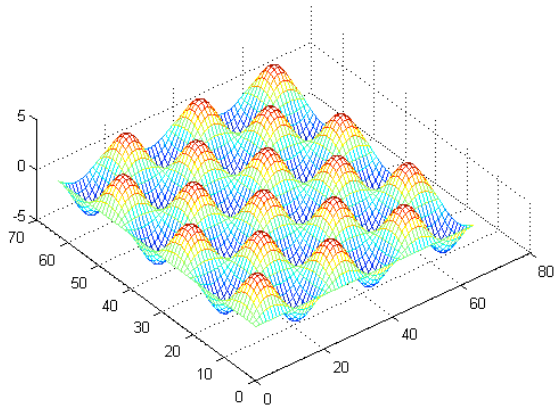
d : Mirror spacing

Origin of the SLM diffraction pattern

2. Phase jumps at mirror boundary when mirrors are actuated

SLM approximating a $\sin(k\,x).\sin(k\,y)$ surface



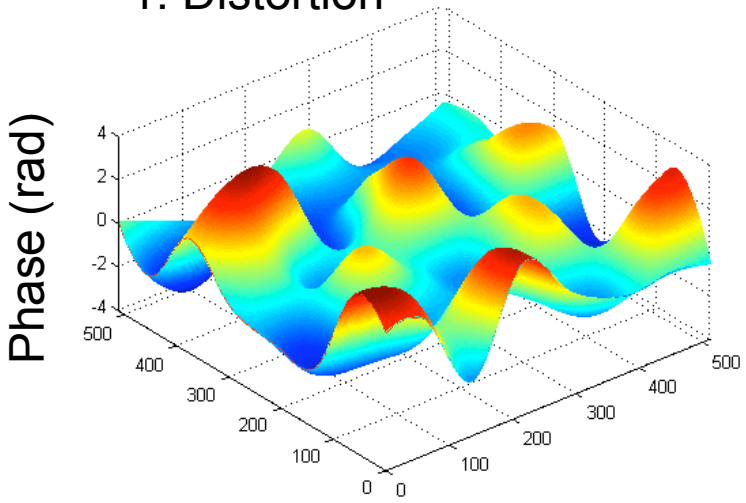


Lowest digit limit for 8bit tilt

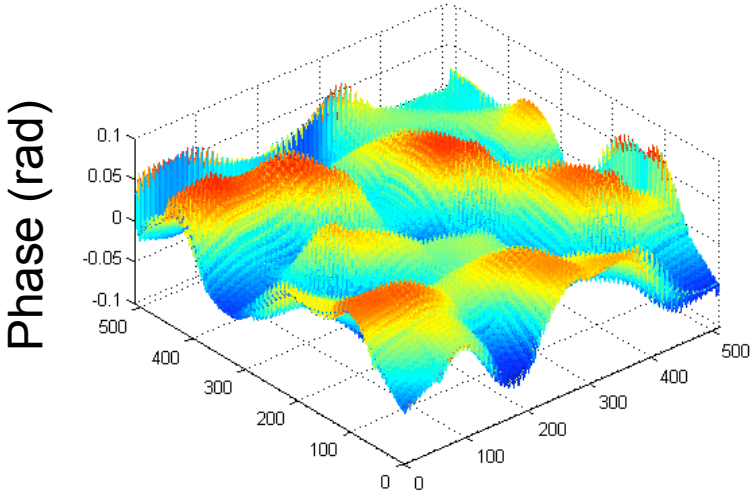
Lowest digit limit for 8bit piston

Example of SLM Phase Correction

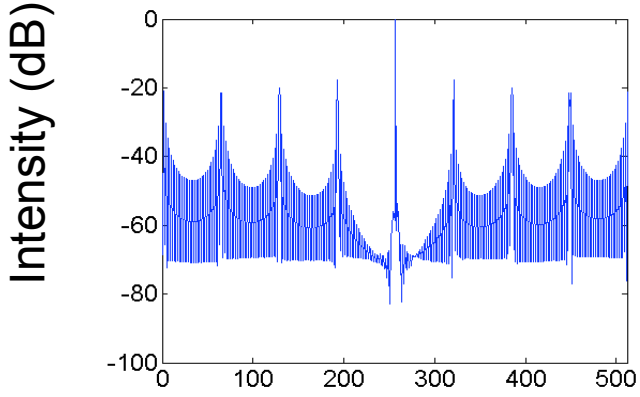
1. Distortion



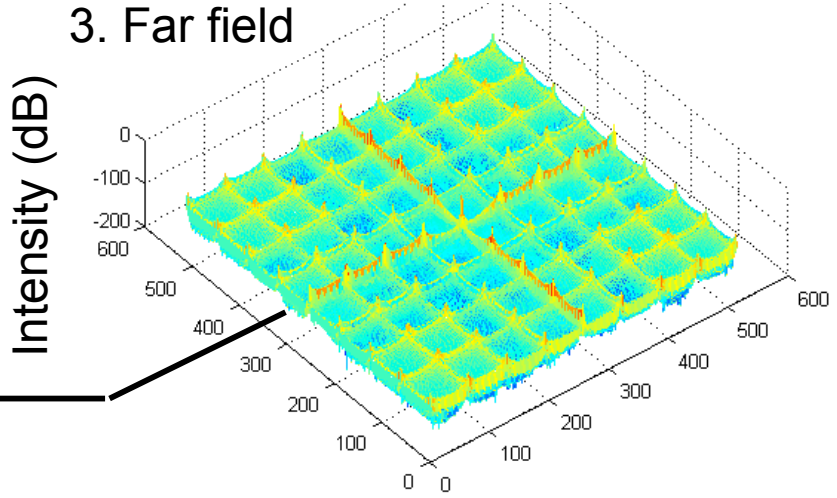
2. After correction with SLM



Far field (section)



3. Far field



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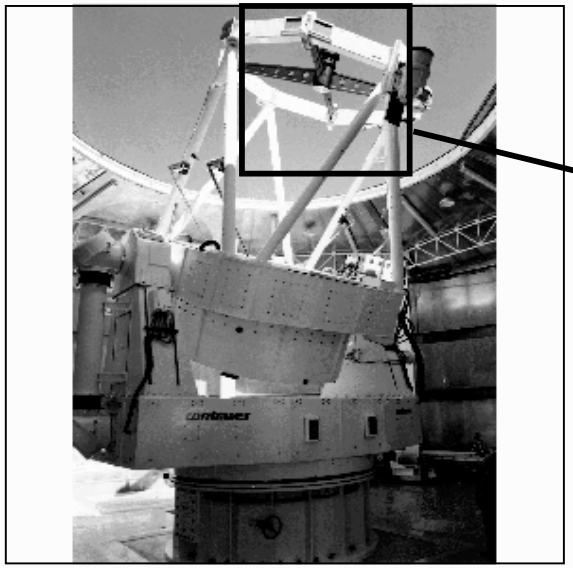
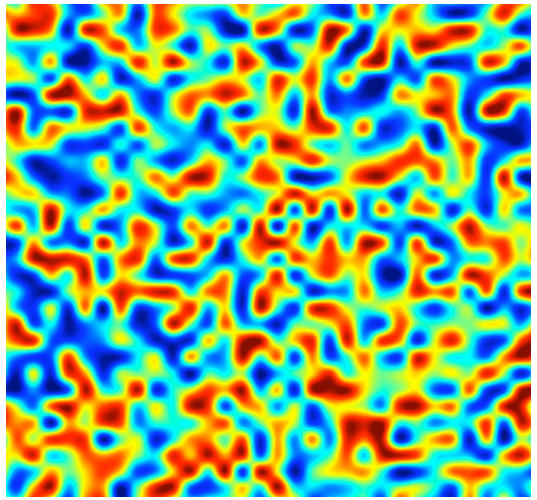
Imaging Through Phase Distortion

Original 1024x1024 pixels



Zoomed Detail (256x256)

Phase distortion (1024x1024)



Simulation:

Grid: 1024x1024

Mirrors: 128x128

Coherence length r_a=32 pixels ⇔ 4 Mirrors

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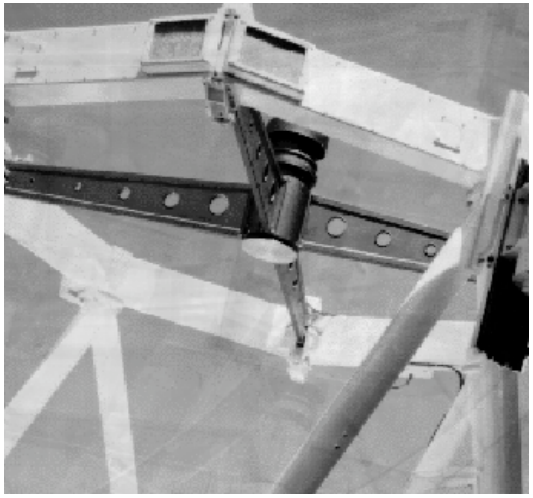
Examples of Corrected Images

Original

After Phase Distortion

Corrected (Phase Jumps Only)

Corrected - 90% fill factor



Corrected- 98% fill factor

Corrected: Yield 90%

Examples of Corrected Images--II

Original

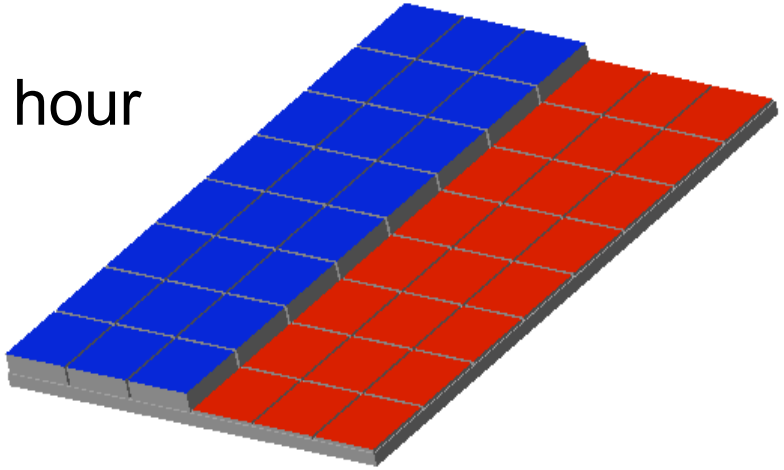
Corrected-μmirror curvature λ/20

Corrected-μmirror curvature λ/50

Small pixel size piston only SLM

SLM for Maskless Lithography, enabling:

- Sub 50nm CD
- One 300mm wafer level per hour



MEMS SLM Technical Goals:

1. Pixel count > 10Milion
2. Pixel size < 3 μm
3. Fill factor >93%, reflectivity >90%
4. Piston stroke >70 nm
5. Efficient modulation @193nm and 157nm
6. Frame rate 10kHz
7. Si based actuators, integrated electronics

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Summary

- Lucent has experience with large micromirror arrays based on the Lambda Router project
- SLM with tip-tilt-piston motion offers unmatched capabilities for adaptive optics and beam steering
- Piston only mirror array can address high resolution needs