The Fabrication and Characterization of a Spatial Light Modulator for Optical Maskless Lithography

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Abstract

•Spatial Light Modulators (SLMs), designed for optical maskless lithography (OML), have been fabricated and characterized. These prototype micro-electro-mechanical systems (MEMS) consist of 65000 mirrors, each as small as 3 microns square. They are the result of a DARPA funded project to extend the current limits of SLM technology for lithography applications.

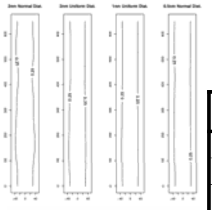
•OML complements conventional advanced 193 nm wavelength lithography by replacing the photomask with a programmable array of mirrors. The throughput of OML scanners would most likely never compete with mask-based technology, but they may be economical for prototyping, for circuit and process development, and for low volume production. Since only the mask is replaced, these machines can be inserted into fabrication facilities without extensive process development; for example, the photoresist used can be identical to that used in conventional lines.

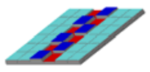
•Contrast is formed by phase shifting the light impinging on the MEMS mirrors. A voltage is applied to electrodes that pull the mirrors in a piston motion. Piston mirrors have the advantage of being configurable in strong phase shift patterns, unlike competing tilt mirror devices. This resolution enhancement may be important, considering that other lithography technologies such as EUV appear to be delayed.

•The devices were designed for 70 to 100 nm piston motion, 2V operation, 5 micron or less in pitch, 90% fill, and up to 10 KHz operation. In addition, the bending parts are made of poly-Si, a material that should not plastically deform during operation. Other materials such as metals used in SLMs require frequent recalibration. The MEMS device has features as small as 150 nm and level to level misalignments as low as 50 nm for a 10 mask process.

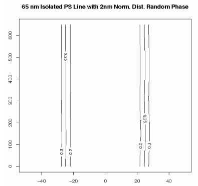
Application Requirements

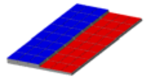
- How precise must we set piston height?
  - Simulation using SPLAT6
  - Random piston variations added to input file
  - Model system: an isolated 50 nm line, 1.1 NA, 0.6 σ, 32.5 nm pixel grid
  - +/-1 nm range is ok, >2nm is ok for strong phase shift
- How much piston throw is required?
  - 2π shift allows for checkerboard piston arrangement at any off-grid point (~100 nm piston throw)
  - 3/2π (~70nm) is adequate for rows but forms same aerial image only at best focus – pattern shift
- How Fast?
  - Much faster than rep rate of fastest 193 nm laser source, up to 10KHz
  - To allow for time to assign new voltages to a complete array of 128x512 mirrors, <100 µs response is needed



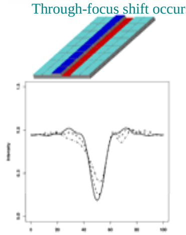


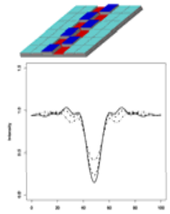
Distribution	CD variation, nm 1 edge
2 nm Normal	3.1
2 nm Uniform	2.2
1 nm Uniform	1.0
0.5 nm Normal	0.8
2 nm Normal, PS	0.2





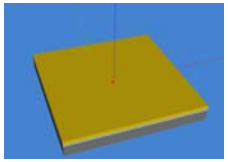
Through-focus shift occurs if checkerboarding is not used.



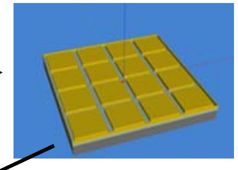


Fabrication Sequence

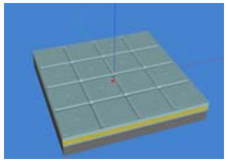
- CMOS-like process steps and toolset.
- 2 different process flows:
  - Integrated SLM device starting with SOI for mirror material addressed with bonded ASIC (flow shown below)
  - Standalone “wired” SLM with pads to apply analog voltages to pre-arranged mirror patterns – maskset used in opposite direction



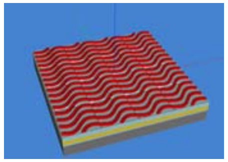
Start with SOI wafer



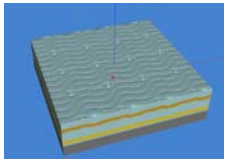
Pattern mirrors



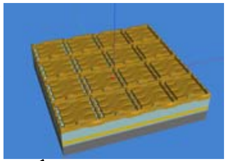
Deposit and pattern vias to connect mirrors to springs



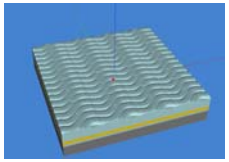
Deposit and pattern springs



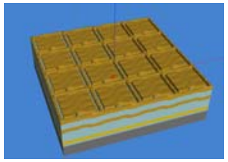
Deposit and pattern vias to connect springs to movable electrodes



Deposit and pattern movable electrodes



Deposit and pattern vias to connect movable electrodes to fixed electrodes



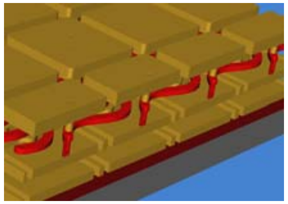
Deposit and pattern fixed electrodes

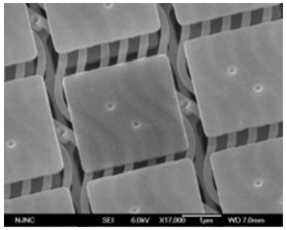
Fabrication - Lithography

- SVGL MS193 nm scanner, 0.6 NA, TEL ACT8 track used to achieve:
  - < 150 nm CD
  - +/-50 nm alignment
- Metrology:
  - KLA 8100 CD SEM – 4 sites/die, all wafers
  - Accenture Q7 alignment measurement system – 4 sites/die, 7 die/wafer all wafers

Fabrication Results

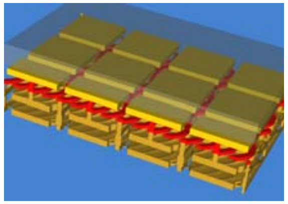
- Below: process simulation view of hard-wired (mirror last) device and SEM view, 30 degrees off normal, of completed device.
- Support pillars aligned to springs less than +/50 nm
- Runners between electrodes 150 nm

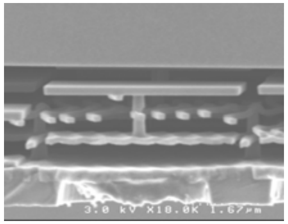




Fabrication Results

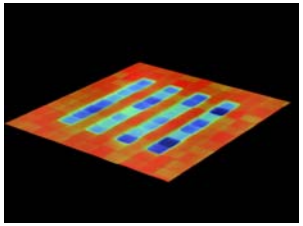
- Below: process simulation view of integrated SLM device and SEM view, cross-section, of completed device.
- Support pillars aligned to springs to much better than +/50 nm
- Springs, electrode spacing, vias, all 150 nm

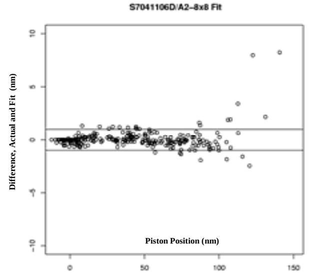


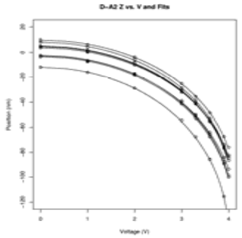


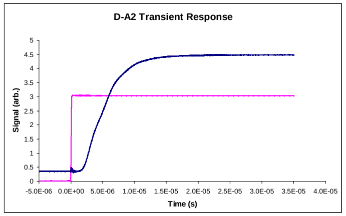
Hard-wired Device Test Results

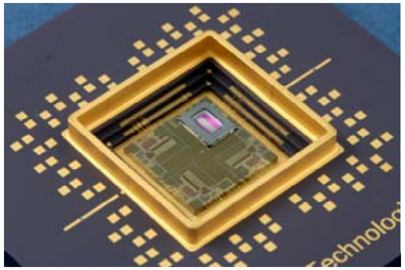
- Analog signals applied to mirrors wired with simple patterns – after release and Al coating
- Piston motion (z) measured with Wyco 3300 Optical Profilometer (see 3D image).
- Z vs. V data collected for variety of devices, example shown in plot below left.
- Ideal design equation with slight modification can fit data to within 1 nm precision, see plot below right.
- Diffraction spot response from L/S array with square wave voltage applied and illuminated with 405 nm laser shows response time of about 20 µs – see graph lower right











Integrated Device

- Photograph on left shows a completed integrated SLM:
  - Bonded to ASIC driver chip
  - Substrate removed
  - HF released
  - Wirebonded in ceramic package
- With appropriate bonding conditions, ASIC functionality is ok
- Currently being tested for full functionality

Conclusions and Further Work

- SLMs have been designed and fabricated with mirrors as small as 3 microns, with feature sizes smaller than 150 nm, and piston throw larger than 100 nm
- Results show that 1 nm precision, and <100 µs response can be achieved.
- The integrated SLM device has been packaged and it has been shown basic electronic functionality is maintained
- We are now in the process of testing motion of integrated SLMs

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