Micromachining Optical Arrays

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Outline

- **Introduction to MOAs:**
  - Project context: The Smart X-ray Optics consortium
  - What are the MOAs and requirements
- **MOAs iterations:**
  - Initial design
  - Spider design
- **Conclusions and further work**

- **Introduction to MOAs**

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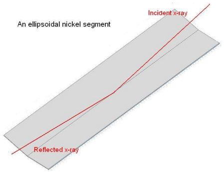
http://SmartXrayOptics.org

The Smart X-ray optics projects

- Enhance performance of existing systems, such as X-ray telescopes

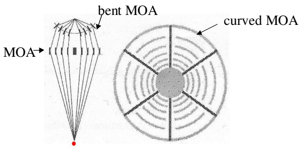
Large scale SXO



- Actively controlled mirror systems

- Micro-structured optical arrays (MOAs) for microfocus sources and X-ray microscopy.

Small scale SXO



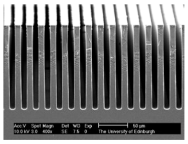
1D focus 2D focus

- Schematic of MOA

- Both use grazing incidence reflection

What are the MOAs?

- New active/adaptive X-Ray optics
  - Use grazing incidence reflection through consecutive aligned arrays of channels
  - Bending the arrays allows variable focal length
  - Flexing parts of the arrays provides adaptive or active systems



- array of channels etched in silicon

Requirements for MOAs

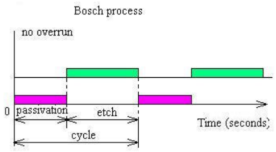
- High aspect ratio devices
  - Vertical walls
    - 20:1 aspect ratio
  - Smooth walls: roughness not to exceed 2nm
  - 5cm radius of curvature

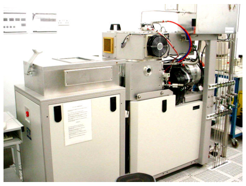
•MOAs iterations

Dry etched MOAs

Bosch Process

DRIE ICP



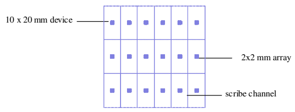


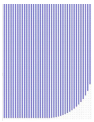
- for etching
  - SF_6, O_2, Ar
- for passivation
  - C_4F_8

Dry etched MOAs

- Initial design

- mask layout





- 20μm and/or 10μm pitch

- single crystal silicon
  - 3", <100>, 380 μm thick, resistivity and type not important

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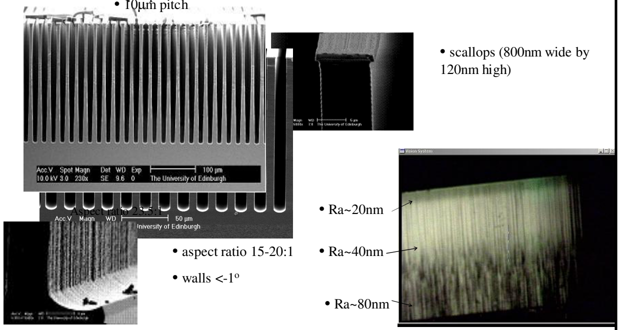
Dry etched MOAs

- Initial design

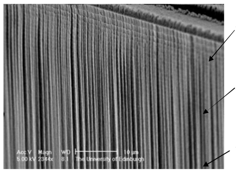


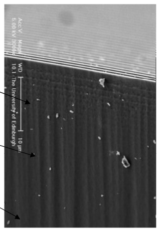
- 20μm pitch
- 10μm pitch
- scallops (800nm wide by 120nm high)
- aspect ratio 15-20:1
- walls <-1°
- Ra~20nm
- Ra~40nm
- Ra~80nm

Dry etched MOA's

- Initial design

- Using overrun and ramping down the C_4F_8
- Dip-off in HF
- Short thermal oxidation (1100°C)
- Dip-off in HF





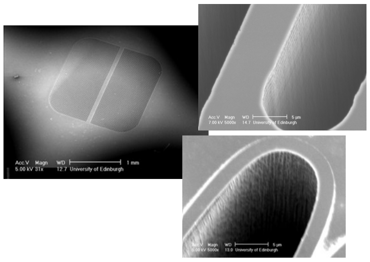
- 20nm->8nm
- 40nm->20nm
- 80nm->30nm

- before
- after

Dry etched MOAs

- Initial design

- MOAs used for reflectivity tests
  - 200µm, <100>



- 5% at 4° incidence angle (Daresbury)
- 3.33% at 2.86° incidence angl (Leicester)

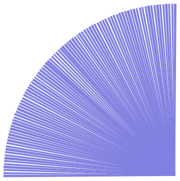
Wet etched MOA's

- Initial design

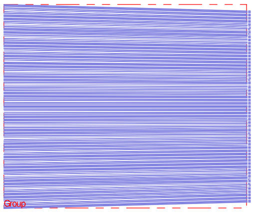
- Silicon
  - 200µm, 3", <110>, high resistivity, type not important

•10x20mm chips with a central 2x2mm array of channels, 20µm pitch

- wagon wheel



- array of fanned channels



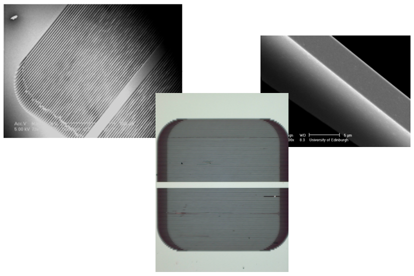
- 0.05° increment

Wet etched MOA's

- Initial design

•10x20mm chips with a central 2x2mm array of channels, 20µm pitch

•Thermal oxide for masking for etching in 20% TMAH at 90°C



•Ra=1.2nm

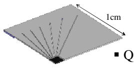
•5.95% for 5.71o incidence angle (Leicester)

Dry etched MOAs

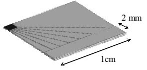
- Spider design

•Design and FEA modelling

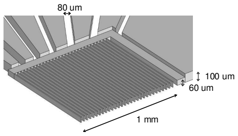
- Quarter top view

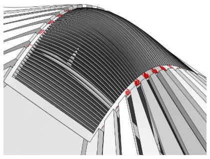


- Quarter bottom view



- Quarter top view of the channels

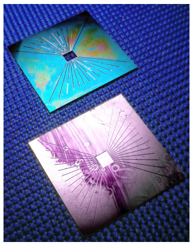


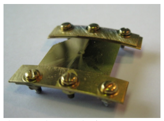


•Avg. ROC = 5 cm

The initial spider model
Dry etched manufactured samples

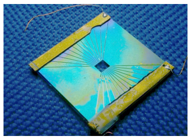
•2cm×2cm×100µm Si wafers.





•3cm ROC

•Clamped sample in a pre-curved jig



•8 cm ROC

•120µm PZT piezoelectric actuators mounted on one spider device

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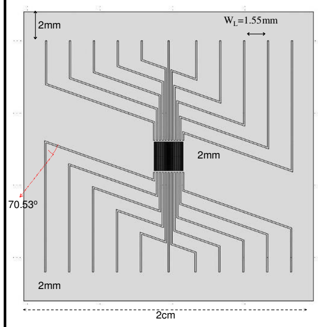
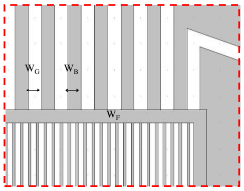
Wet Etched spider MOA



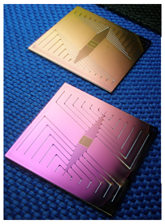


•Wet etch compatible model definition for an spider design with number of legs N_L=20. The micro-channels are located in the centre 2×2mm region. The trenches are drawn parallel to the silicon channels and at an angle of 70.53° coinciding with the {111} planes in <110> silicon. The insert depicts the levers meeting the micro-channels.

•12µm pitch (8 µm wall and 4 µm channel)

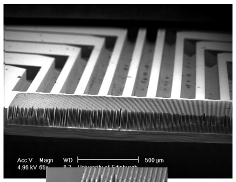
Wet Etched spider MOA
Manufactured samples

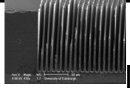
- 3”, 200µm, n and p type <110>, high resistivity
- 4”, 60, 80 and 100 µm, p type <110>, temporarily bonded to carrier wafers
- 100nm thermal oxide, 100nm stoichiometric nitride masking layer
- 40% KOH, 80°C, etched device by device



Model	N_L	W_B	W_G
M1	24	80	80
M2	20	100	100
M3	28	70	70
M4	20	80	120
M5	24	100	60
M6	20	120	80

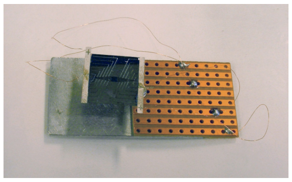
Design parameters of the six different spider-MOA designs which were wet etched in silicon.

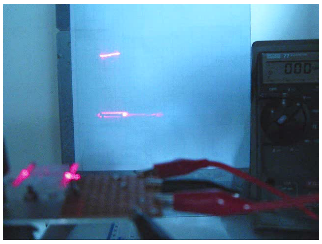




•wall angle 89.6°

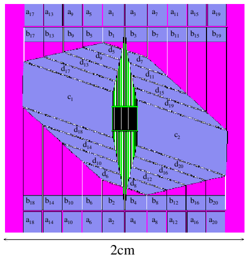
Wet Etched spider MOA
Test results



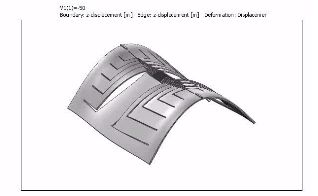


•The MOA curvature calculated from the dimensions of the image varies from 6.5cm on the left to 5cm on the right.

Spider MOA with segmented electrodes (FEA modeling)

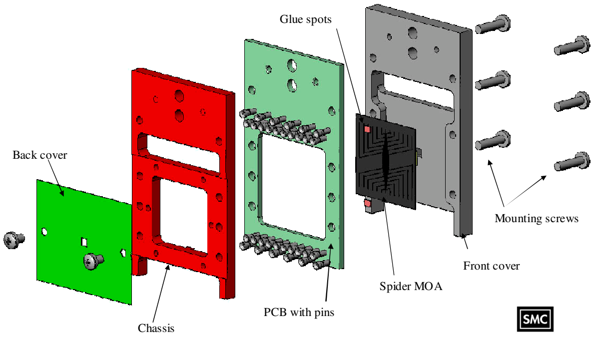


- •100µm Si
- •75µm PZT actuator

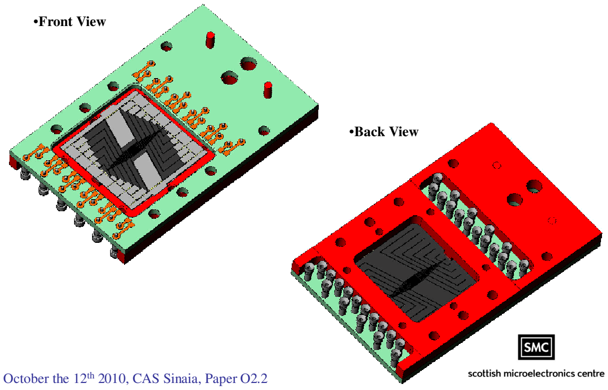


- •Extra capabilities added using segmented electrodes:
- •Curvature profile control
- •Tip / Tilt angle (+/-3mrad)
- •Z control (+/-20µm)

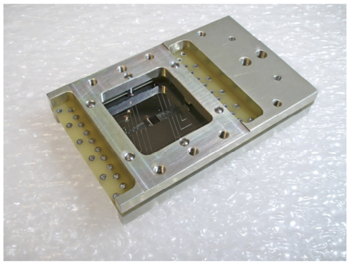
Spider MOA packaging



Spider MOA packaging



Spider MOA packaging



•Back view of an MOA spider, PCB and chassis on the gluing station

Conclusions and further work

Conclusions and further work

- Vertical walls can be obtained using both dry and wet etching.
- Roughness of less than 2nm can be obtained only by wet etching.
- A wet etch compatible spider arrangement has been design which uses trenches parallel to the {111} planes in <110> silicon wafers.
- Preliminary results of a wet etched spider device actuated with two piezoelectric strips show that the MOA can be bent to a radius of 6.5cm without failure of the MOA channels.
- A proposed configuration with segmented electrodes has been modelled which would add extra capabilities to the spider MOA chip.
- Future work will concentrate on the manufacturing of an actuator arrangement with segmented electrodes, its packaging structure and the device integration. Once these issues are solved the intention is to carry out X-ray testing of wet etched spider MOA devices.

•Acknowledgments

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smart x-ray optics

Thank you for your attention

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