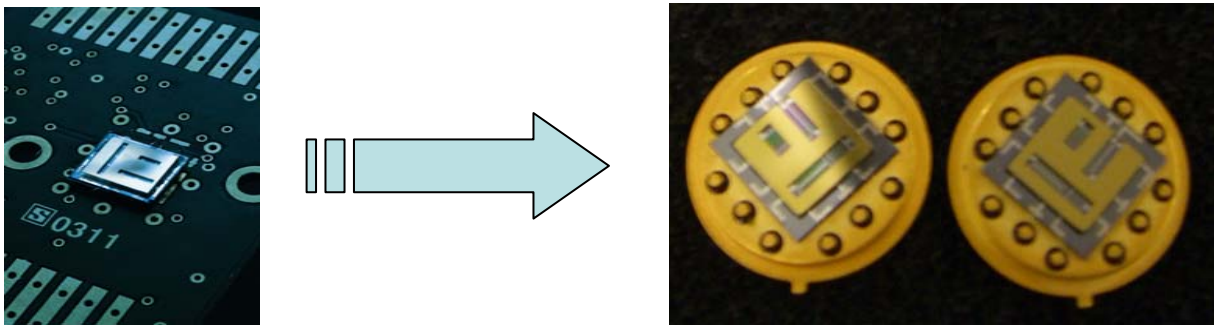
Department of
Micro and Nanotechnology

Development and Initial Characterisation of 2nd Generation MEMS Sun Sensor



J. H. Hales, T. Ansbæk, R. Xu, J. Larsen, J. Wulff, M. Pedersen, R. Fléron and Z. J. Davis

jhh@mic.dtu.dk

DTU

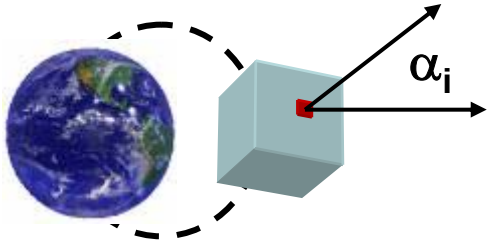
Outline

- Sun sensor principle
- General Fabrication Scheme
- 1st vs. 2nd Generation Performance Comparison
- Design of 2nd Generation
- Characterisation
- Status & Outlook

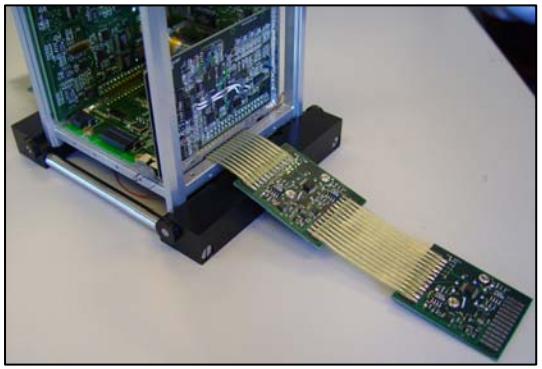
Attitude Determination

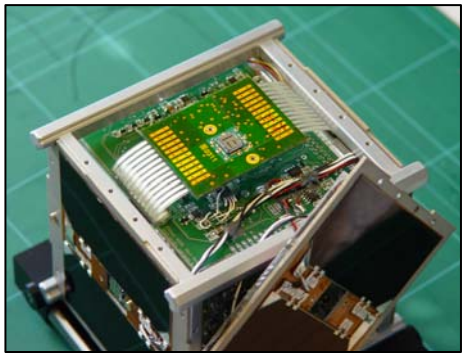
Basic Principle:

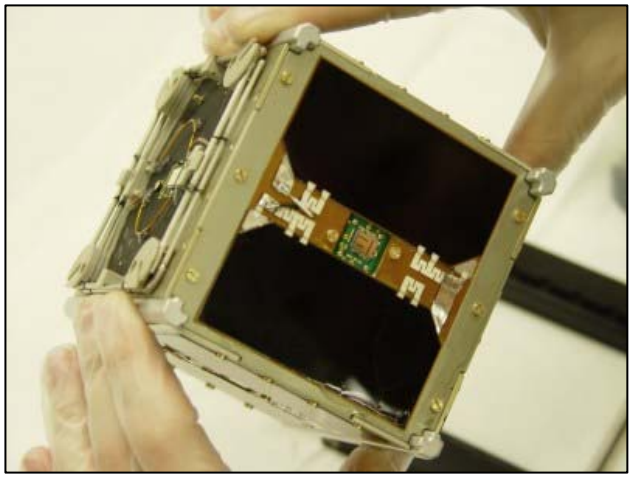
Detect the angle of the sun with respect to the sensor.



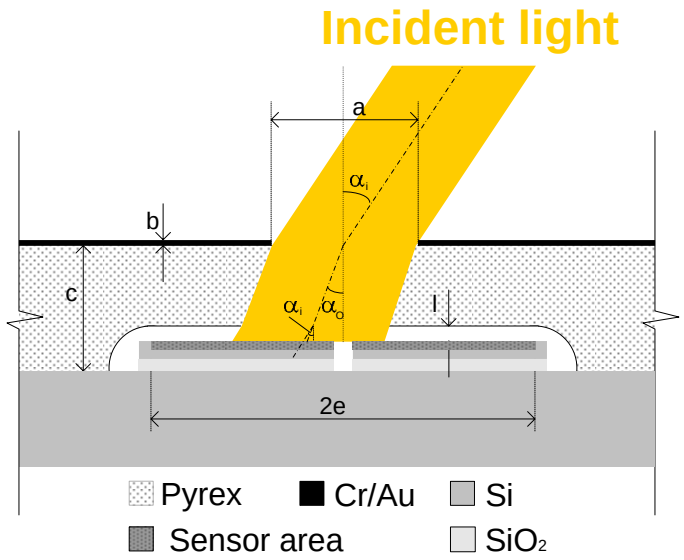
Implementation of MEMS in order to meet requirements and constraints from CubeSat project.

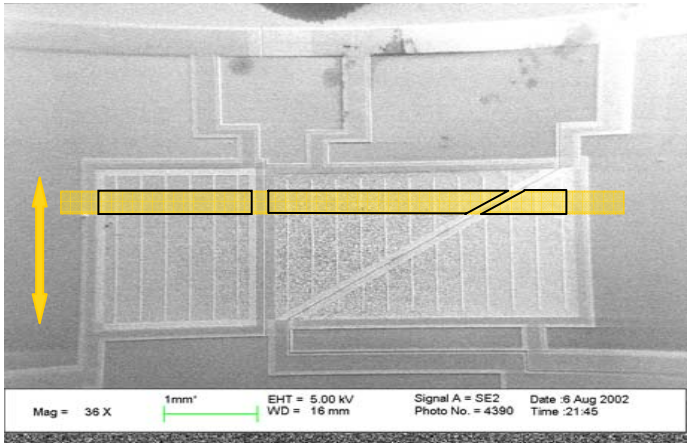


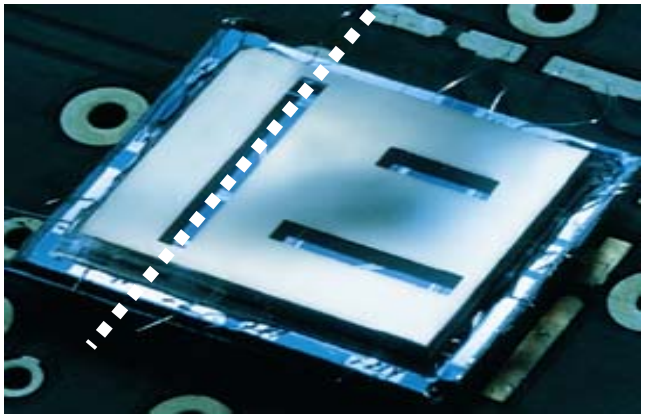




Transducer Principle

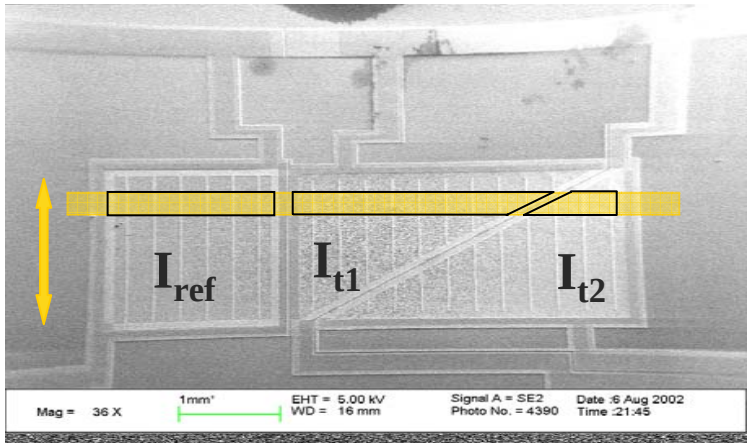


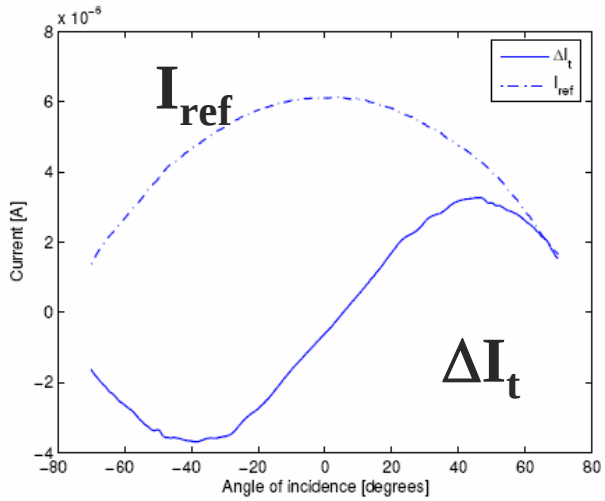


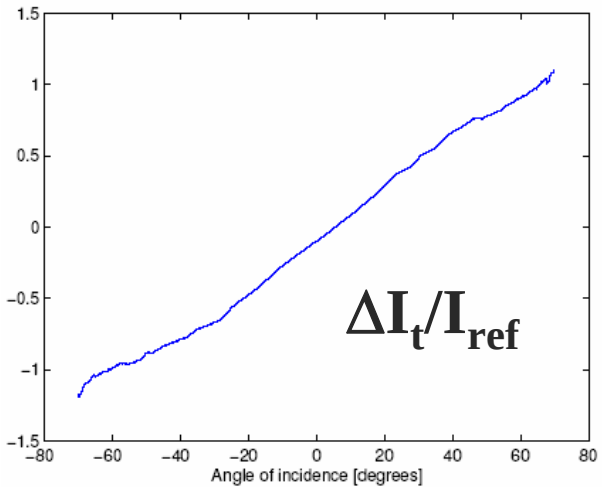


$$\frac{\Delta I}{I_{ref}} = \frac{\frac{E_e \cos(\alpha_x)\cos(\alpha_y)}{V}\eta(A_1(\alpha_i) - A_2(\alpha_i))}{\frac{E_e \cos(\alpha_x)\cos(\alpha_y)A_{ref}}{V}\eta} = \frac{A_1(\alpha_i) - A_2(\alpha_i)}{A_{ref}}$$

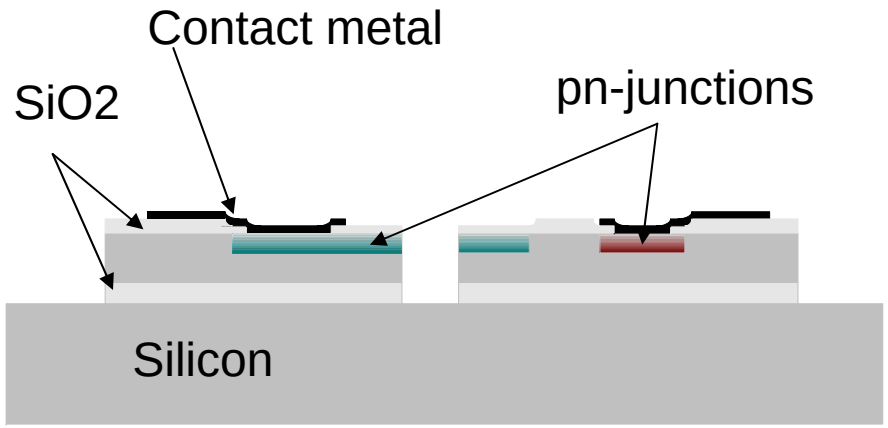
Transducer Principle

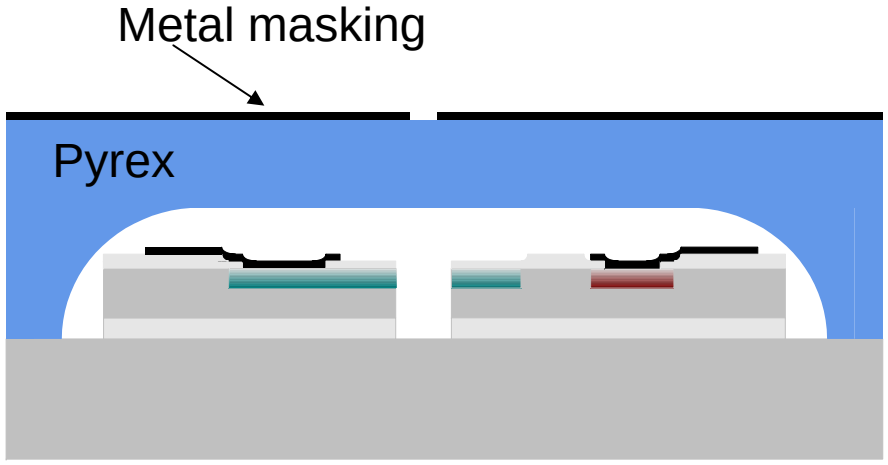






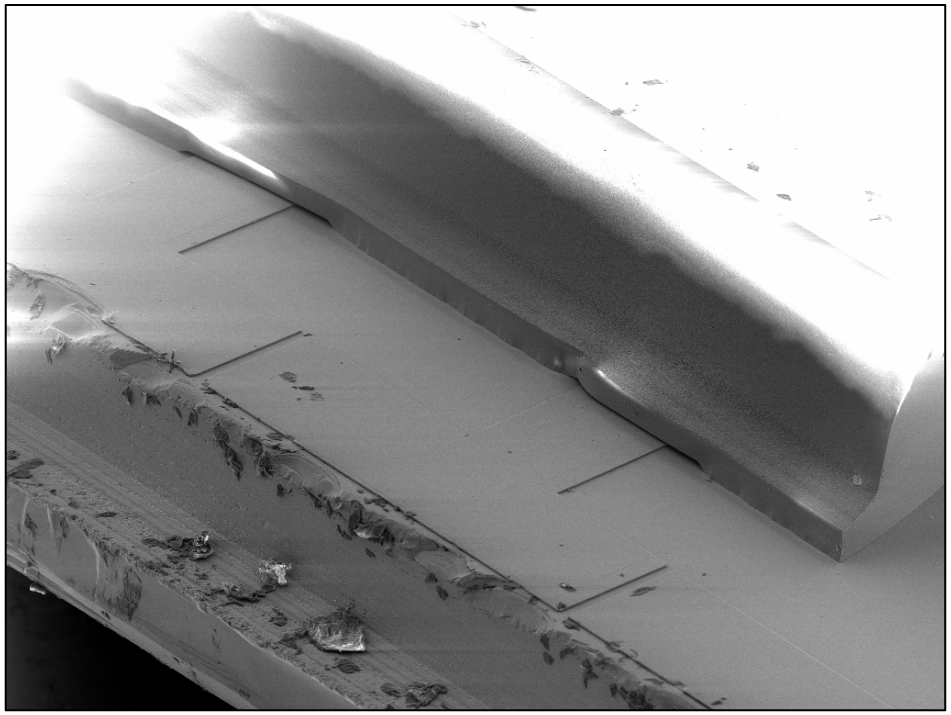
Fabrication

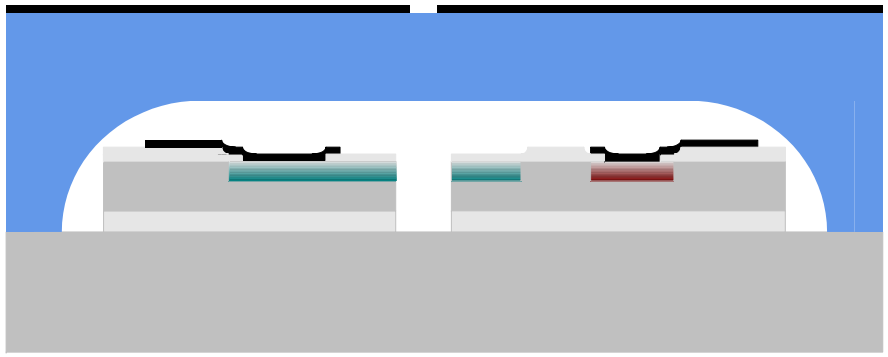




- SOI wafer
  - Ion implantation
  - Thermal oxidation
  - Metal contacts
  - RIE
- Pyrex wafer
  - Metal patterning
  - HF etch of Pyrex
  - Anodic bonding

Fabrication





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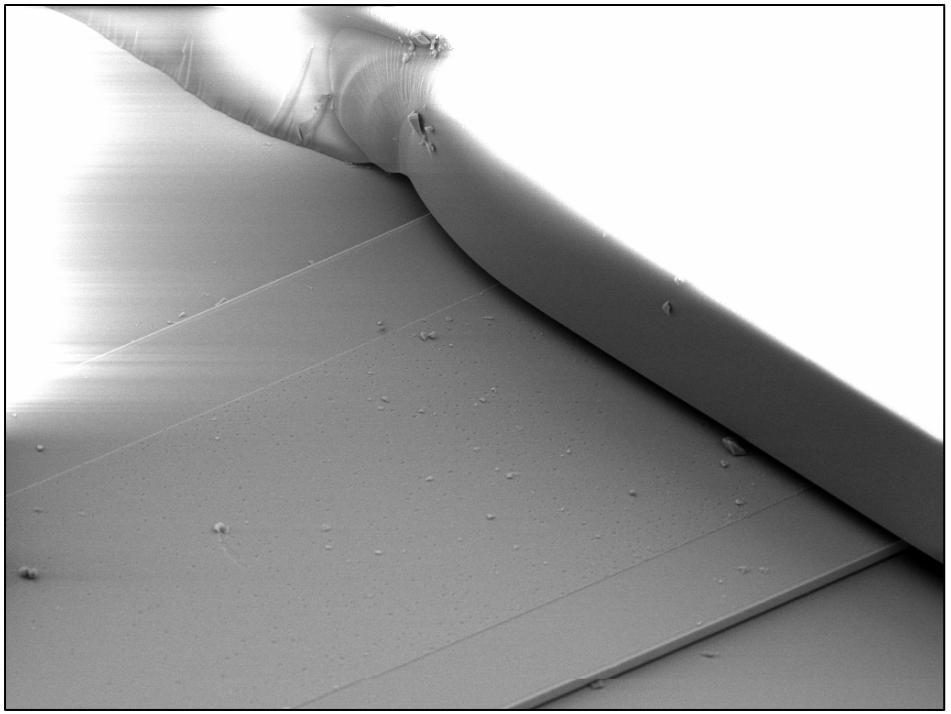
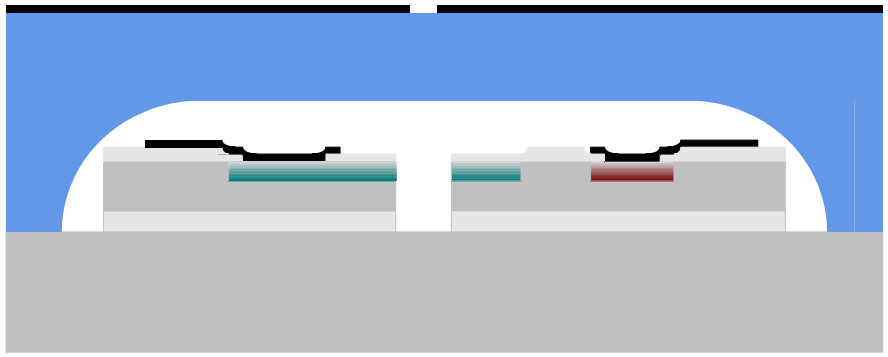
Fabrication





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  - RIE
- Pyrex wafer
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  - Anodic bonding

Comparison – 1st vs 2nd

- General requirements
  - FOV > 110°
  - Resolution < 1°
  - High UV-sensitivity
  - Large signal-to-noise ratio

	1st Generation	2nd Generation
Dark Current	**2 pA**	**0.8 pA – 0.8 nA**
QE	**4 % @ 450 nm**	**50-95 % @ 450 nm**
Junction depth	**660 nm**	**< 200 nm**

Bulk Diode Designs

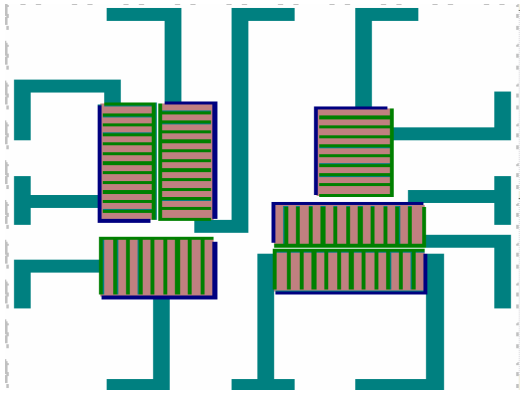
- pn-junction situated in the bulk (UV-absorption in the bulk depend on carrier lifetime)

n+ contact

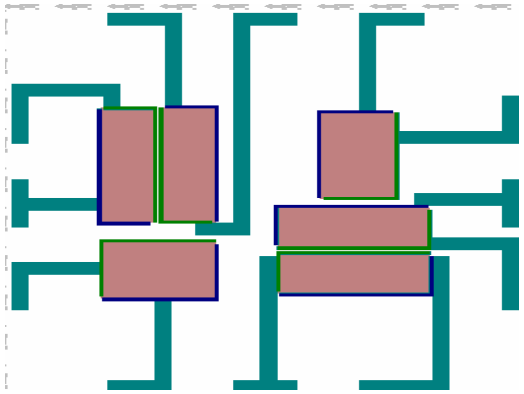
p+ contact

n+ device

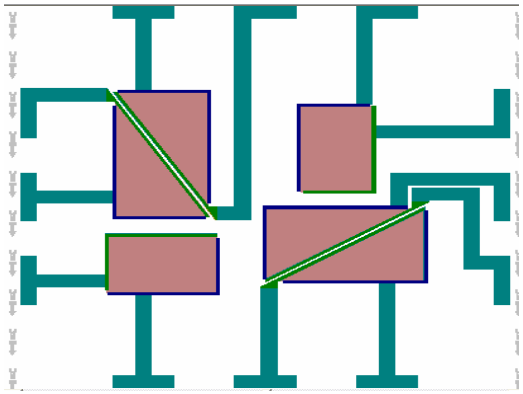
Metallization



Finger

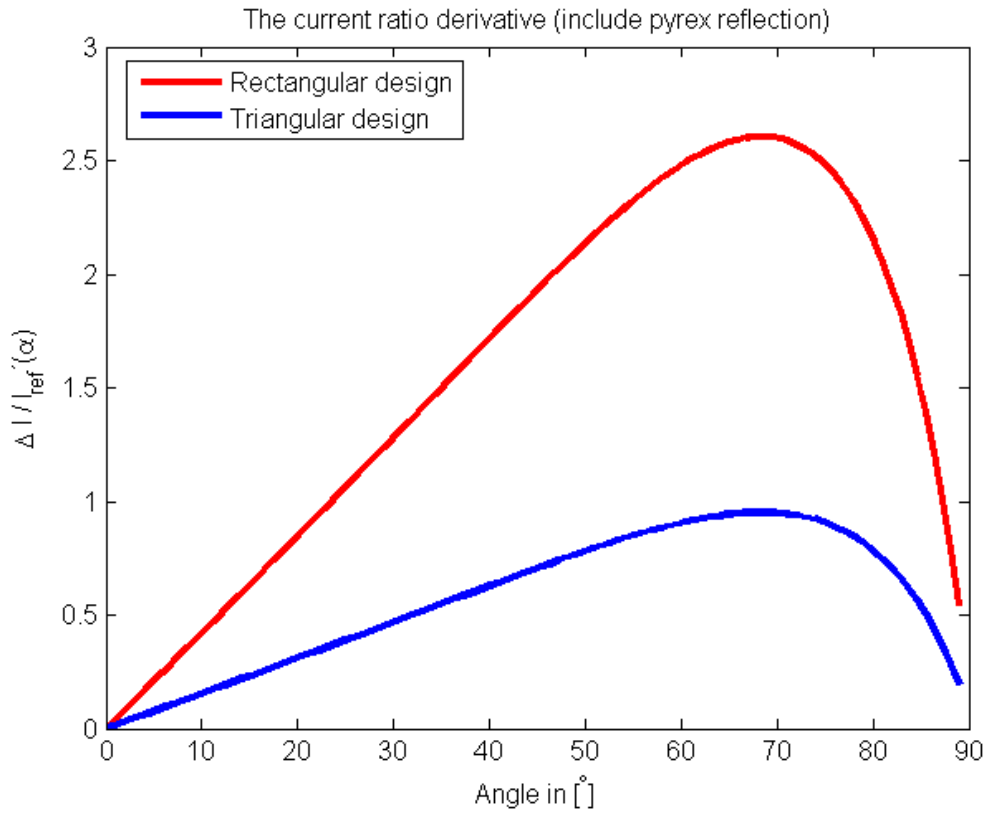


Rectangular



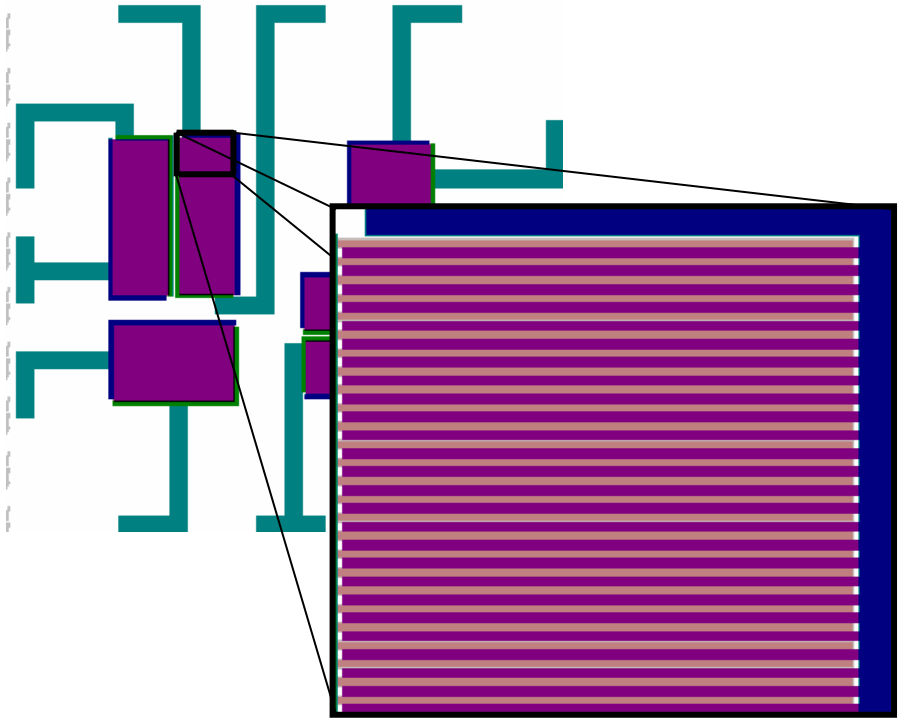
Triangular

Design Specifications



Surface Diode Design

- **~ 70 % surface-diode coverage (depletion layer extends all the way up to the surface)**

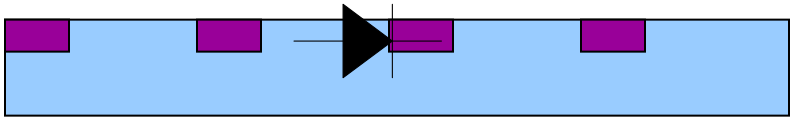


n+ contact

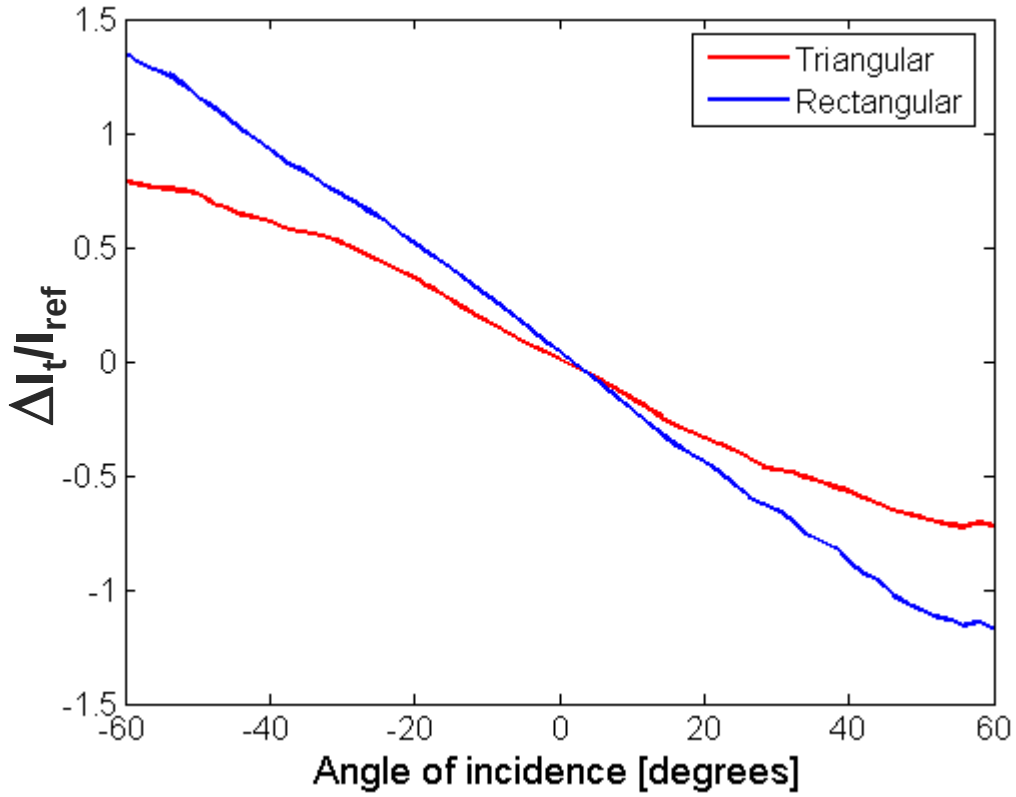
p+ contact

n+ device

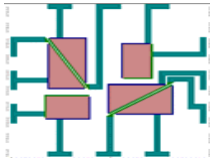
Metallization

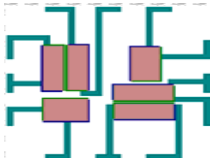


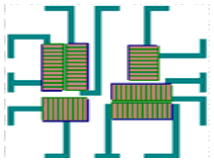
Angular Dependency

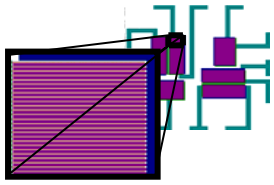


Nonlinearity FOV = 120º





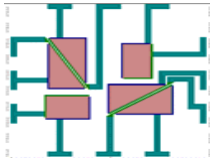


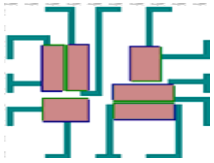


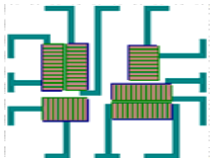
Chip	Sensitivity	Linearity	Accuracy	Accuracy
	u/º	% FS	º (1σ)	º (3σ)
1T	17.3	9.1	±2.5	±7.4
4T	14.4	7.6	±1.7	±5.1
6T	14.3	9.5	±2.0	±5.9
1R	23.1	5.1	±0.7	±2.1
4R	22.2	5.7	±0.8	±2.4
6R	22.4	5.2	±0.8	±2.3
1F	20.9	5.4	±0.9	±2.7
4F	21.3	6.6	± 0.9	±2.6
6F	22.7	5.5	±0.9	±2.7
1M	24.1	5.3	±0.8	± 2.3
4M	24.0	5.8	±1.0	±2.9
6M	22.0	6.9	±1.2	±3.6

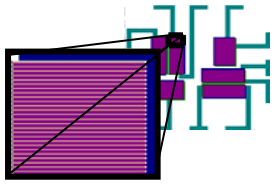
Theoretical estimation: ± 0.5º FOV = 120º

Nonlinearity FOV = 60º





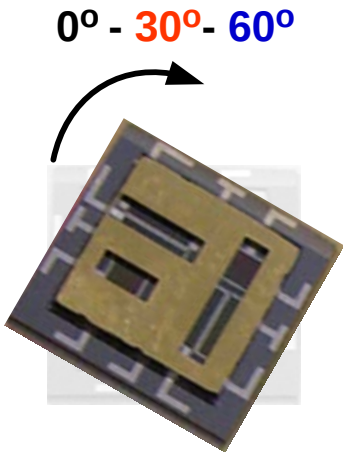


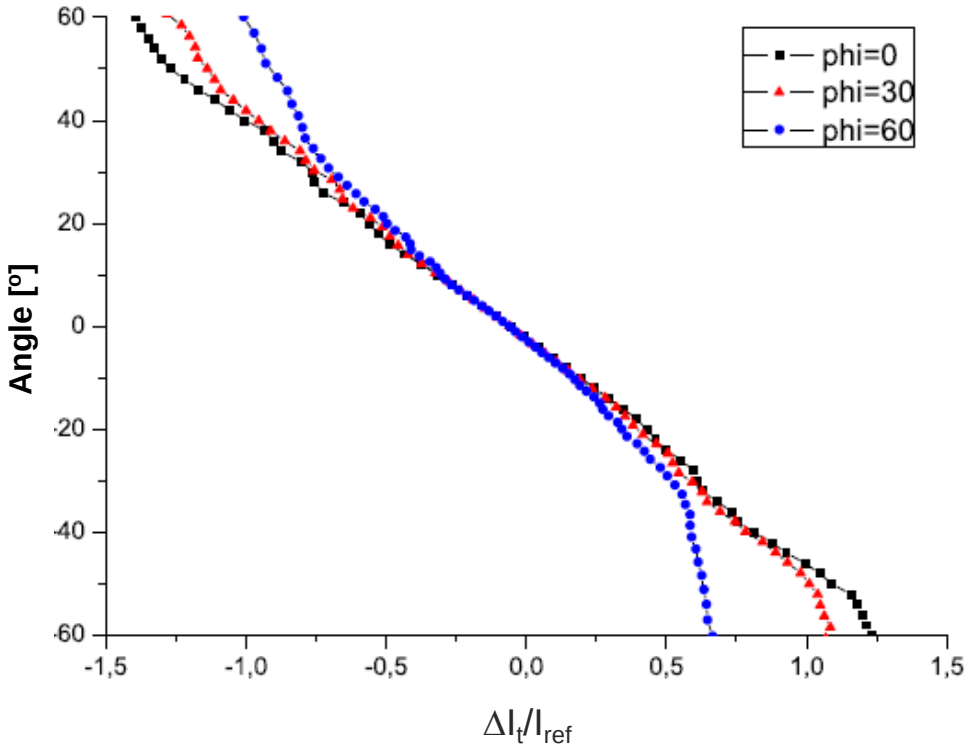


Chip	Sensitivity	Linearity	Accuracy	Accuracy
	u/º	% FS	º (1σ)	º (3σ)
1T	20.4	4.2	±1.5	±4.5
4T	17.0	2.3	±0.3	±0.9
6T	16.2	5.4	±0.9	±2.6
1R	24.4	3.7	±0.5	±1.4
4R	23.5	1.7	±0.4	±1.1
6R	23.9	2.1	±0.3	±0.8
1F	22.2	4.4	± 0.5	±1.5
4F	23.1	3.1	±0.4	±1.1
6F	24.0	1.5	±0.2	±0.6
1M	28.0	1.3	±0.2	±0.5
4M	25.4	1.0	±0.3	±0.8
6M	25.3	2.4	±0.4	±1.1

Theoretical estimation ± 0.002º FOV = 60º

Cross-Axis Sensitivity

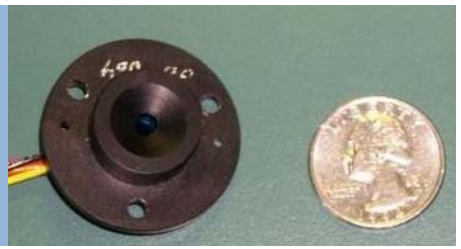


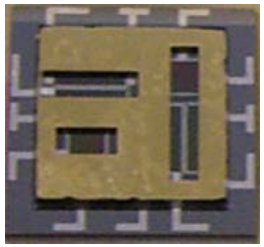


~ 5º accuracy for FOV = 60º

Comparison
State-of-the-Art

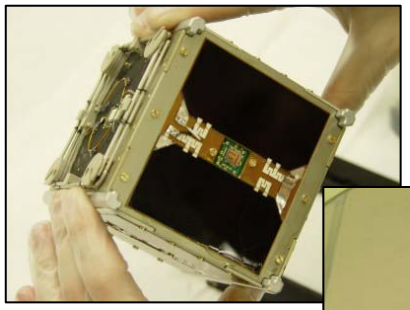
	NASA APS	Quad Sun Sensor	2nd Generation
Type	Digital	Analog	Analog
Angular Accuracy	0.017°	1°	5° (1° possible)
FOV	60	60	60
QE	42 % @ 550 nm	N/A	75 % @ 550 nm
Size	4.2 cm^3	23.2 cm^3	~3.4 cm^3
Mass	9 g	36 g	3 g
Manufacturer	JPL	AeroAstro	MIC/DANCHIP





Flight History and Future

- DTUsat1 - Launched June 2003
- SSETI-Express - Launched October 2005
- COMPASS-1 – Scheduled for launch January 2008
- SwissCube – Launch planned mid-2008
- DTUsat2 – Launch planned: end-2008



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Status & Outlook

Achievements

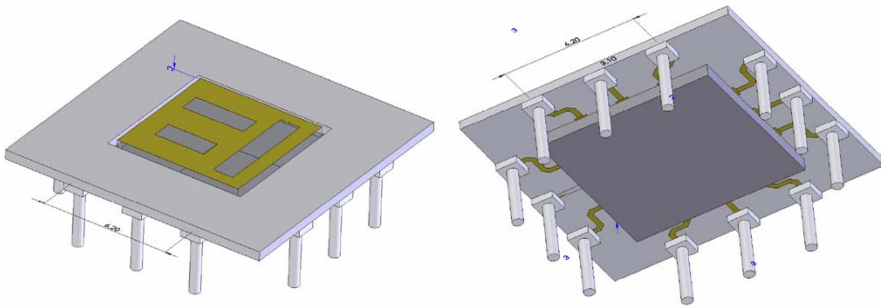
- Significantly higher performance obtained
  - QE ~50-95 %
- High UV sensitivity
  - Shallow pn-junctions
  - Integrated optical filter
- Larger signal-to-noise ratio
- Ceramic packaging

Challenges

- Issues with cross-axis sensitivity
  - Internal reflection
- Non linear fitting
- System integration

Prospects

- Total system
  - Accuracy: < 1^{o}
  - Mass: 3 g
  - Power: 5 mW



Acknowledgements

- Thor Ansbæk
- Ruichao Xu
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- Jack Larsen
- René Fléron
- Martin Pedersen
- Lars Alminde
- Anja Boisen
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- Zachary Davis