ESA 7th Round Table on MNT

Aspects of Micropackaging and System Integration of MEMS Devices

Advanced Technology Centre – Bristol, UK

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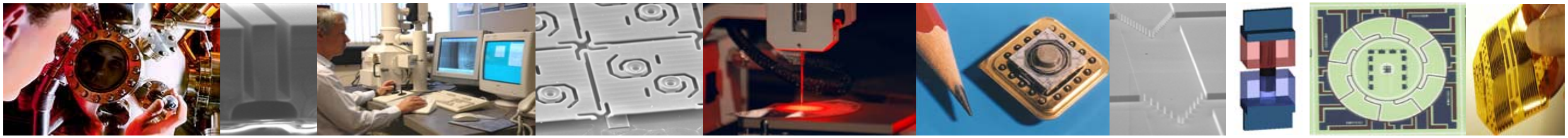
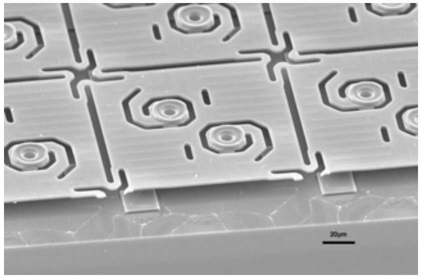


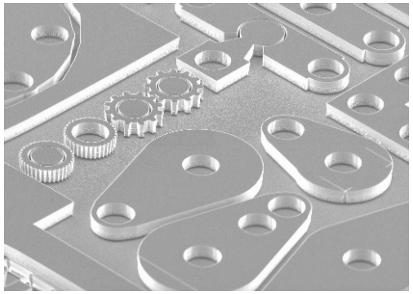
Summary

- MEMS for SPACE
  - A low volume specialised requirement for
    - MEMS Sensors, Actuators, Structures
  - Novel Packaging solutions required for optimum system performance
- Issues associated with niche MEMS products

  e.g. in Aerospace and Defence industries
    - Where to get qualified devices made
    - Novel Packaging
- Manufacturing routes

  – MEMS fab and packaging for Space Environment
- Examples
  - Development of Space Gyro
  - RF MEMS
  - Aerodynamic Flow control
  - Digital Sun Tracker
- Conclusion
  - A flexible design, proof of principle and niche volume manufacture of MEMS devices for Space Applications is possible.





Development of MEMS Gyro for Space

BAE SYSTEMS

BAE Systems involved with development Si MEMS gyros since mid 1990's

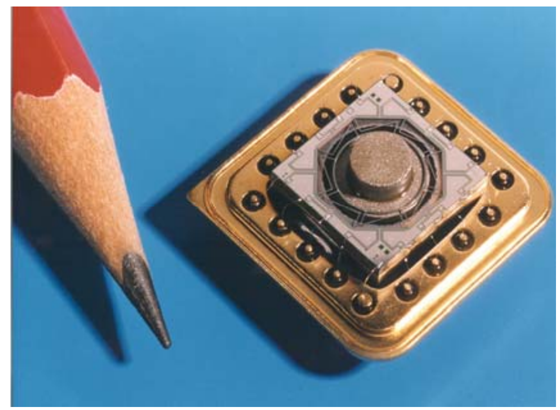
Inertial Sensor Business - originally a BAE Systems Company activity, now Atlantic Inertial Systems a Goodrich Company

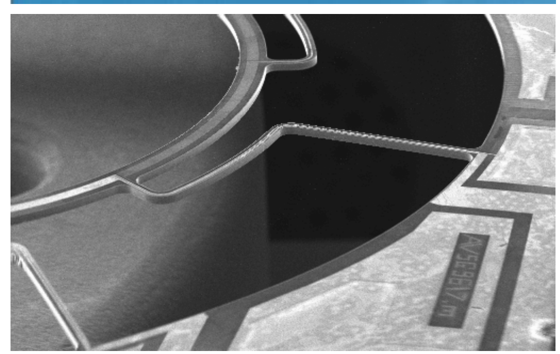
AIS Atlantic Inertial Systems

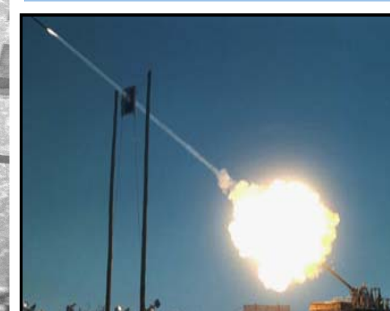
First to market with a high volume commercial Si MEMS gyro

-Targeted at automotive applications with
-~2 deg/sec bias drift
-Supplied >17 million units into automotive
 and commercial markets

Military
100 deg/hr & gun hard – integrated into IMU – three gyros & three accelerometers
Very good performance over temp, shock, vibration







Development of MEMS Gyro for Space Requirements

MRS Key Target Parameters

Target specifications	
Configuration	- 3-axis/rate mode - <4W/600g unit
Bias stability (3σ) over 24 hours, $\Delta T < \pm 10^{\circ}C$	< 5 deg/h
Angular Random Walk	< 0.2 deg/√h
Range	Up to 20 deg/s
Output Rate	1-10 Hz
Command/Monitor I/F	RS422 async channels (SpaceWire)
Rate Outputs	RS422 async channels Analogue Channels

MEMS is enabling technology for required low mass, power, cost.

Positions MEMS gyro for:
- initial acquisitions
- anomaly detection
- anomaly recovery
- safe mode

applications.

Modest rate range and output bandwidth compared to normal MEMS applications.

Simple User Interfaces

SELEX Sensors and Airborne Systems · AIS Atlantic Inertial Systems · esa · S·E·A

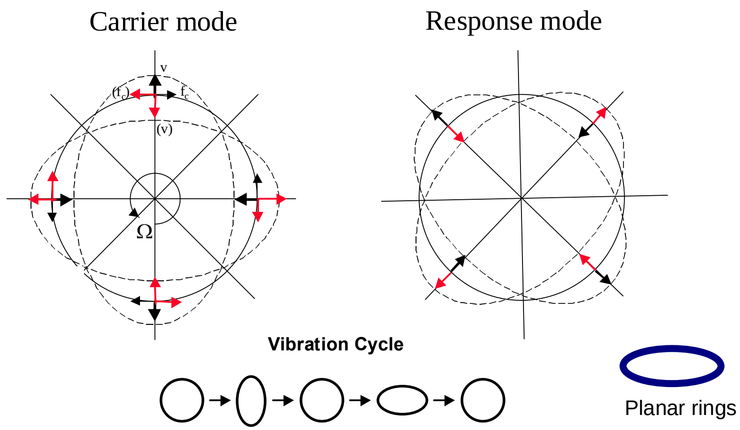
BAE SYSTEMS

Development of MEMS Gyro for Space

- •Use DRIE Si Resonant vibrating ring structure (as previous commercial and military products.
- •Small gaps, high aspect ratio
- •Small AC signals – need low parasitic capacitance
  - Glass substrate
    - (anodically bonded Glass-Si-Glass)

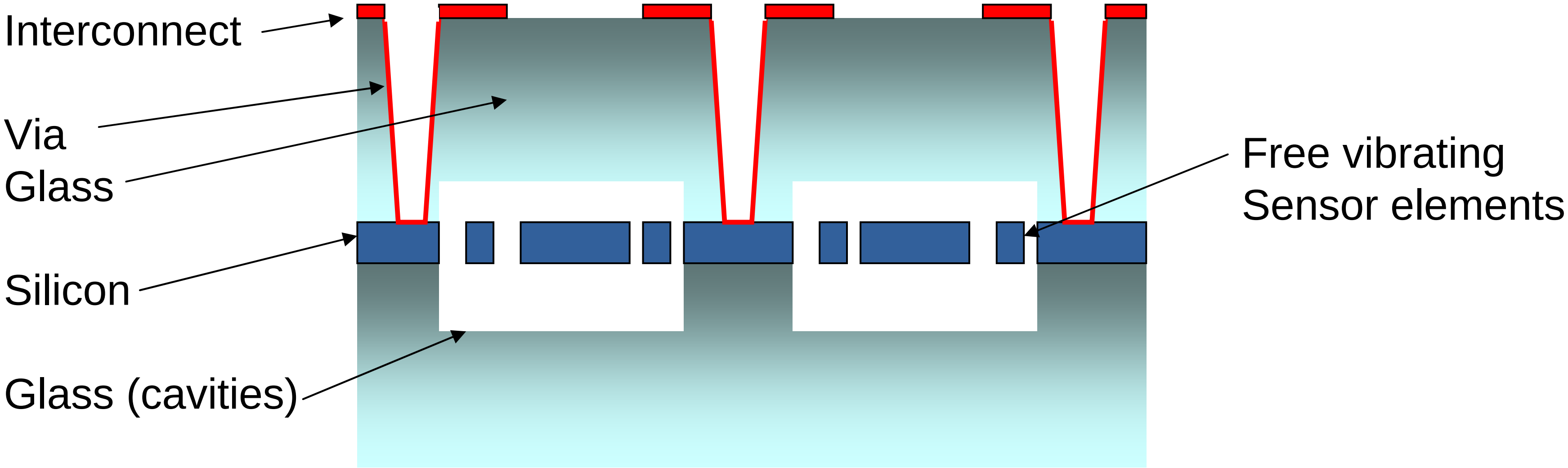
- •Interconnect to asic and local JFET OpAmps
  - Through glass vias (analogue of TSV)
    - Powder blasted
    - Metalised
- •In situ Vacuum and wafer scale packaging
- •Rad Hard Electronics

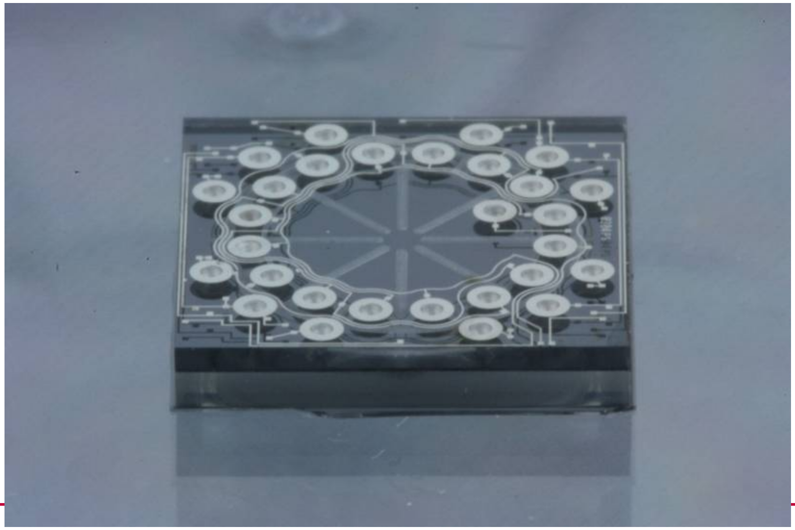
Vibrating Structure Gyro Principles

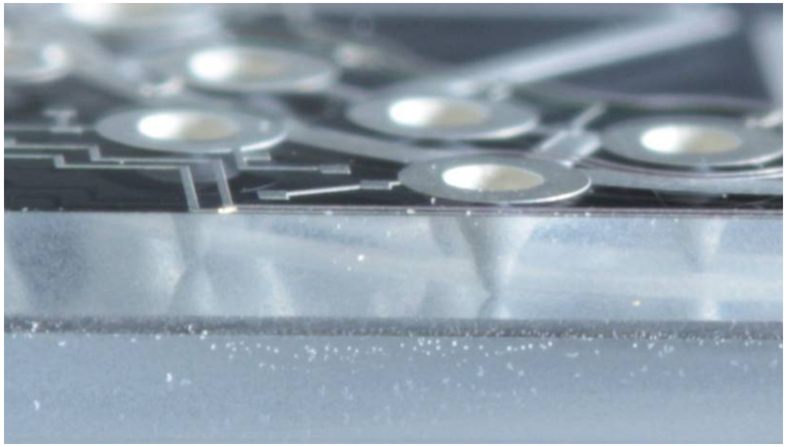


Development of MEMS Gyro for Space
Silicon on glass with through glass vias

BAE SYSTEMS

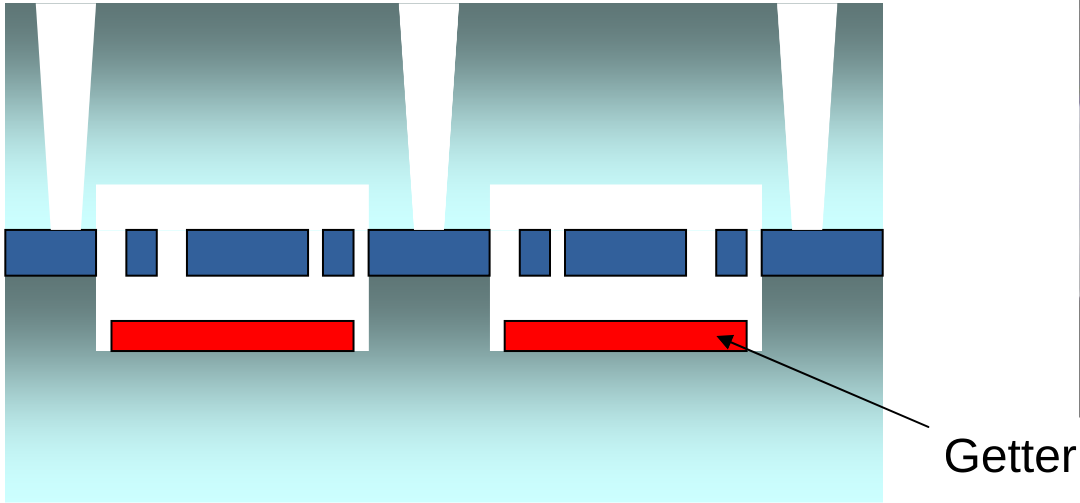


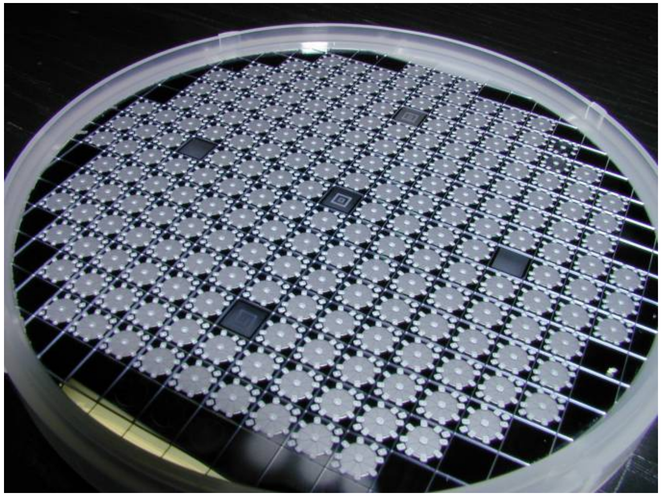




Development of MEMS Gyro for Space Wafer level Vacuum Packaging

BAE SYSTEMS





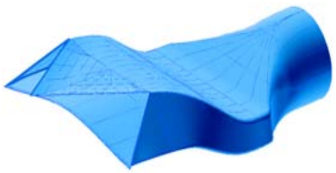
Thin film getter, PVD into glass cavities

Ensures long vacuum life even when SA/Vol ratio non ideal

Wafer bonding – can be anodic or glass frit

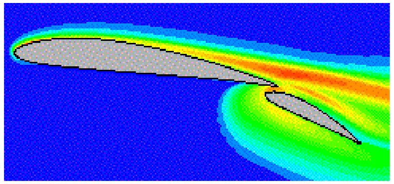
The MEMS Si Gyro now commercially available as SiREUS, a compact low power, low mass, 3 axis orthogonal Coarse Rate Sensor system

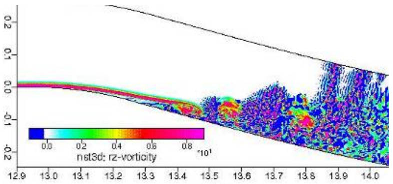
Opportunities for MEMS-based Flow Separation Control

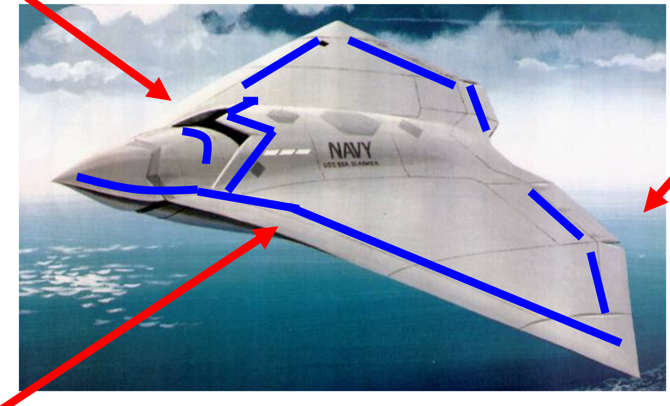


Propulsion and LO Propulsion Integration
- **Inlet distortion**
- **Pressure recovery**
- **Flow unsteadiness**
- **External / internal lip separation**
- Compressor stall/surge

The Benefits
- Improved Performance
- Improved LO
- Reduced System Complexity/weight
- Increased Design Freedom







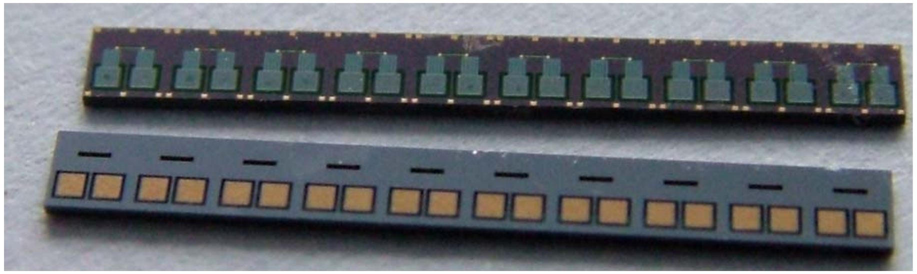
Trailing Edge Control
- **High lift**
- **Manoeuvre**

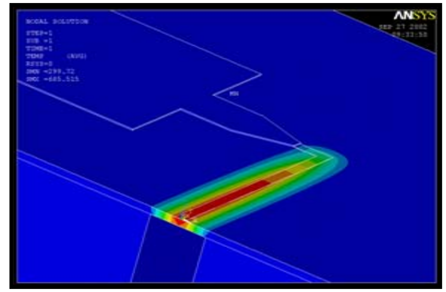
Low level periodic forcing modulates vortex rollup

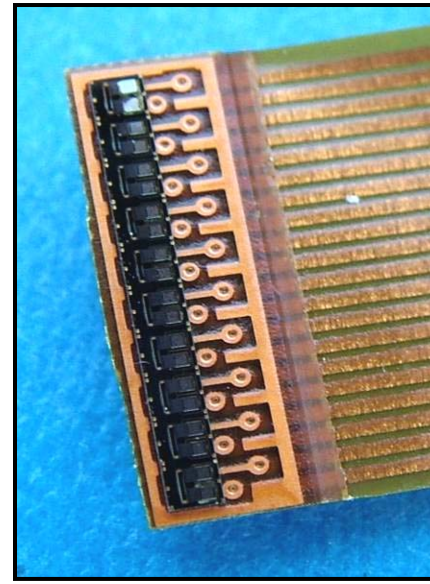
Leading Edge Control
- Boundary layer and vortex control
- **High lift**
- **LO manoeuvre/stability**
- Buffet

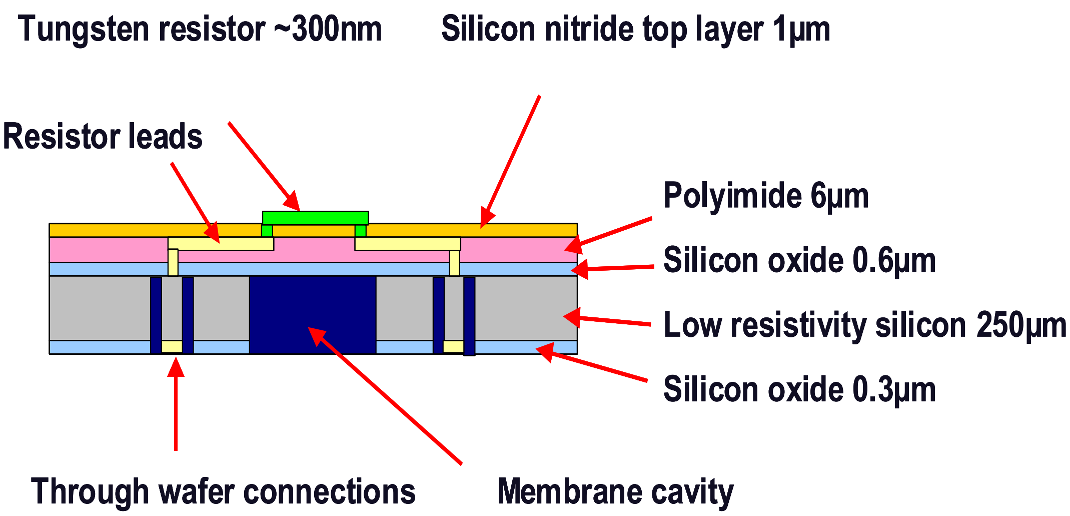
Technology Demonstrated
With non MEMS flight control In FLAVIIR project

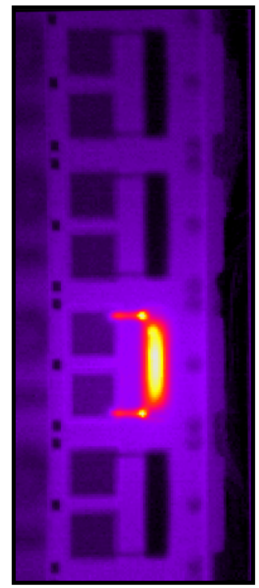
MEMS Flow Sensors

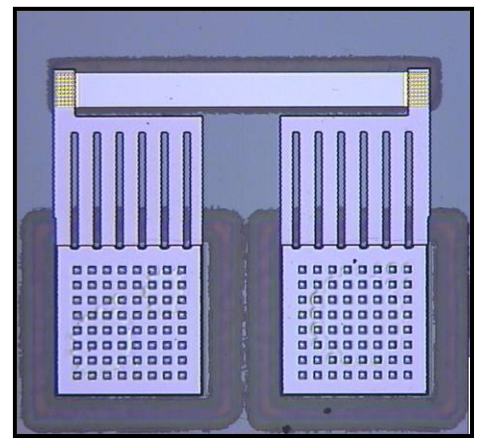








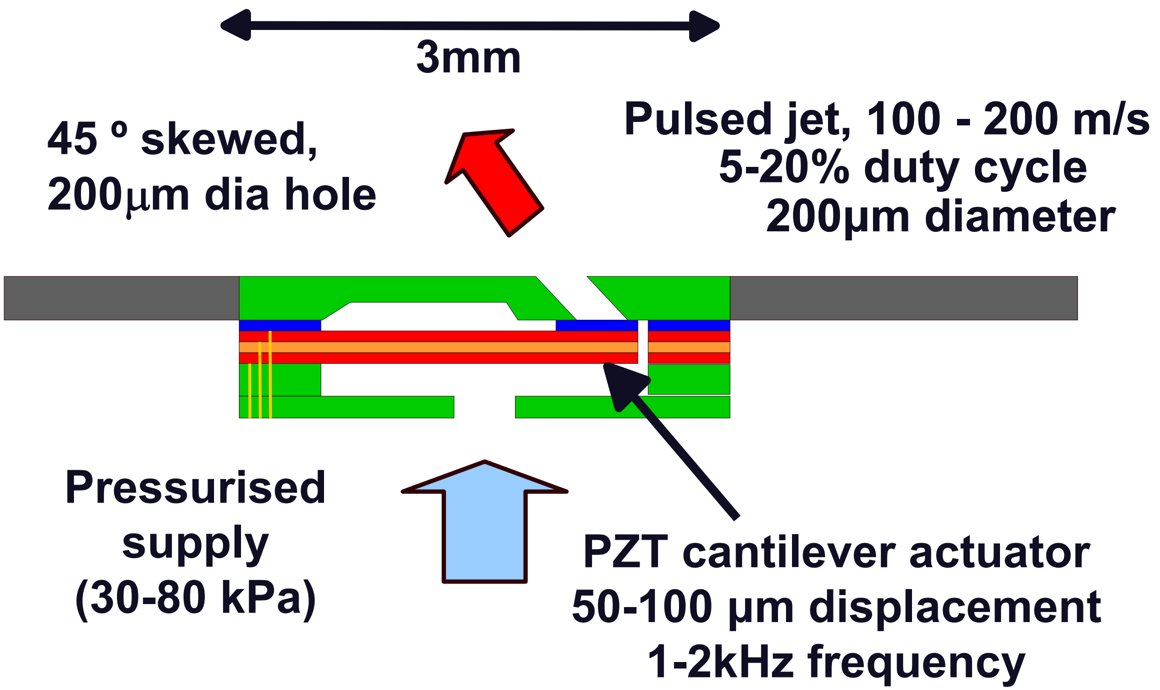


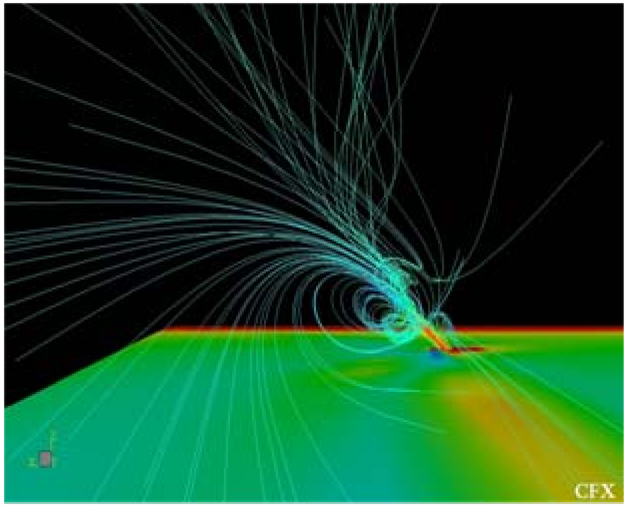


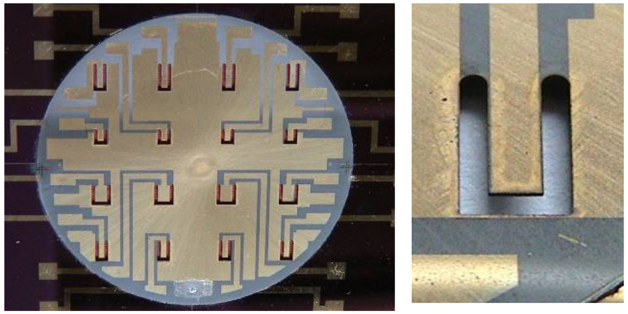
Designed for robustness, sensitivity, good frequency response

10 x sensitivity of conventional stick-on hot film, 30 kHz cut-off

MEMS Pulse-Jet Flow Actuator



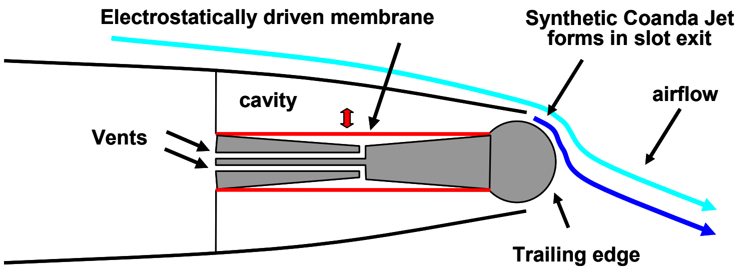


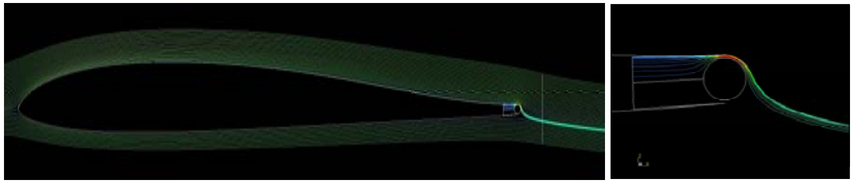


Robust, high authority (force & displacement), small footprint and thickness.

Bulk PZT properties Bonded & structured at wafer level

MEMS Coanda jet actuation for MAV
Full aero authority without moving parts





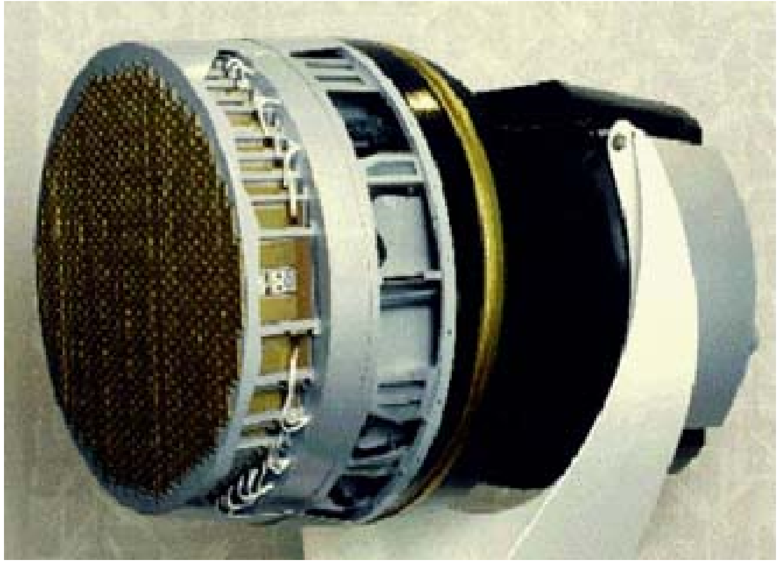
Precision silicon trailing edge box structures

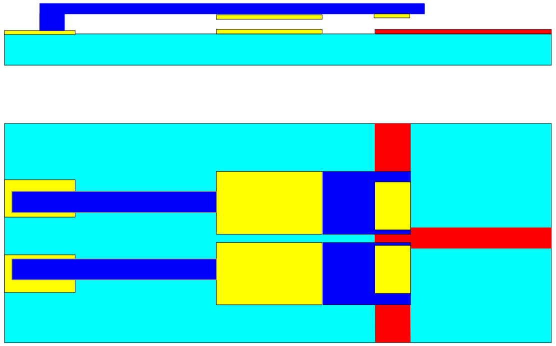
150mm MAV

RF MEMS: MEMS components for RF circuits

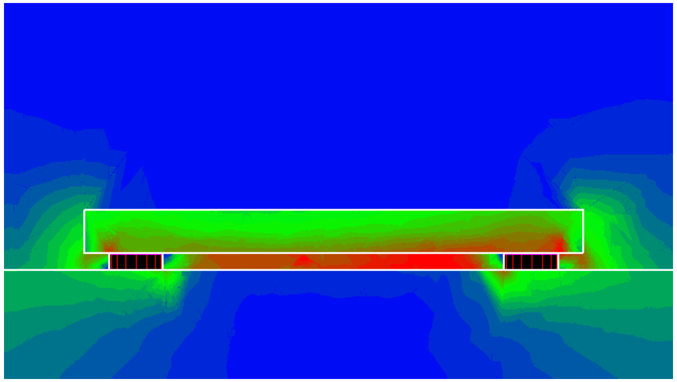
Advantages:
- size
- insertion loss
- Q factor
- cost
- linearity

Applications
- RADAR
- Electronic warfare





MEMS switch design



RF simulation

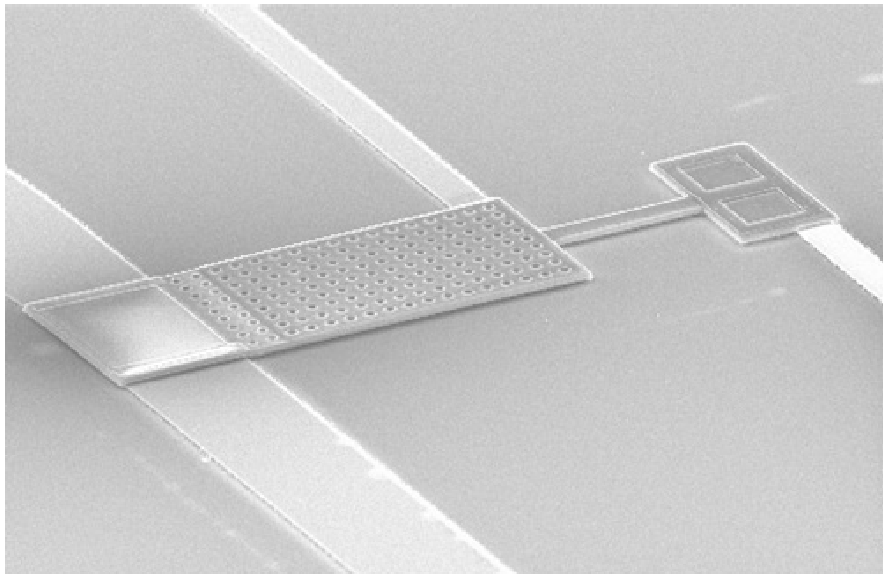
RF MEMS switches

Early cantilever design

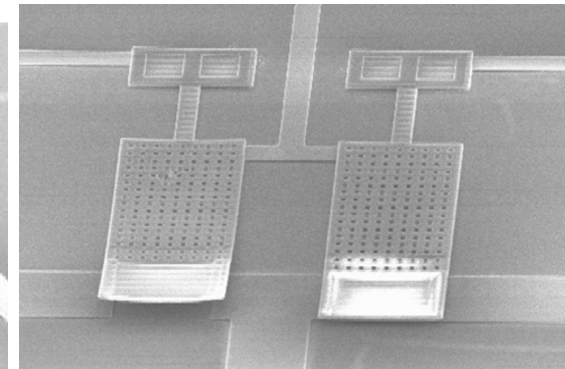
Control line

RF in

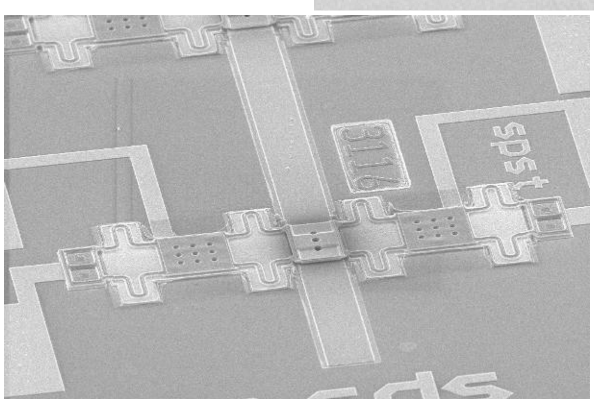
Contact
up-down
travel 3um



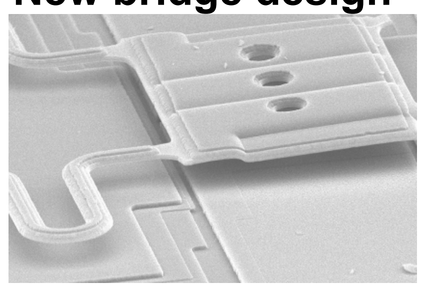
RF out



OFF ON



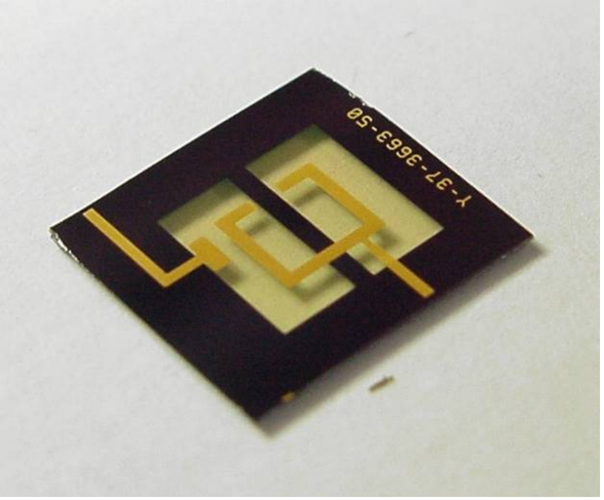
New bridge design



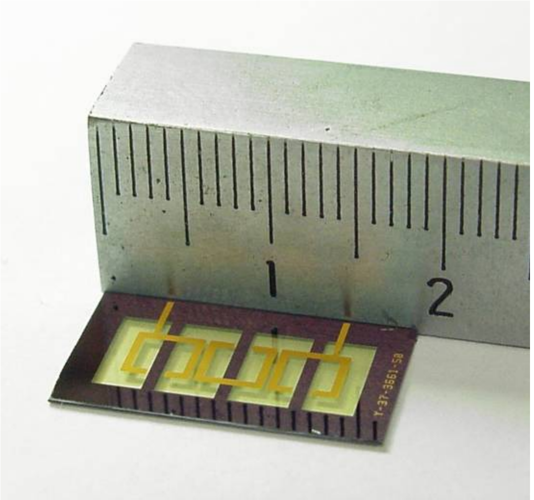
Fabricated filters

BAE SYSTEMS

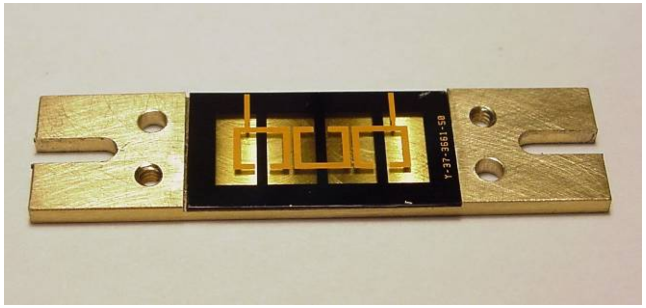
Gold tracks on nitride membranes on silicon frames (stackable) – give high Q (~3-400)



Input resonator



complete 3 section filter



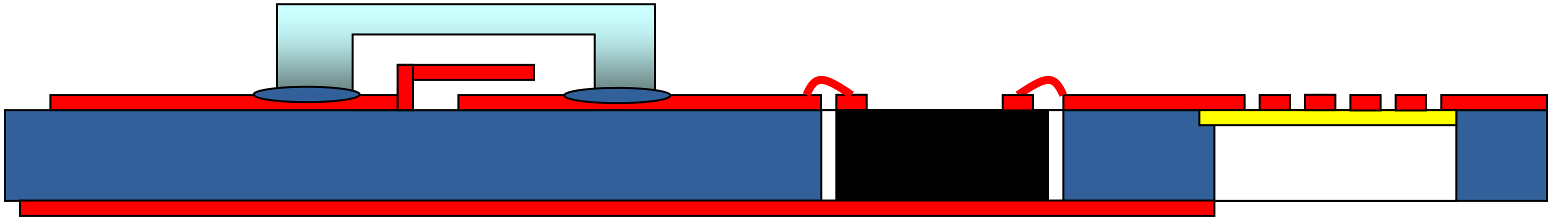
packaged filter

RF MEMS Technology

Switches	Vac Packaged – high Q interface to phase delays
Phase Delays (microstrip)	Fairly large structures

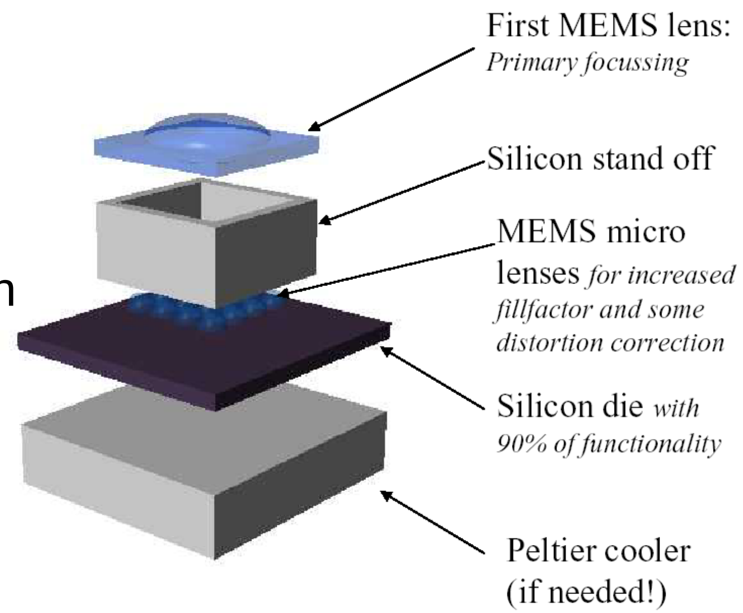
GaAs Chips e.g Amplifiers interface (co-planar) to microstrip over Si

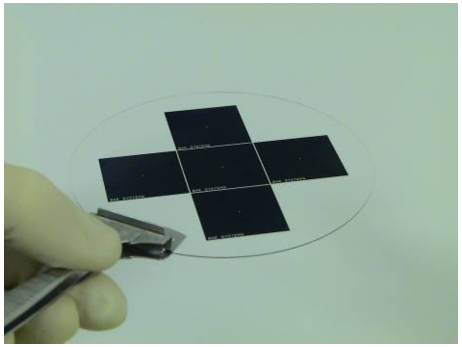
High Q Filters	Membranes “conductors in vacuum” dielectric



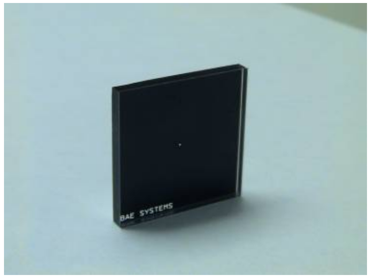
ESA Sun Sensor on a chip project

Concept
Create a low cost standard Sun Tracker product applicable to a wide range of Satellite (and Rover?) uses.
Use APS Imaging Chips and wafer scale integration & packaging techniques





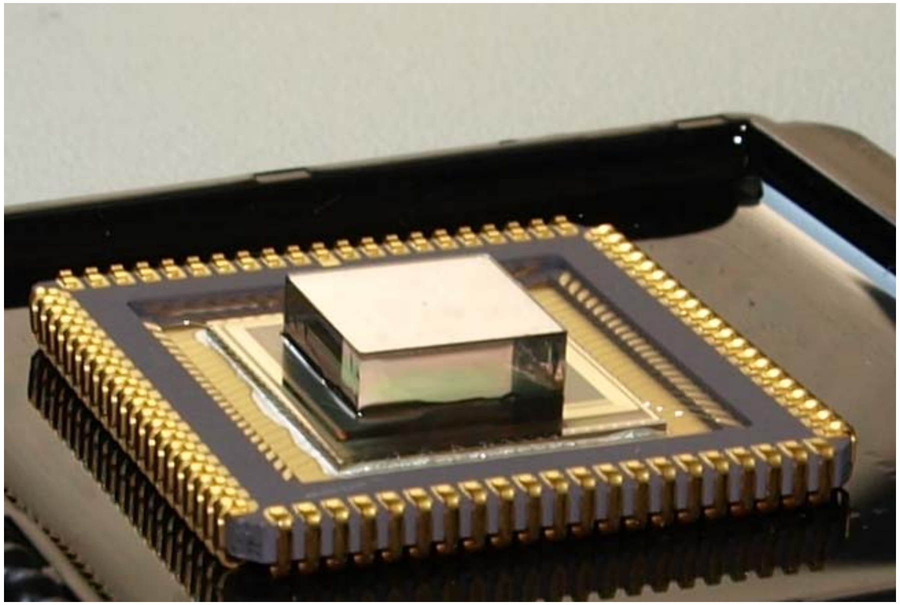
MEMS pinhole sandwich chips to be Integrated directly with sensor chip



ESA Digital Sunsensor
-Sun Sensor on Chip (SSoC)

BAE SYSTEMS

Initial breadboard integrated device
-die level packaging not wafer level



Pinhole and chip bonded

SELEX GALILEO
A Finmeccanica Company

Prime contractor overall instrument design

CMOSIS image sensors

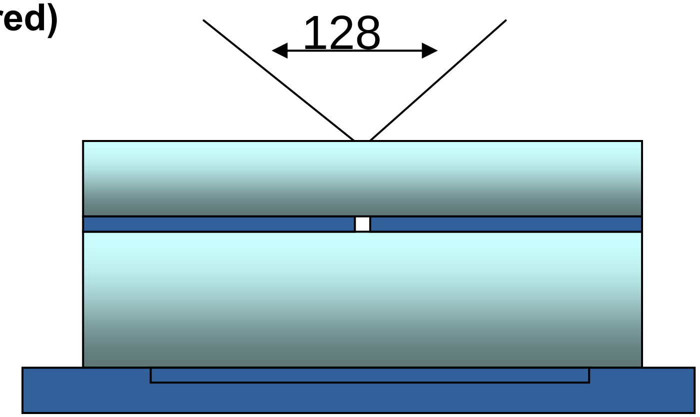
Design & Supply of APS Imaging Chip

BAE SYSTEMS
Advanced Technology Centre

Design fabrication of Optical Chip
and Wafer Level Packaging

Digital Sun Sensor Specification

• FoV	± 64 deg
• APS sensor complexity	512 x 512 (but 6 lines each edge unused)
• Storage temp range	-60 to +120C (-65 desired)
• Required temperature range	-55 to +95C
• Radiation hardness	18yr GEO 1Mrad
	5 yr LEO 25krad
• AR coat/Sun Attenuation layer on top glass	



To meet these requirements

- Chip

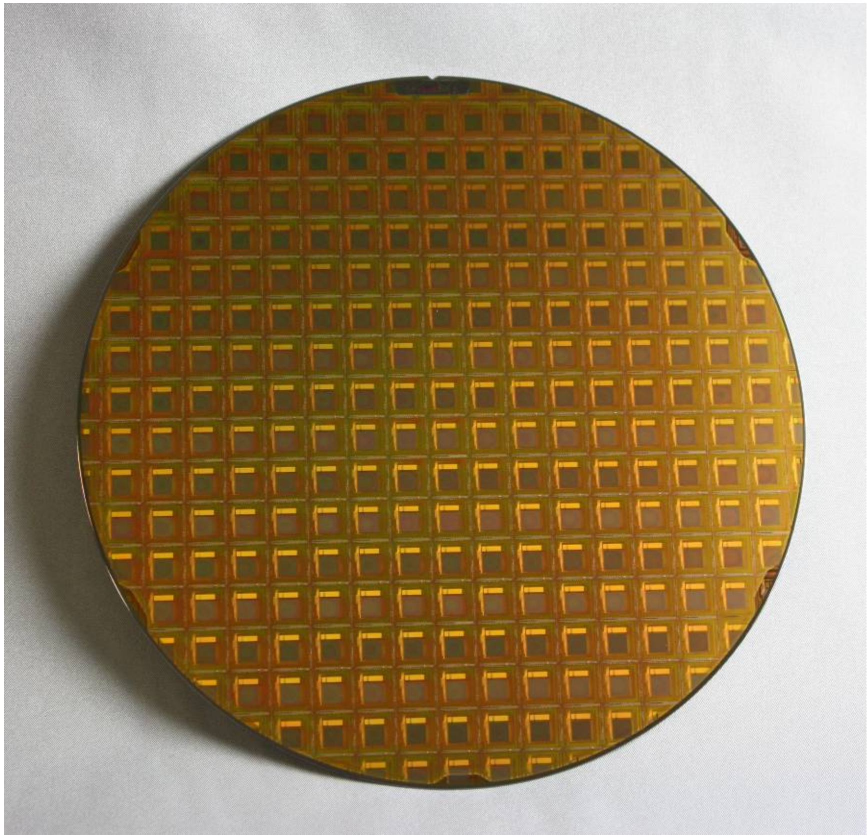
• APS Pixel pitch	10 µm
• Chip	11 x 11.4mm (sensor 5.12x 5.12mm)
• Sun size on array	18 pixel dia

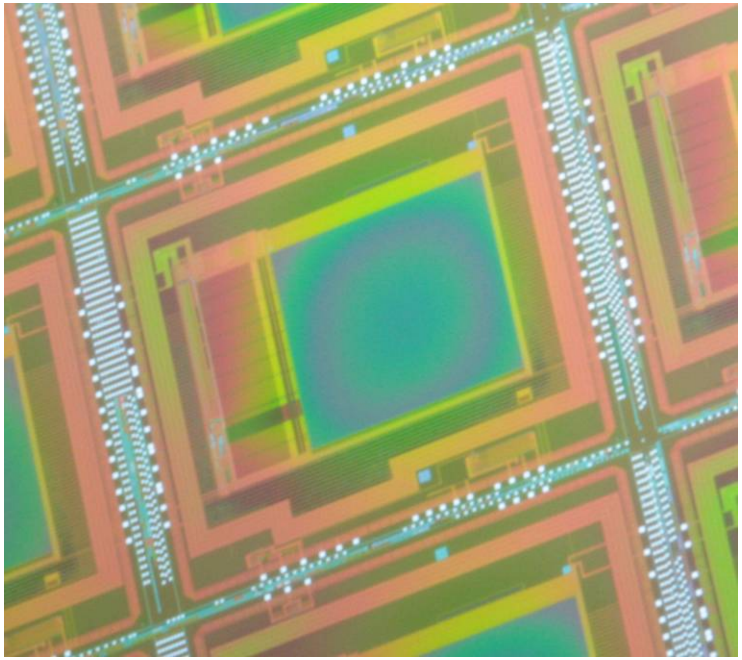
- Optics

• Glass Structure	2.5mm glass/Pinhole layer/3.2 mm glass
	planarity < 10 arc secs or 0.25 microns over a chip
• Pinhole to APS pixel alignment	5um
• Pinhole layer reflectivity	<5% internally
• Rad hard	tested to 300KRAD TID
• Optically matched	no air interface at CMOS Glass or Glass/Glass interface

- Packaging/Fabrication
  - Wafer level fabrication
  - Hermetic sealed

Digital Sun Sensor
Active Pixel Sensor Development



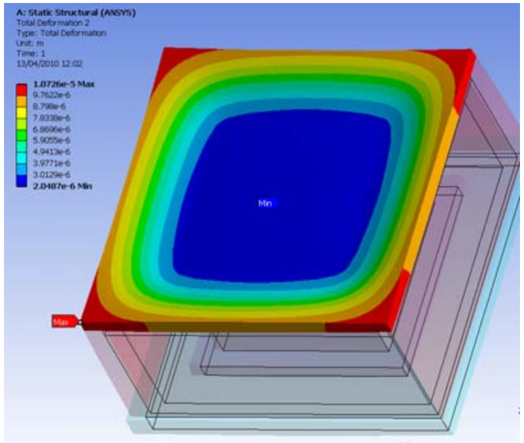


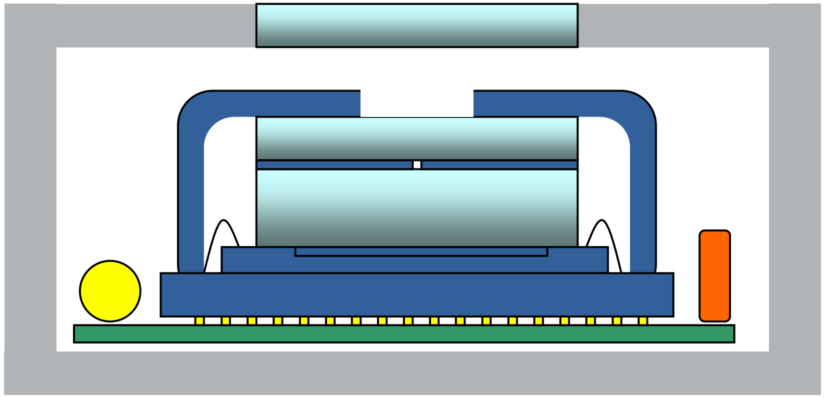
8" CMOS Wafer & magnified view of Active Pixel Sensor die

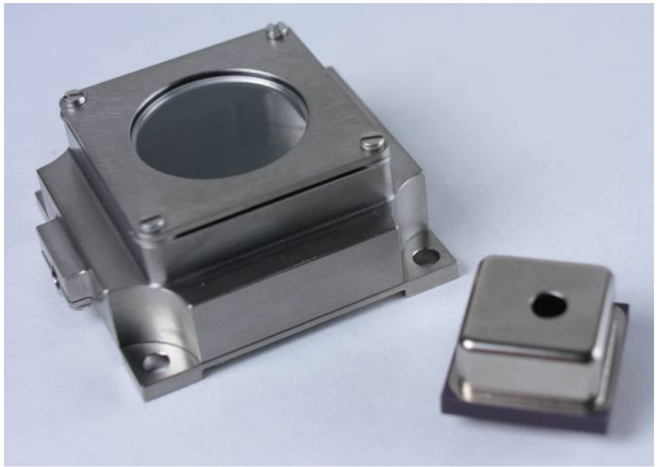
Digital Sun Sensor
System Level Packaging

BAE SYSTEMS

- Overall packaging
  - Packaged chip mounted on pcb, fitted in non-hermetic metal enclosure
- Overall Package
  - 42.0 x 45.0 x 19.8 mm
- Overall Mass
  - 65g (expected)
- I/O
  - SpaceWire/RS422







Conclusions

Illustrated Fabrication and Packaging issues for a range of MEMS devices useful to space applications

Despite low volume niche MEMS requirements of space

Often complex /non standard fabrication and packaging techniques required

It is possible to produce and package and qualify MEMS devices for space applications