# Development of MEMS SOI microinertial components for small autonomous vehicles - accelerometers, gyroscopes and magnetometers

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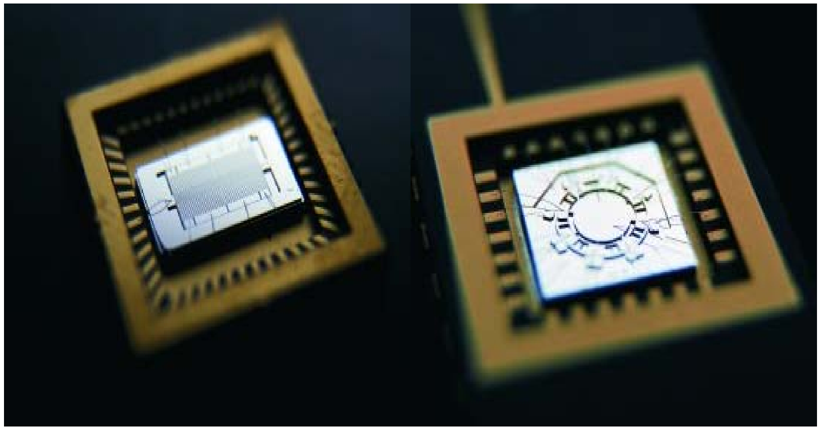
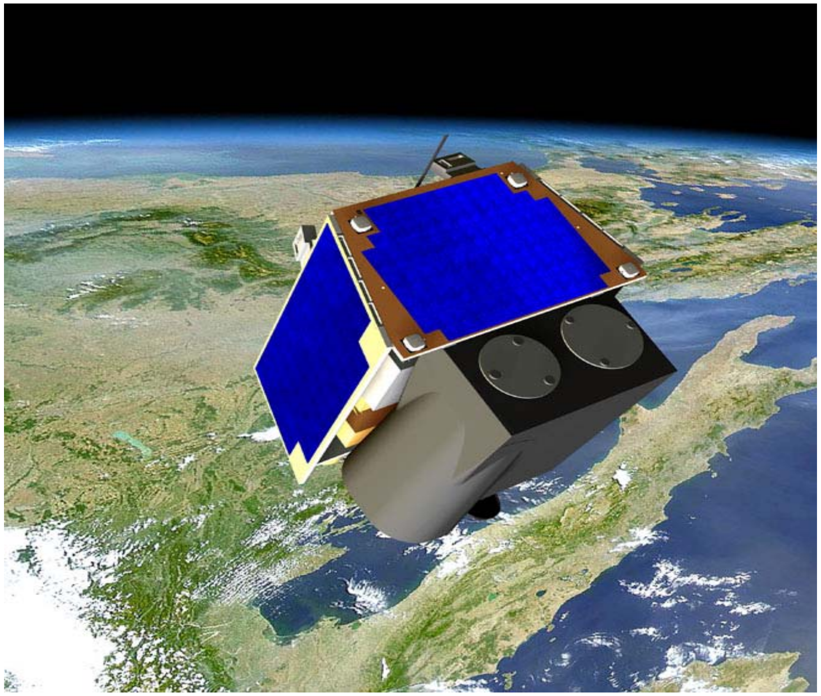
Micro Nano Technology Business Group
Optronics

**10th October 2007**





QinetiQ

www.QinetiQ.com

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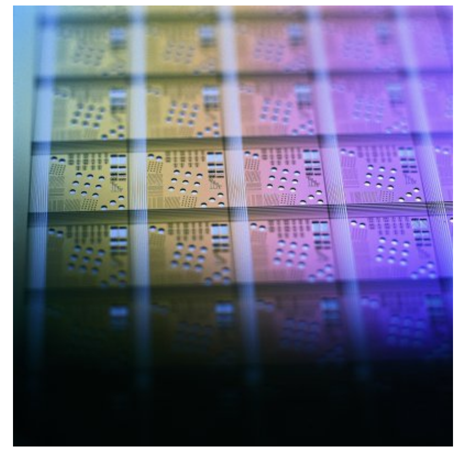


# About QinetiQ

QinetiQ is a leading international Defence and security technology company

Founded in 2001, from the UK's national Defence laboratories, the company has **6 decades of experience** in delivering cutting-edge technology


>11000 staff
>$2B turnover

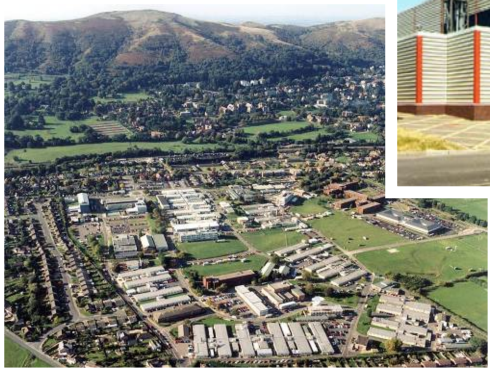

QinetiQ Inc

APOGEN TECHNOLOGIES

PSI Planning Systems Inc.

Foster-Miller

WESTAR



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# QinetiQ MEMS Introduction

## Provider of custom military & commercial MEMS solutions

- Experienced, integrated team of about 30 staff
  - Supported by leading design & prototyping facilities
  - Broad applications base & stable processes
    - Smart sensors, inertial, optical & IR, RF &  bio-MEMS
- Access to pan-QinetiQ specialist teams

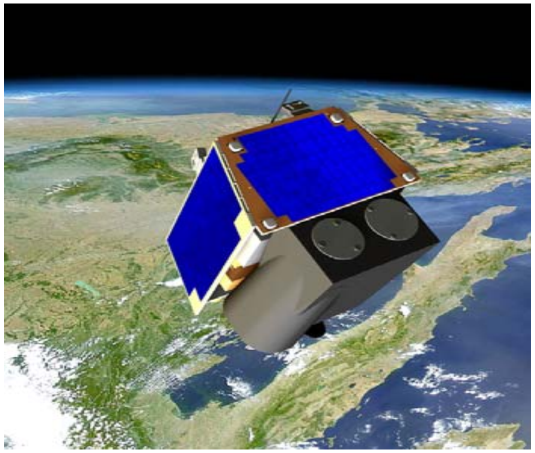
## Key Capabilities

- MEMS design and modelling
- Electronic design (PCB / MCM / ASIC)
- Microsystems with embedded processing
- Microstructure fabrication (ISO9001)
  - Legacy CMOS line in class 10/100 clean room
  - MEMS-specific tooling including:
    - DRIE, XeF2 etch, PECVD silicon, oxide & nitride
    - Double-sided mask alignment
    - Critical point dryer
    - Wafer level packaging
  - Advanced metal CVD
- Advanced characterisation and test

# Vision

Navigation grade components for small autonomous vehicles

- Ultra compact IMU with 6 degrees of freedom inertial
  - Optional 3 axis magnetometer/gradiometer
- Small volume
  - Target $1cm^3$
- Additional virtues
  - High fidelity
  - Low mass
  - Low power
  - Robust
  - Reliable



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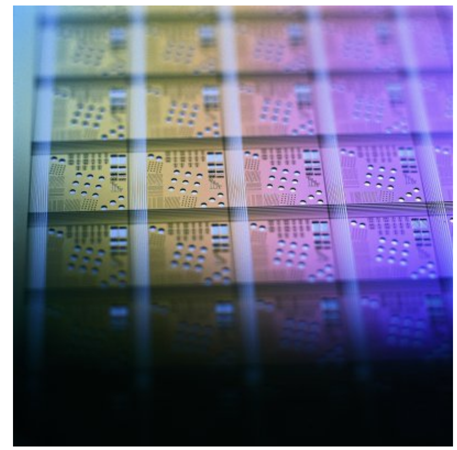
# 02
# Technology



Design access kits
(process-specific)

MEMS design and
simulation

System-level simulation
(Electronics + MEMS)

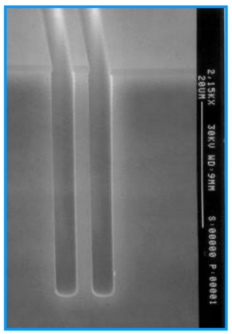
## MEMS FABRICATION

**Surface Micromachining**

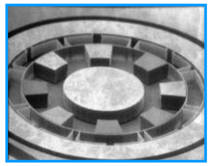
- Metal-nitride
- Polysilicon

**High Aspect Micromachining**

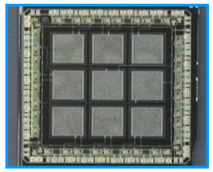
- SOI
- Si



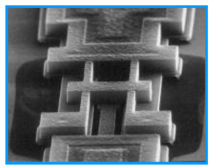
## MEMS FUNCTIONS



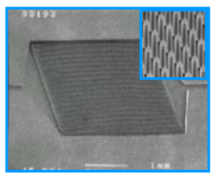
Microinertial



Environmental
(multisensors)



Comms
(RF + Optical)

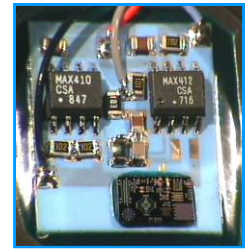


Biomedical

## ELECTRONICS

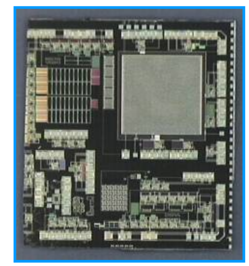
**Hybrid Integration**

- MEMS + COTS
- MEMS + ASIC



**Monolithic Integration**

- MEMS + CMOS
- MEMS + BiCMOS



MEMS Foundry

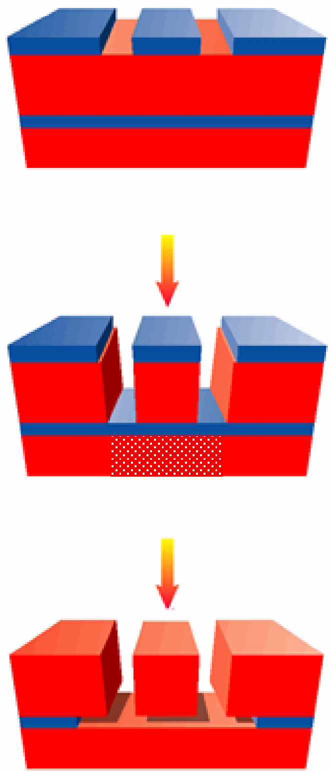
INTEGRAM*plus* Si Service
MEAD consortium

IC Foundry

# SOI High Aspect Ratio Micromachining

## DRIE-based (CMOS compatible)

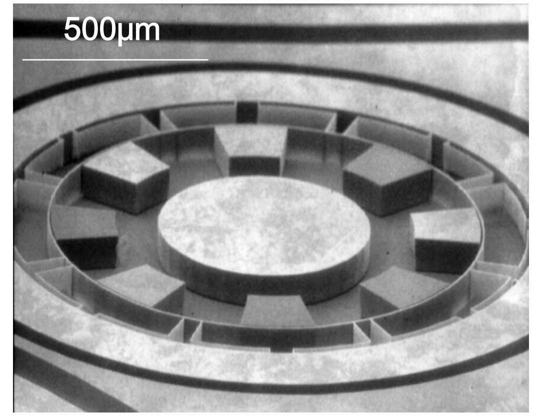
- Double-sided DRIE option



Pattern mask

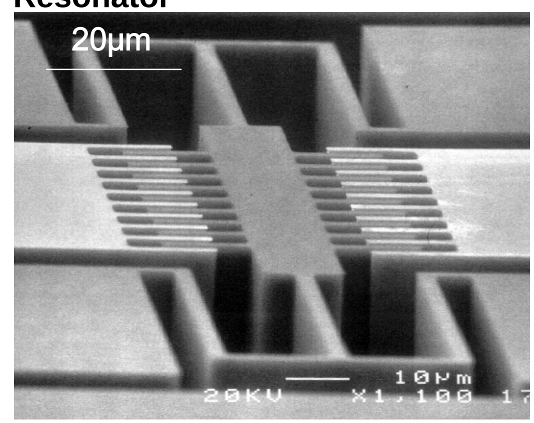
Deep dry etch
to buried layer
(optional back etch)

Remove sacrificial layer



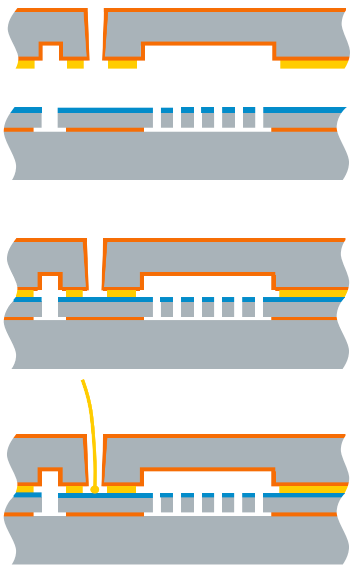

**Gyroscope**

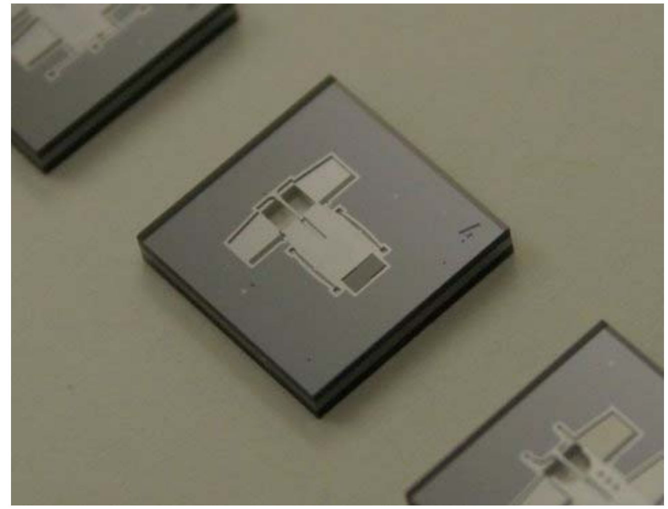
**Resonator**



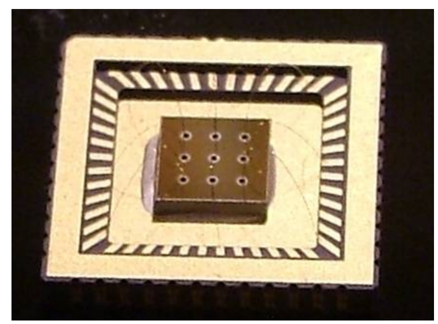
# Wafer level packaging

- Metal seal bonding techniques for full hermetic/ vacuum encapsulation
- Low temperature photosensitive polymer bonding techniques
- Anodic bonding used for 3-D assembly



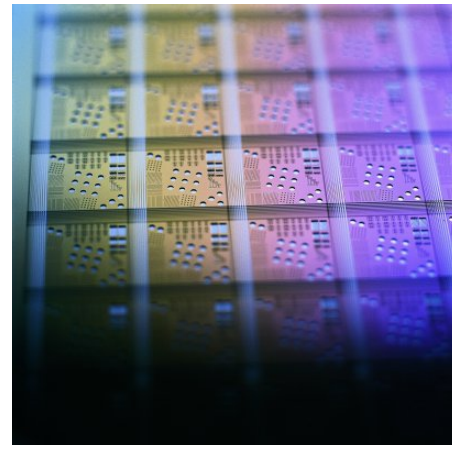



Multi wafer stack including SOI, Si and glass wafers



03

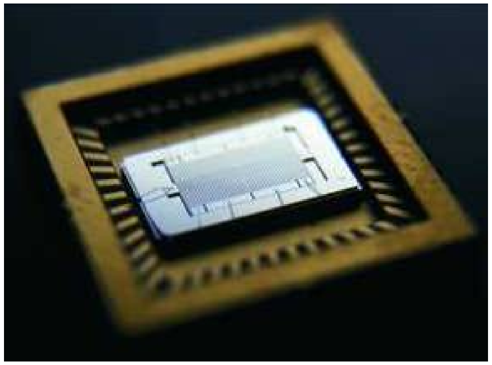
# Inertial Components

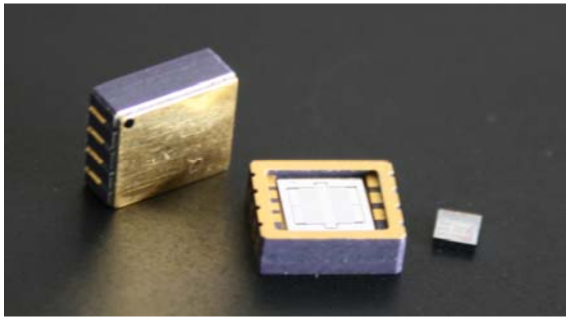


# Accelerometers

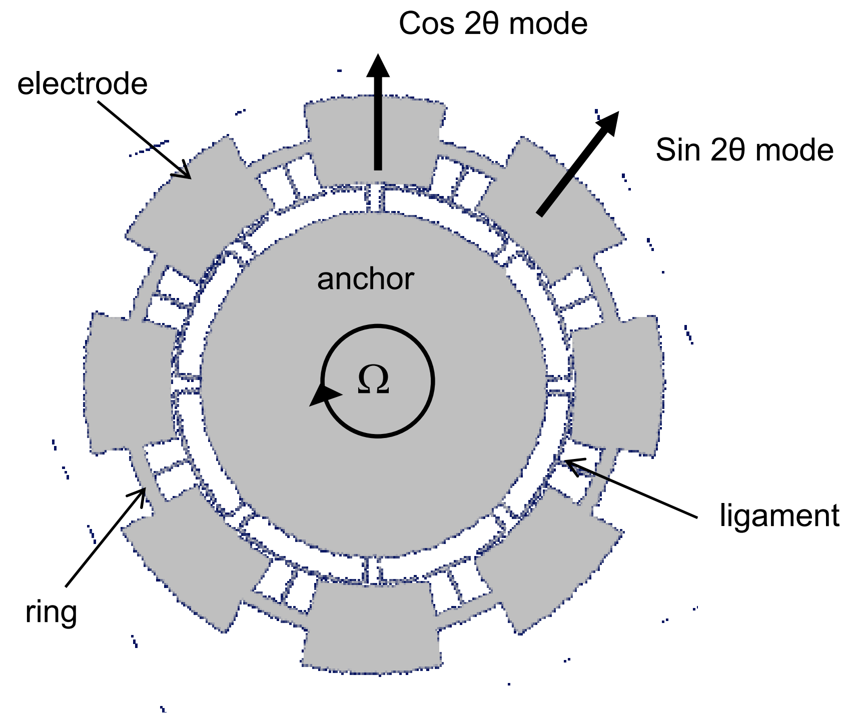
Single axis lateral device

- Capacitive pickoff
- Wide range of full scale options
  - 4'g' – 1000's 'g'
- Bias stabilities of <1mg achievable
- Ceramic package
  - One with integrated ASIC, decoupling and interconnect
- Wafer level packaging currently being assessed



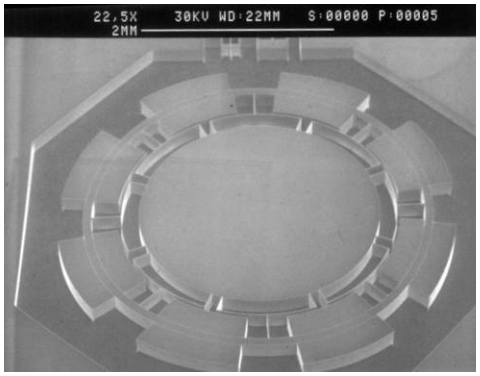


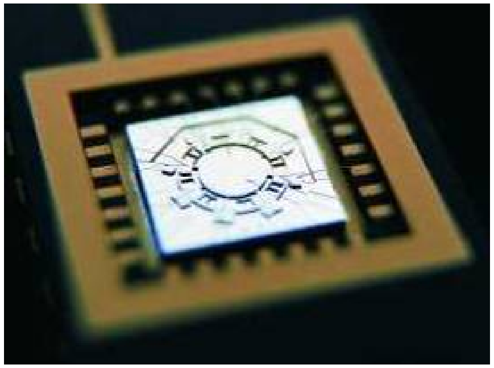
# Gyroscopes




## Ring resonator

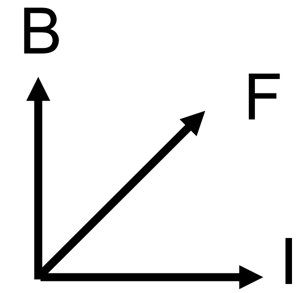
- Angular rotation couples Cos 2θ and Sin 2θ modes
- Currently open loop and uncompensated
  - 100 deg/hr performance
- High precision etch process
  - Very small mode split <few Hz
    - No need for laser trimming



- Various extra outputs allow signal processing to compensate
  - Ring frequency, primary amplitude …..
  - Target improvement to <1deg/hr

# Magnetometers



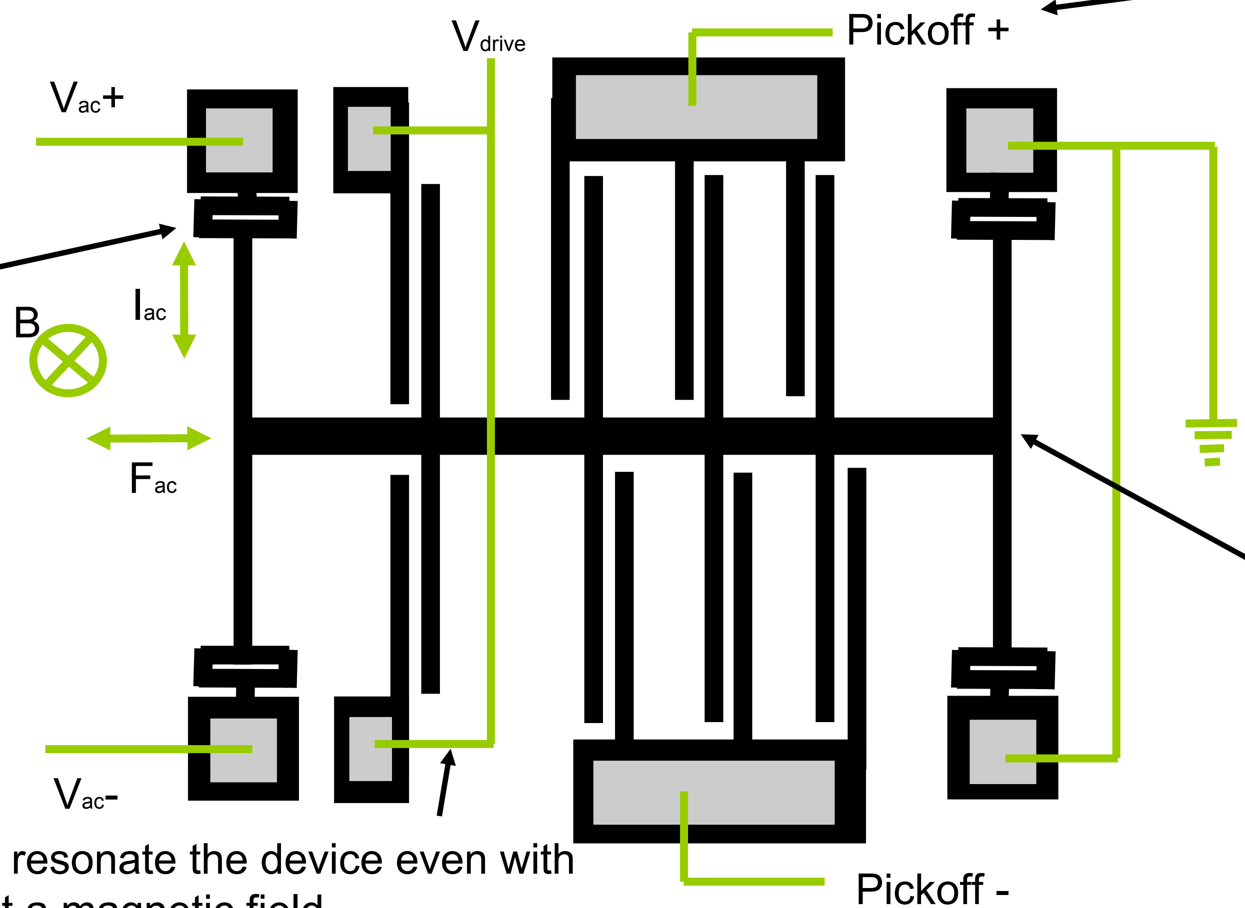

$$\vec{\mathbf{F}} = L \cdot \vec{\mathbf{I}} \times \vec{\mathbf{B}}$$

Resonant mechanical device based on Lorentz force

- Current flowing through a wire exerts a force in the presence of a magnetic field
  - Very small effect - 1mA,1000um,100nT gives 100fN force

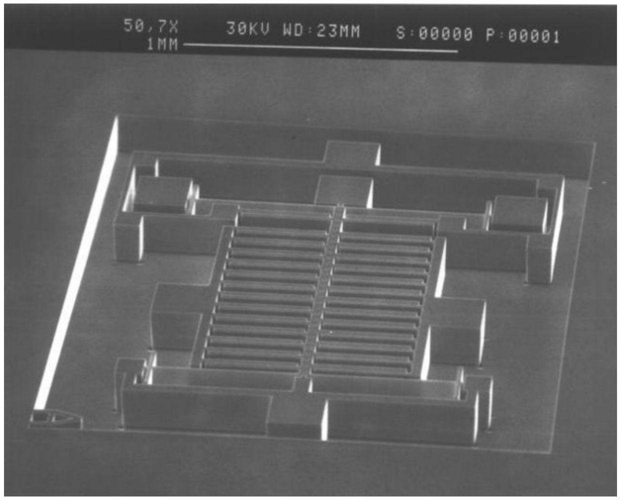
- High Q resonant system amplifies small forces to large amplitude movements at the resonant frequency
  - Pass an alternating current down the beam at the resonant frequency

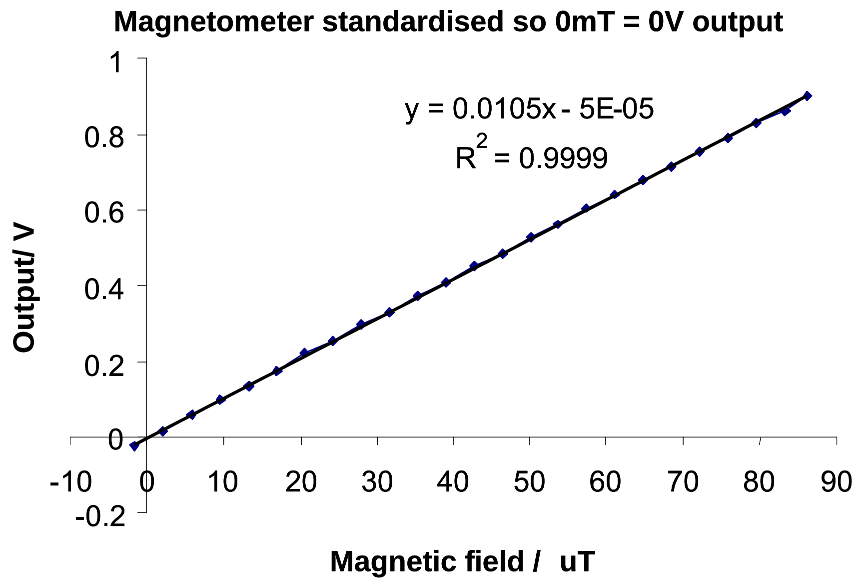
# Magnetometer



# Magnetometer

- Resonant frequency ≈5kHz
- Package pressure ≈1mbarr
- Currently 10-20nT/√Hz
  - Sufficient for 0.05 deg in earth field for 1second integration

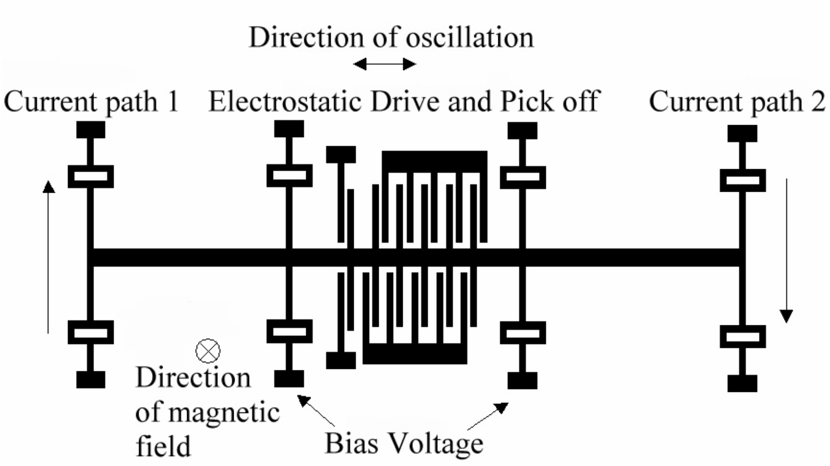


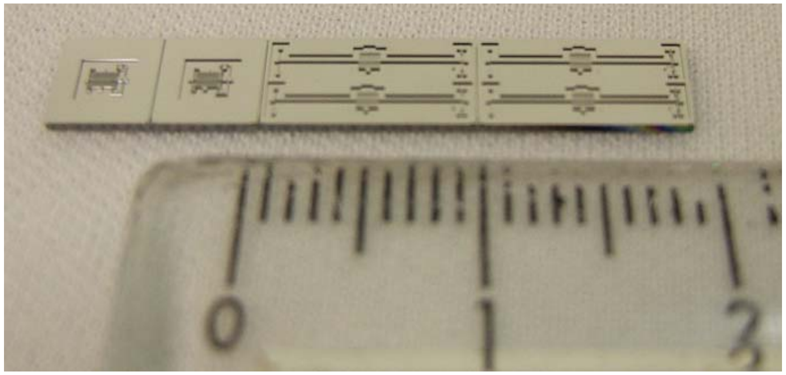



# Gradiometer

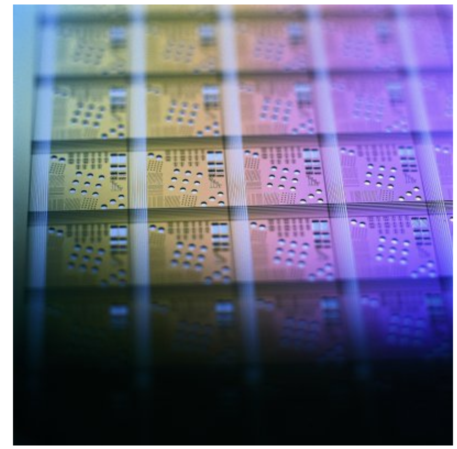
Extend the length of the magnetometer and add a second current path

- The two current paths are driven in opposite directions to give a balanced force with a uniform field
  - No output in uniform field, output when there is a gradient
- Target of 1-5nT/ √Hz
- Successful fabrication of structures in excess of 16mm baseline
  - 10mm baseline likely for practical device



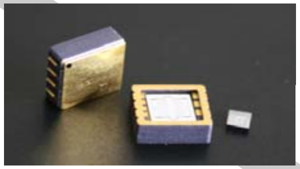
# 04
# IMU scaling

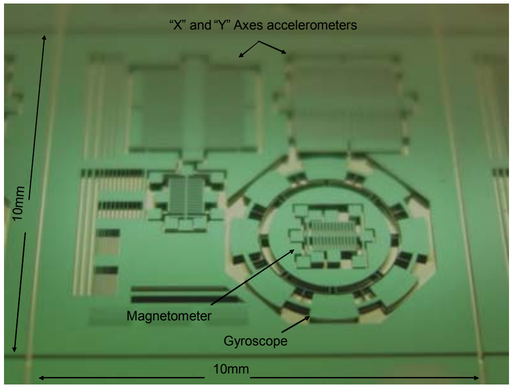


# IMU Scaling

3" (75mm) cube – COTS electronics

1" (25mm) cube – ASIC electronics



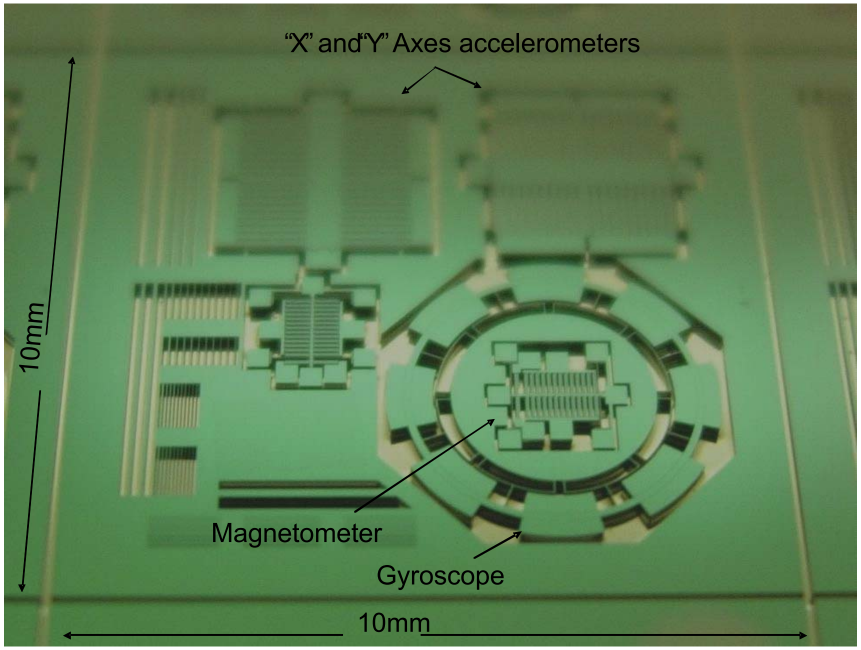



10mm cube – multi component MEMS chip, chip scale packaging, ASIC electronics

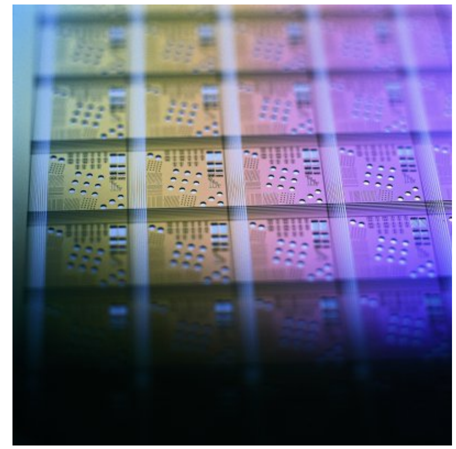
# Multi component chip

Accelerometer, gyro, magnetometer fabricated on the same chip.

Common chip level vacuum package <1mbar



## 05
## Conclusions



# Related programs

## Physics of failure

- Various collaborative programmes
  - Europe, US

## Space radiation testing

- Space department Farnborough

# Conclusions

Individual components demonstrated

- Desired performance achievable

Single chip multi component designed and fabricated

- Novel assembly with electronics and testing to be completed
- With suitable funding first prototypes could be available in 2-3 years

# Acknowledgements

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The Global Defence and Security Experts

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