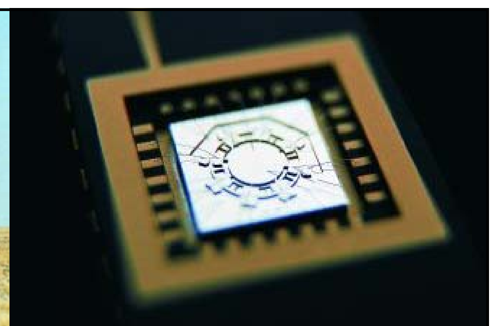

HSTSS Silicon Gun Pressure Sensor - Phase I

David Combes - QinetiQ Malvern

22/Jun/2004

Introduction

- Project and aims
- Approach
  - Modelling, fabrication & packaging
- Packaging issues
- Test results
- Conclusion
- Questions

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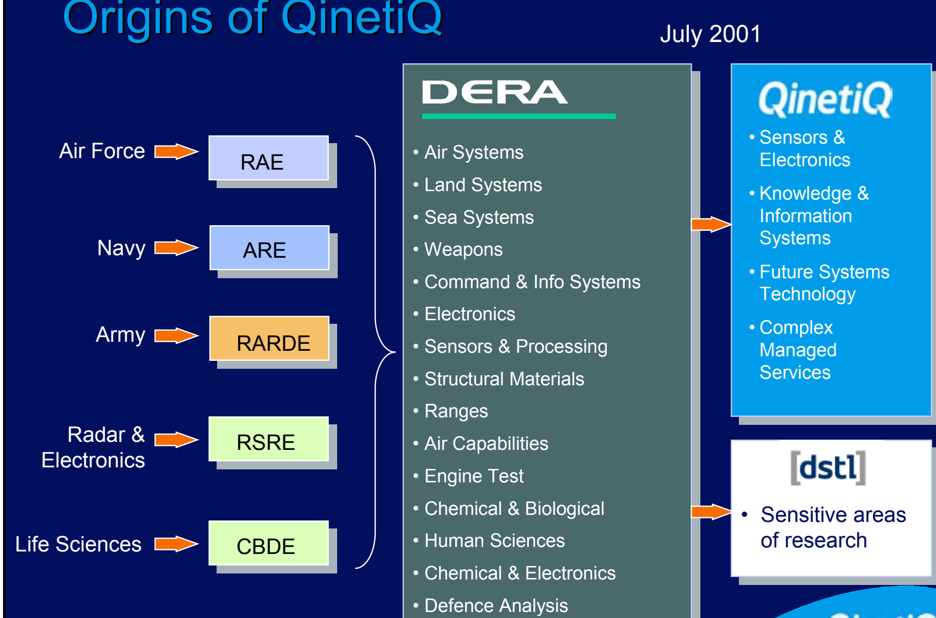
Origins of QinetiQ



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Overall project aims

- Projectile mounted, reduced cost miniature pressure sensor for HSTSS (Hardened Subminiature Telemetry Sensor System)
  - Alternative to piezoelectric, Kistler type gauges
  - Acceleration, light and temperature insensitive
  - Small, and easy to read out
- To survive gun launch accelerations up to 100,000g
- To survive and measure pressures up to 100,000 psi
  - Accurate and repeatable measurement

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Phase I

- Mainly concerned with prototype sensor element
  - To survive and measure pressures, and inform further work required to achieve aims
  - ~ 1 year programme
- Further phase required for development and testing required to demonstrate fully functional, production ready device
- Output of phase I - 8 packaged sensor elements
  - Capable of measuring pressures up to 100,000 psi
  - Capable of surviving gun launch
  - Minimal form factor

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Project team

- Fort Halstead - Gun systems
  - Gun and ammunition systems research
  - Gun and rocket test ranges and instrumentation
- Malvern - Microsystems & Microengineering
  - MEMS design and modelling
  - Electronic sub-system design
  - Microstructure fabrication
  - Advanced characterisation
  - Engineering solutions

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Approach

- Bridge configured piezo-resistive silicon sensor
- Provides linear output voltage with change in pressure
- DC response characteristics
- Silicon - robust, cheap, readily processed
- Allows exploitation and application of MEMS technologies, and potential integration of smart functions
  - Temperature compensation etc
- Suitable for miniaturisation

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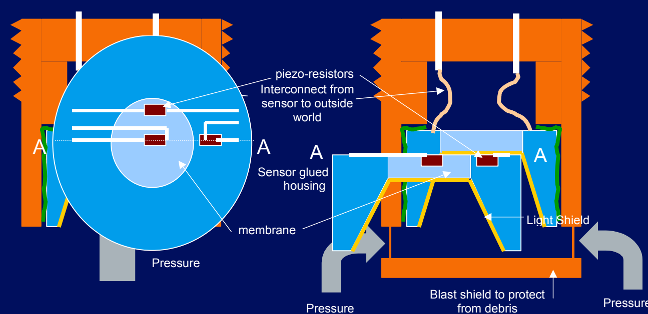
Approach

- Piezoresistive membrane sensor



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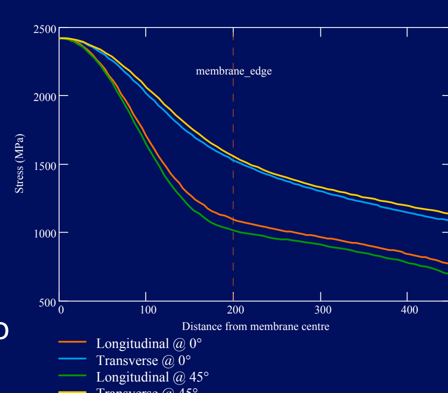
Mechanical Modelling

- Mechanical finite element analysis
  - To inform design
  - Map stresses in device
  - Map strain for piezoresistors
  - Package included in analysis
- 100µm fillet radius chosen to give acceptable stresses



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Fabrication

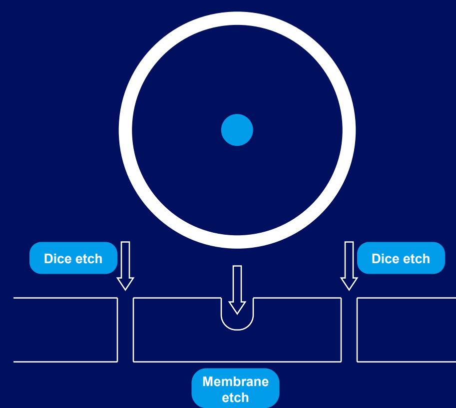
- Silicon has high theoretical intrinsic strength
  - Practical strength depends on surface finish and defects
  - Quoted figures vary widely
    - 7GPa - 0.7GPa
- Fabrication process a key component of work
  - Need smooth etch profile (in all directions)
  - Use Deep Reactive Ion Etch (DRIE) tool to create initial circular membrane profile
  - Post process to smooth further
  - Etch dice

Isotropic etch development

- Wet etching - wetting problems
- Gas phase etches investigated
- Fluorine based plasma etch- smooth profile, good surface finish
- Wet etching may be used to further smooth

Etch dicing

- Saw/Cleave
  - Not highly controllable
  - Limited geometry (straight)
  - Forms stress raisers
- Etch dice using DRIE



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Packaging

- Steel M12 package, similar to Kistler M6213
- Gasket/attach layer for testing - Epoxy
- Face sealing using compression washer

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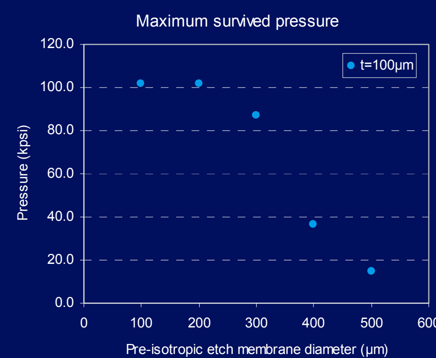
Mechanical test results

- Carried out in parallel with mechanical modelling
- Survival test - Budenberg dead weight tested to 100kpsi
- Membranes with no transducer elements tested - available early
- Several membrane designs showed they were suitable for high pressures
- Stress limit of around 2GPa



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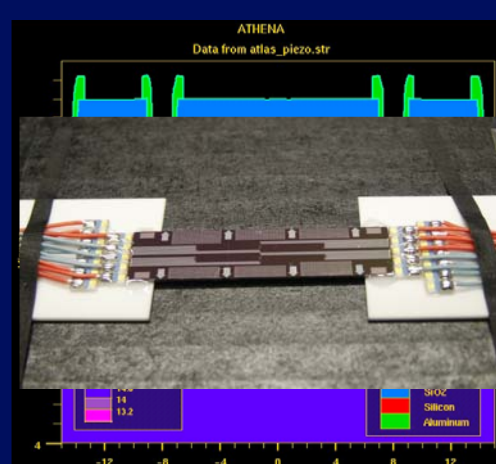
Piezoresistors

- P-Type piezoresistors
  - Allows lower temperature co-efficient of piezoresistivity
- Simulated using Silvaco's Athena™
- Test devices fabricated to validate models
- Simulated $\approx 680\Omega/\square$
- Measured $\approx 710\Omega/\square$



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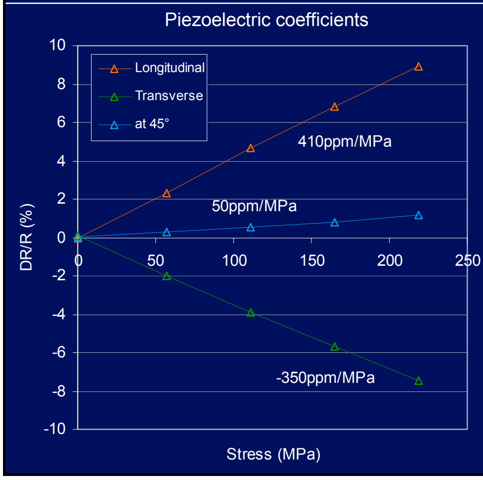
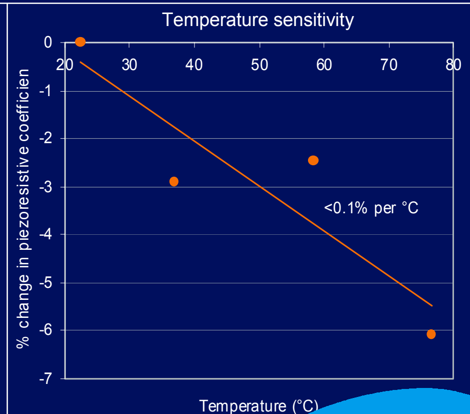
Piezoresistors

- Good match with modelling
- Low temperature sensitivity, potential for further gains





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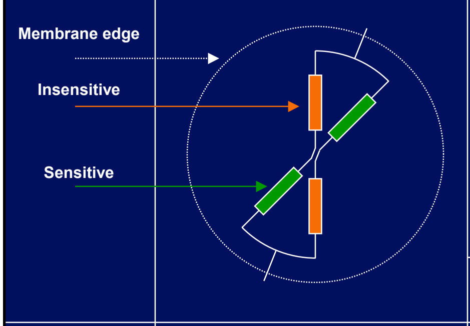
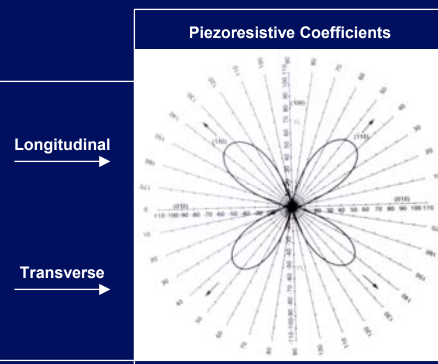
Membranes with piezoresistors

- Bridge configured sensor
- Two sensitive, two insensitive devices





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Packaging issues

- Attachment of suitable bond wires to small die area proved difficult
- Wire-bonder identified which provides solution - Westbond 7440
  - Some problems obtaining samples - now solved
  - Will be testing in next few weeks
- Modifications made to package to allow conventional bonds and soldered connections

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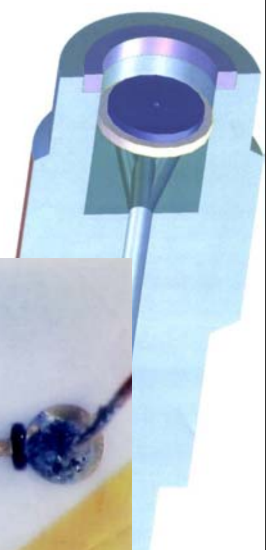
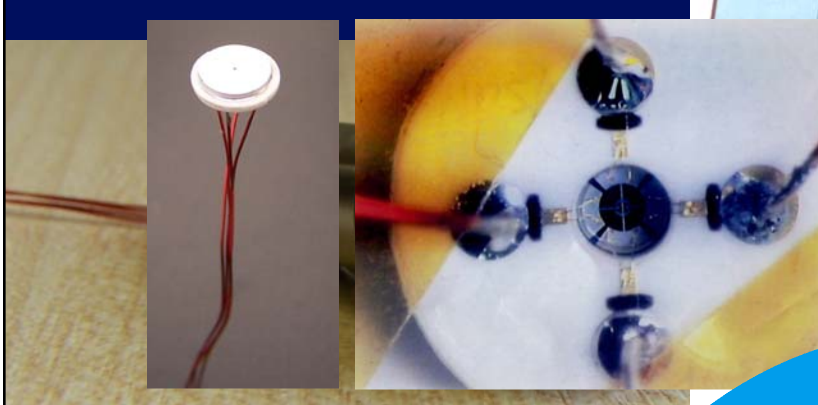
Modified package

- Uses ceramic header, metal support
  - Conventional wire bonds to header
  - Solder connections from header





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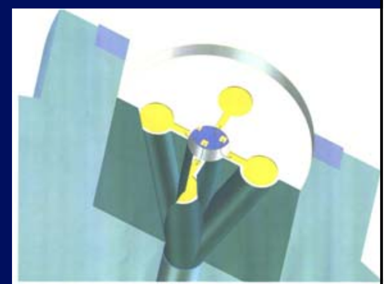
Modified package issues

- Provides devices with less support
  - Increases strain in die and membrane
- Die level device failures under reduced pressure
- Analysis of failed devices show modified package not providing sufficient support
- No such problems with unmodified package
  - Devices in original package type with bonds made by a Westbond tool (or similar) are the best solution



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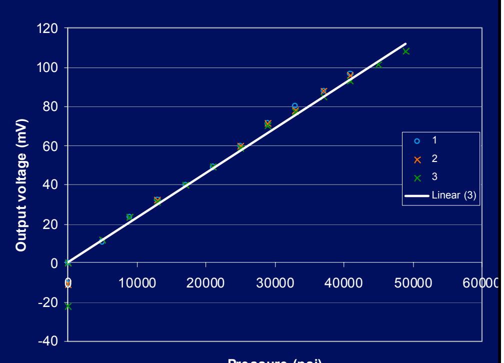
Transducer testing

- Devices in modified package tested - Electrical performance as expected
  - Linear & repeatable
- Epoxy relaxation an issue - alternatives under investigation
- Devices in unmodified package tested with no electrical connections
  - Most sensitive (weakest) devices showed they were suitable for full range pressure measurement



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Conclusion

- A silicon piezoresistor bridge was identified as capable of meeting requirements
- Models were created to simulate both the mechanical and semiconductor physics of the devices
  - Devices were fabricated to validate models
  - Good predictive performance
- Processes were developed for fabrication of the mechanical structure and implanted piezo-resistors
- Solutions identified for packaging

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Conclusion

- A silicon piezo-resistive pressure sensor has been developed suitable for
  - Measuring 100,000psi (high degree of confidence)
  - Surviving 100,000g (high degree of confidence)
  - Low cost production
  - Miniaturisation
  - Easy interface
- Phase II funding is being sought to further develop the sensor and packaging to facilitate production of such sensors for ballistic applications

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Supplemental information

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What is QinetiQ?

- Profitable, growing, high technology P.L.C. formed from majority of DERA
- Approx. 8,500 staff
- Turnover approx. $1.2B
  - 80% for Ministry of Defence
  - Commercial work growing rapidly
- One of Europe's largest science and technology organisations
- Approx. 3200 patents in force, 1400 pending
- 10 spin-out companies

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