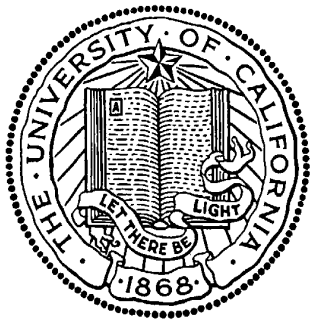
Harsh Environment Sensor Cluster for Infrastructure Monitoring

Single-Chip, Self-Powered, Wireless Sensor Systems



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Berkeley Sensor & Actuator Center

BSAC

Harsh Environment Sensor Cluster

The National Science Foundation
Industry/University Cooperative Research Center on MEMS

*"BSAC conducts **industry-relevant, interdisciplinary research on** micro- and nano-scale sensors, moving mechanical elements, microfluidics, materials, and processes, and systems that take advantage of progress from integrated circuit, networking, bio, and polymer technologies."*

Cluster Sensor for Energy & Power

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Harsh Environment Sensor Cluster

Energy Industries	Geothermal	Oil & Gas Exploration	Industrial Gas Turbines	Aircraft Engines	Automotive Engines
Required Sensing Temperatures	 375°C	 275°C	 600°C	 600°C	 300°C
Desired Sensing Measurands	• Pressure • Temperature • H_2S • Strain	• Pressure • Temperature • Hydrocarbon • Strain	• Pressure • Temperature • Flame speed • Acceleration	• Pressure • Temperature • Flame speed • Acceleration	• Pressure • Temperature • Flame speed • O_2

- **“Harsh environment” includes extremes of pressure, temperature, shock, radiation and chemical attack.**
- **Real-time sensing within harsh environments enables increased operation lifetimes, improved efficiency and reduced emissions.**

Geothermal Energy

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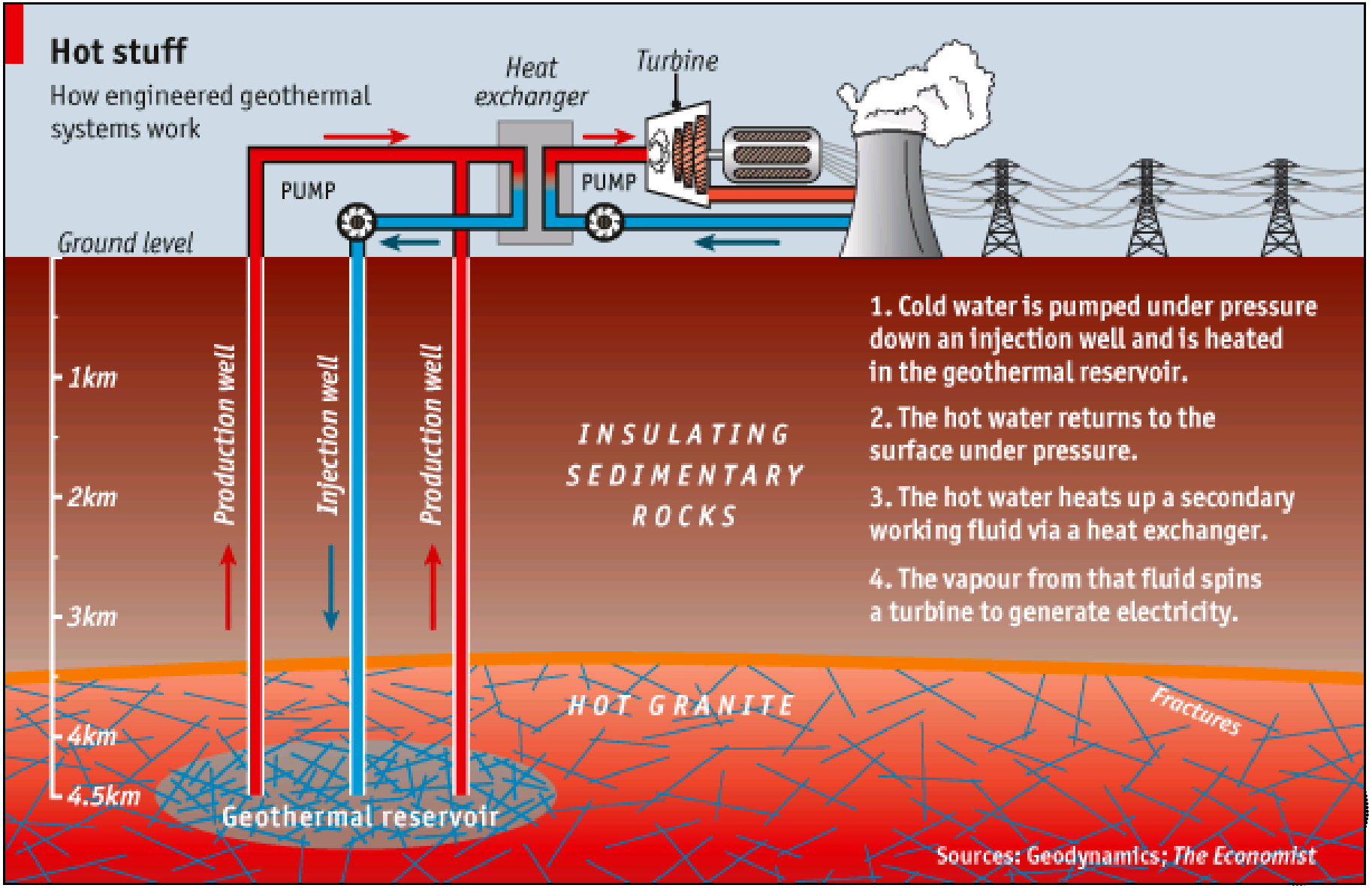
Harsh Environment Sensor Cluster



Geothermal Resources in Japan

BSAC

Harsh Environment Sensor Cluster

List of Geothermal Power Plants in Japan

Mori	Ohnuma	Sumikawa
Matsukawa	Kakkonda	Uenotai
Onikobe	Yanaizu-Nishiyama	Hachijo- Jima
Suginoi	Takigami	Ohdake
Hatchobaru	Ohgiri	Kirishima-kokusai Hotel
Yamagawa	Kuju	

Source:
http://wwwsoc.nii.ac.jp/grsj/geothermalinJ/Res&PP/P_Plant/main121.html

Sensor Cluster in the Ground

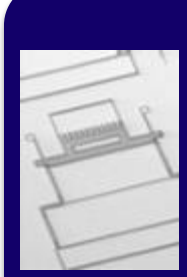
BSAC

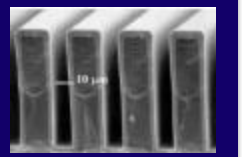
Harsh Environment Sensor Cluster

Self-powered, Wireless, Multi-Chip Sensing Module

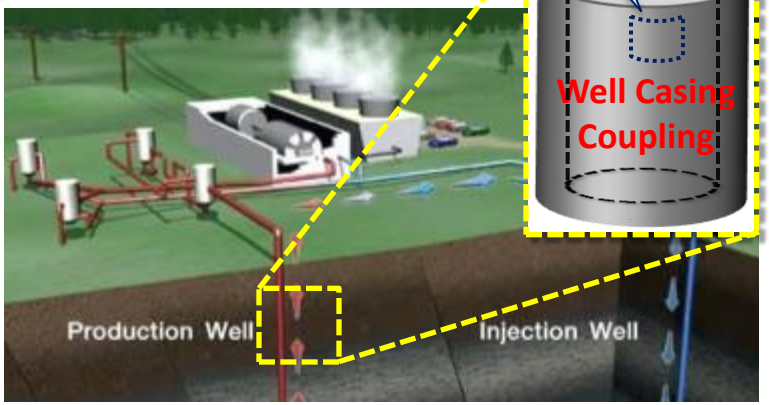
SiC Integrated Circuits

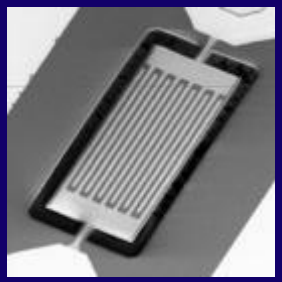
SiC/AlN Scavenging Power Source





SiC/AlN Harsh Environment Sensors



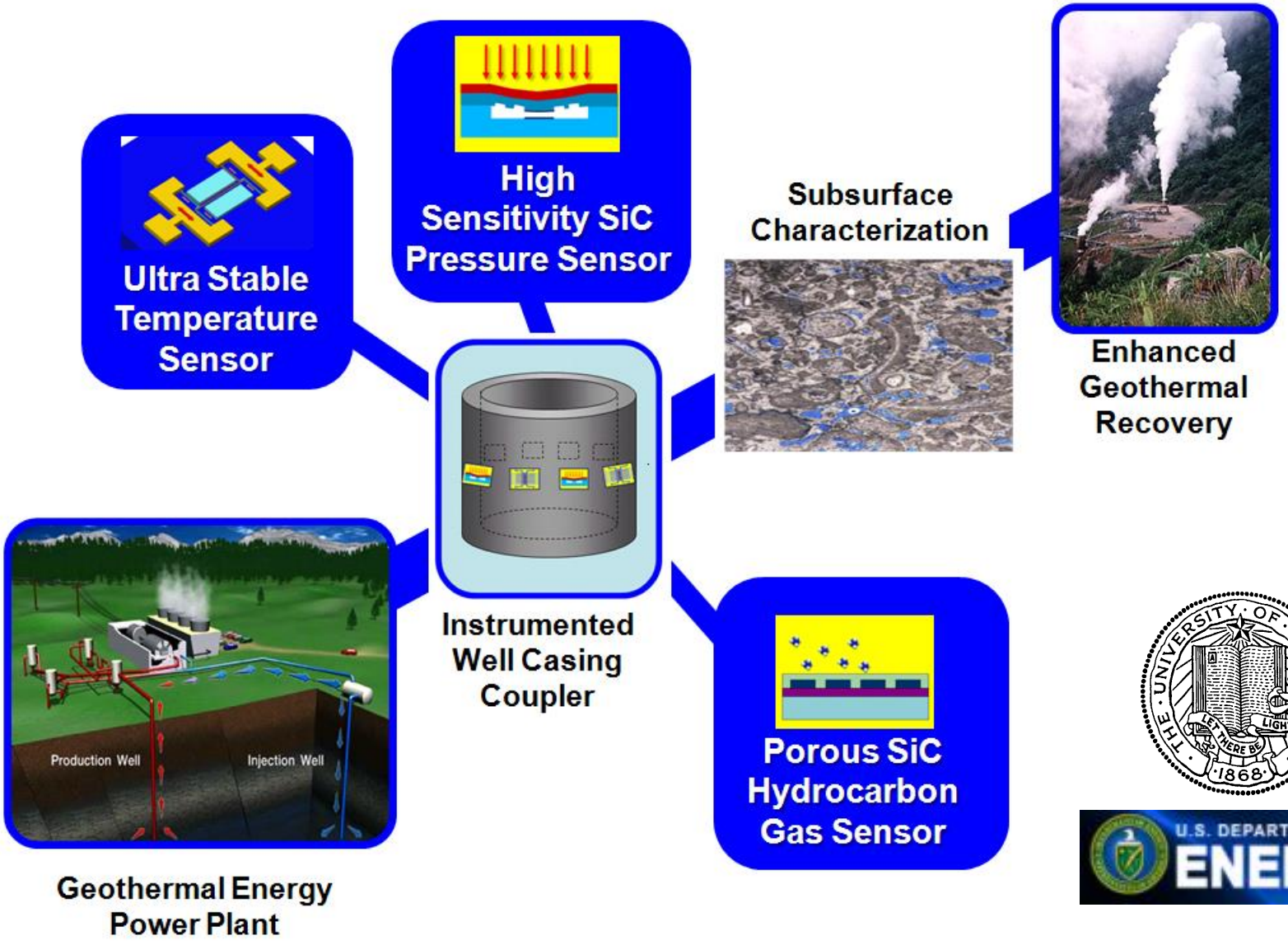


AlN RF Telemetry Components

Efficient, Clean & Smart Geothermal Energy Systems

Cluster Sensor in the Ground

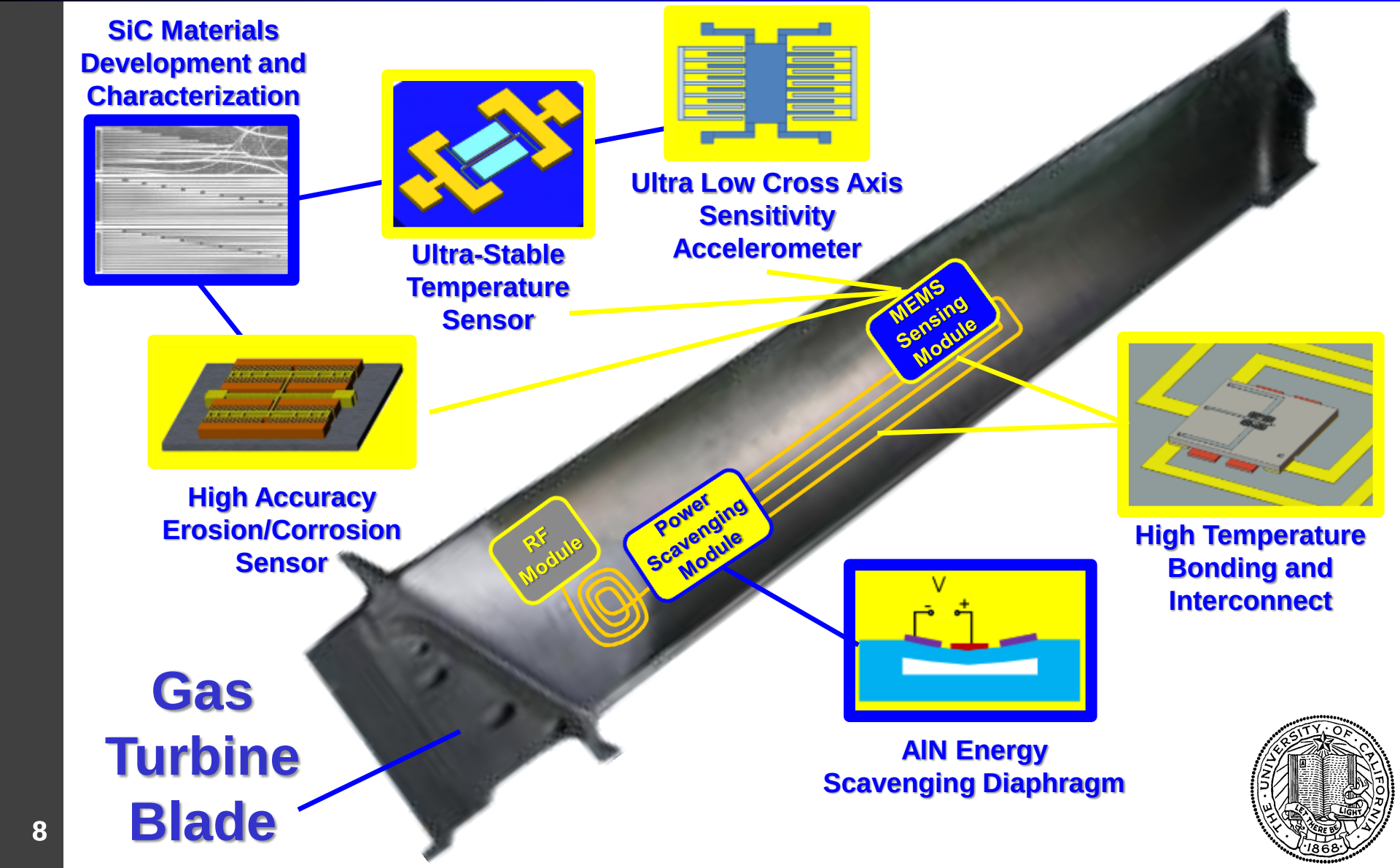
Harsh Environment Sensor Cluster



Cluster Sensor in the Gas Turbine

BSAC

Harsh Environment Sensor Cluster

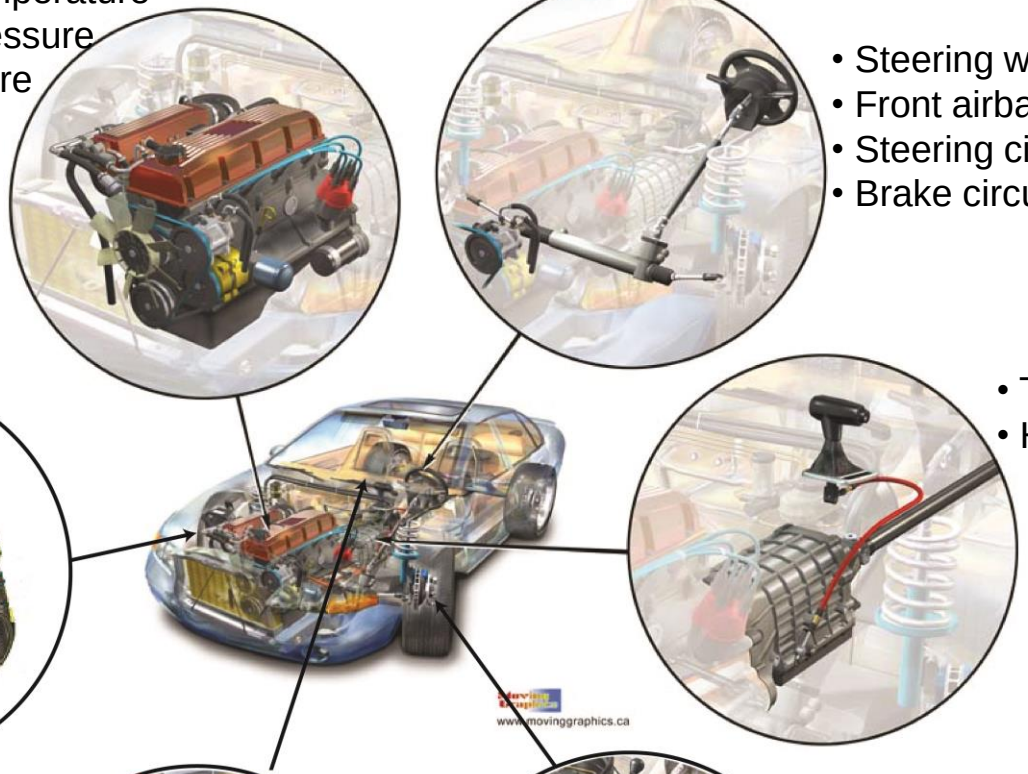


Cluster Sensor for Transportation

Harsh Environment Sensor Cluster

- Combustion chamber temperature
- Combustion chamber pressure
- Manifold absolute pressure
- Mass air flow sensor
- Oxygen sensor
- Exhaust NO_x sensor

- Pressure sensors
- Accelerometer array



- Steering wheel angle sensor
- Front airbag accelerometer
- Steering circuit oil pressure
- Brake circuit oil pressure

- Transmission torque
- Halfshaft torque

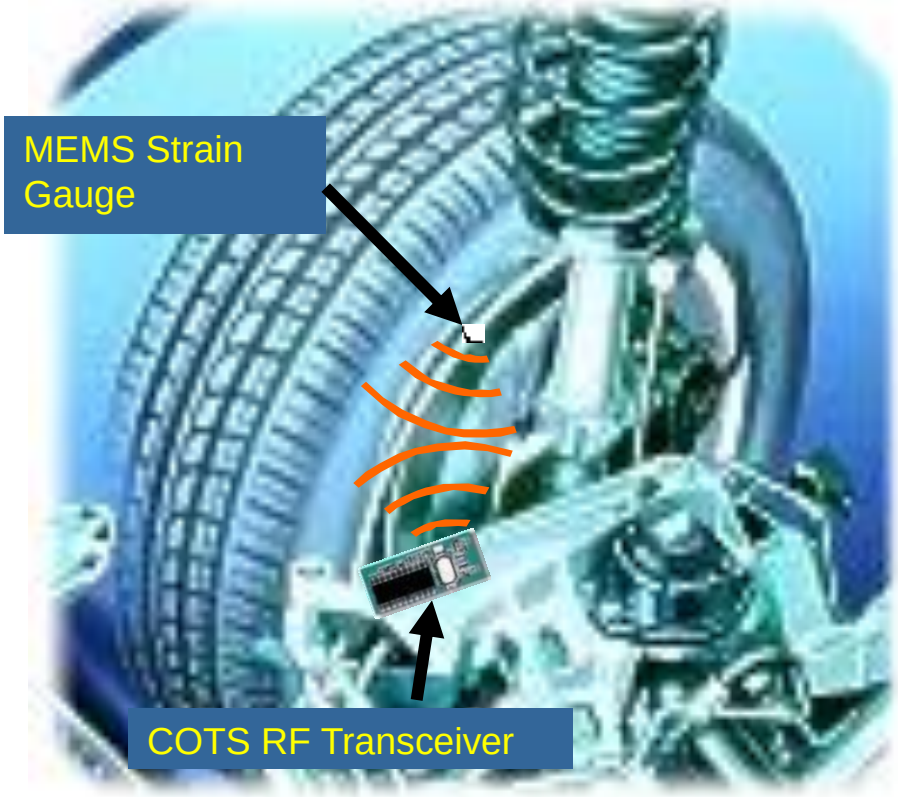
- Airbag accelerometers
- Air quality filtration sensor
- Rain sensor
- Passenger temperature
- Pedal position sensor

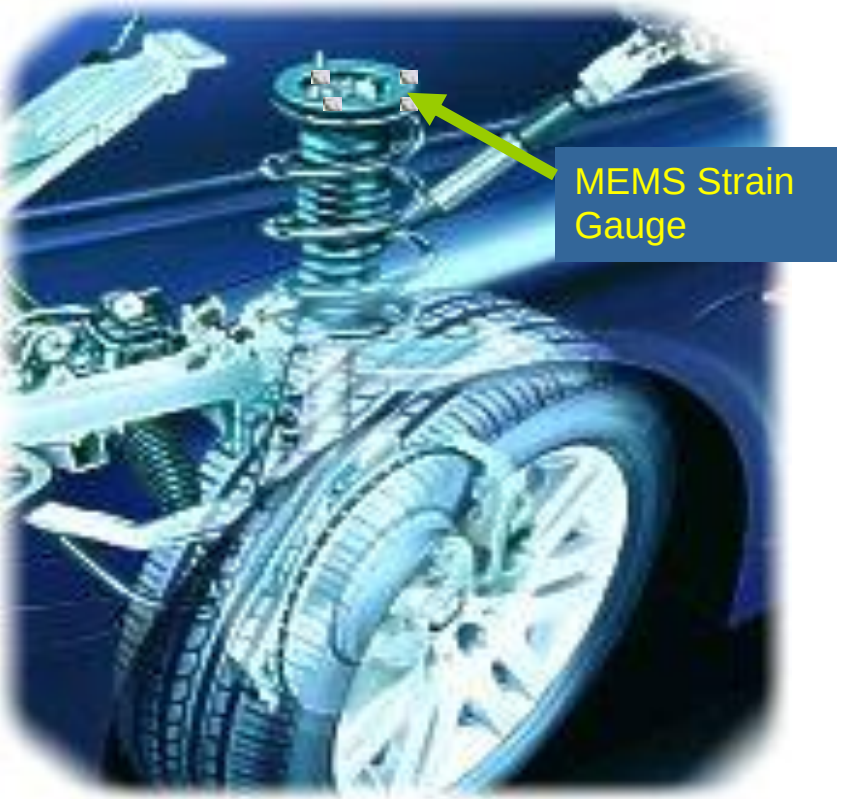
- Angular rate (roll over)
- Chasses tilt sensor
- Wheel speed rate (ABS)
- Wheel torque sensor
- Active suspension sensor

Sensor Cluster in the Automobile

BSAC

Harsh Environment Sensor Cluster

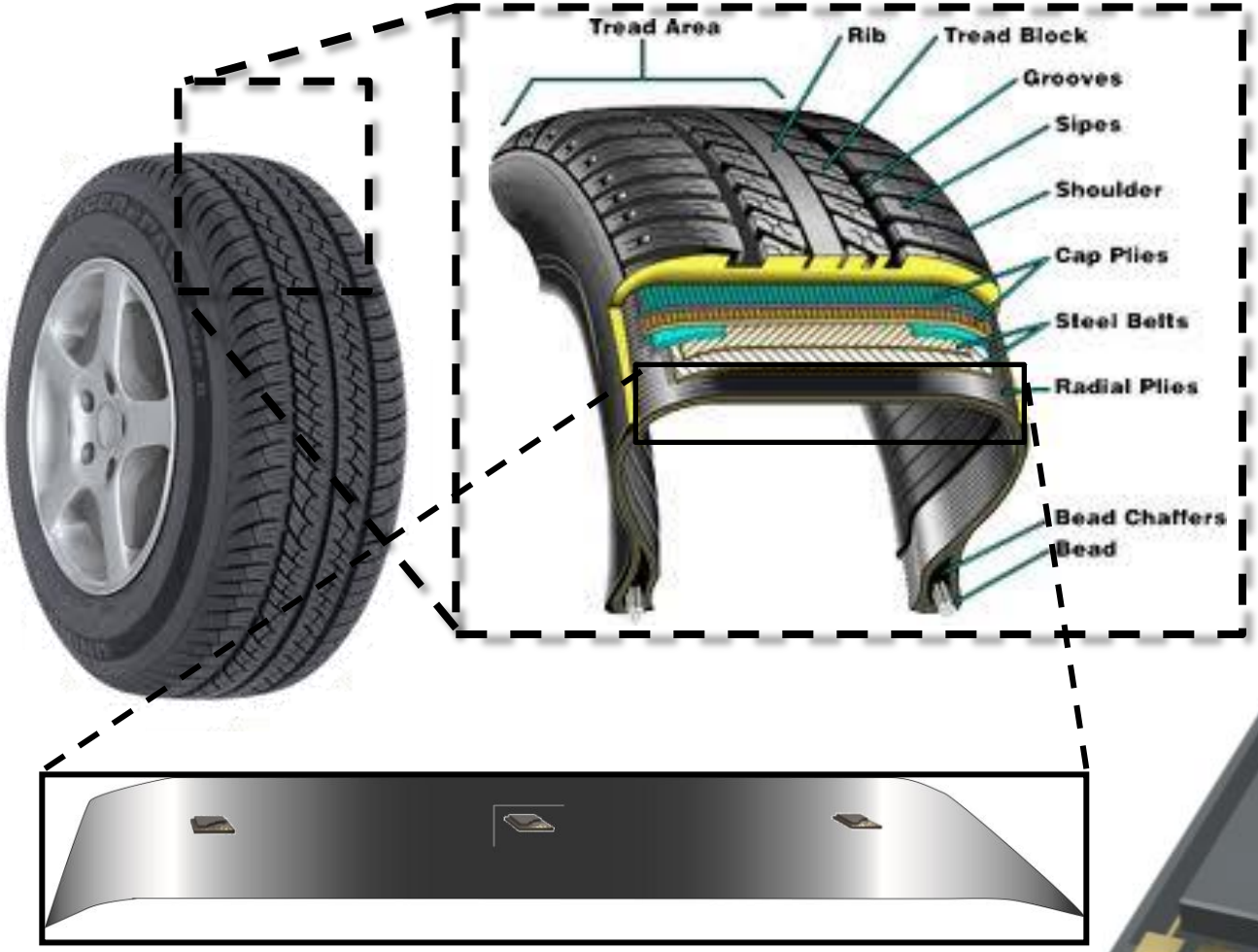




- **MEMS Sensor on Wheel Communicates via RF to Transceiver on Chassis**
- **MEMS Sensor on Shock Tower Measures Vertical Forces On Chassis for DSC Application**

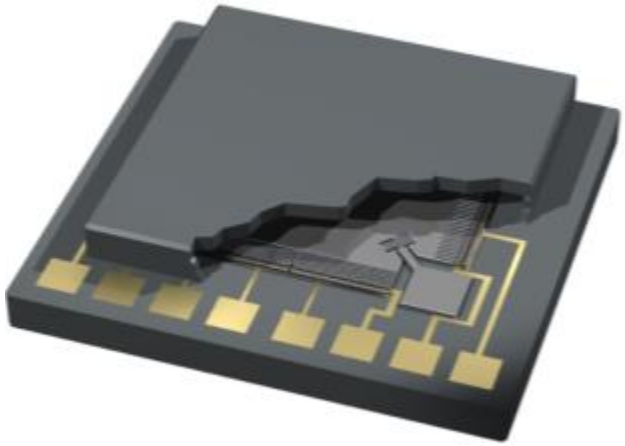
Sensor Cluster in the Tire

Harsh Environment Sensor Cluster



3-Point Array of Sensors

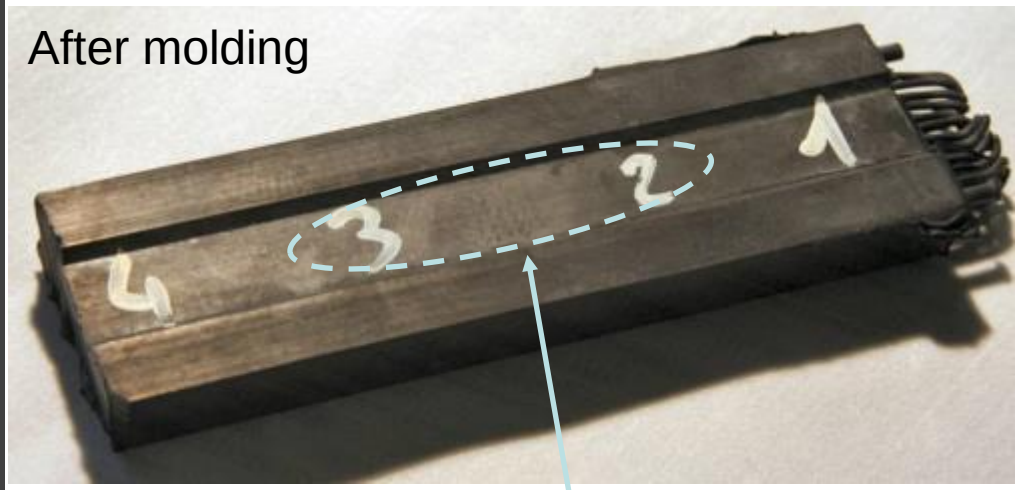
<u>Sensor Types</u>:
Strain Sensors
Pressure Sensors
Accelerometers



Molding & Vulcanization

BSAC

Harsh Environment Sensor Cluster



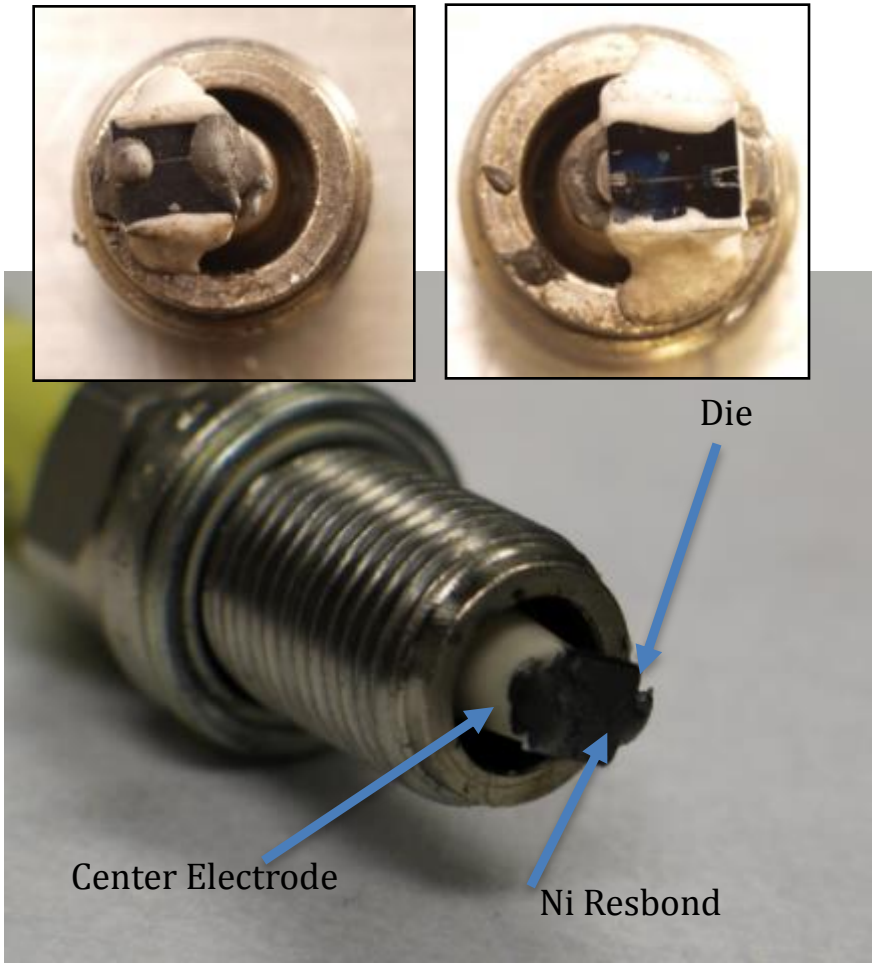
Embedded samples

After samples retrieval

- **4 embedded samples**
- **5x5mm2 each**
- **Array of SiC Zener diodes**
  - Survivability test
- **Si substrate covered with SiO2/SiC**
  - Delamination test
- **Two Si substrates**
  - Bare Si
  - Si + Ni (2nm)
  - → Sample/rubber adhesion

Cluster Sensor in the Auto Engine

Harsh Environment Sensor Cluster



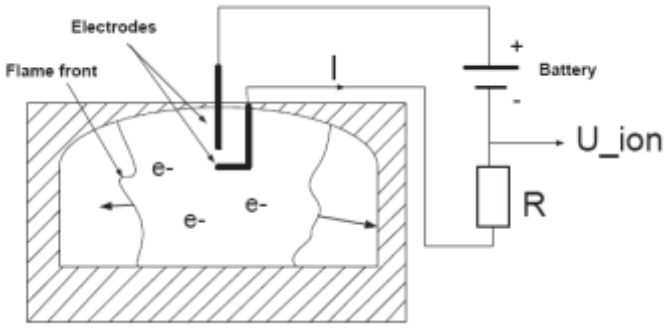
Test Fixture for signal collection. There are two die attachment methods:

1)<u>Simultaneous Electrical and Mechanical Attachment</u> via Ni Resbond with Auxiliary Mechanical Attachment via Ceramic Adhesive

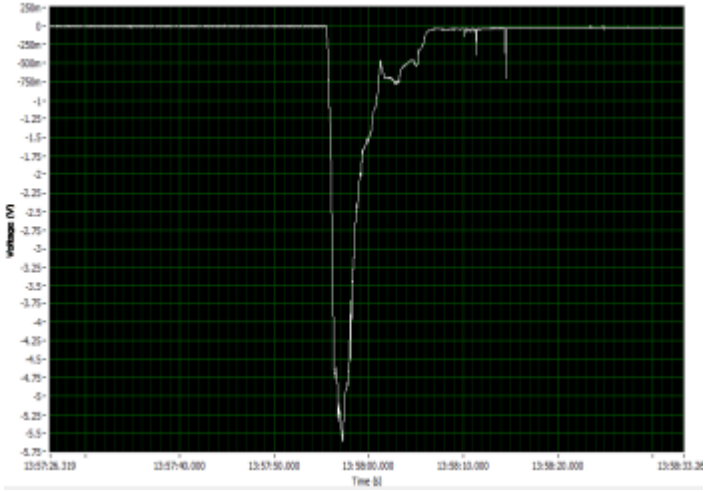
2)Separate Electrical and Mechanical Attachment via Ceramic Adhesive for Mechanical and Aluminum Wire Bonds for Electrical

Cluster Sensor in the Auto Engine

Harsh Environment Sensor Cluster

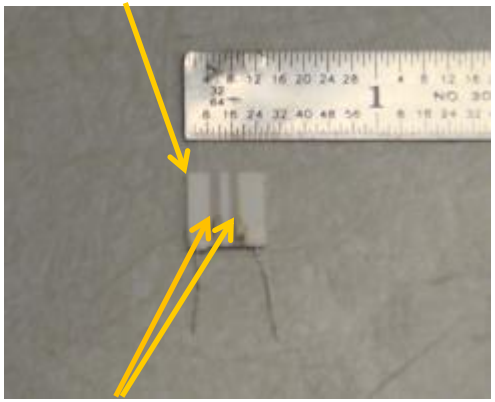


Bias voltage -> leakage current -> ion concentration detection



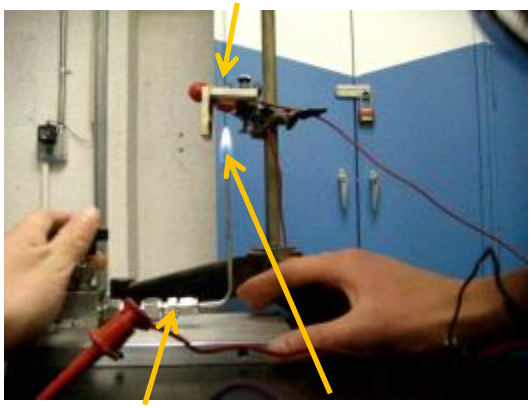
5.5V peak signal (from 120V bias voltage). Expecting **< 0.010V resolution**.

1 cm^2 fired alumina substrate



Sintered Pt electrodes (1mm wide, 1mm gap)

Ceramic shield to protect wire leads



Controlled flame jet

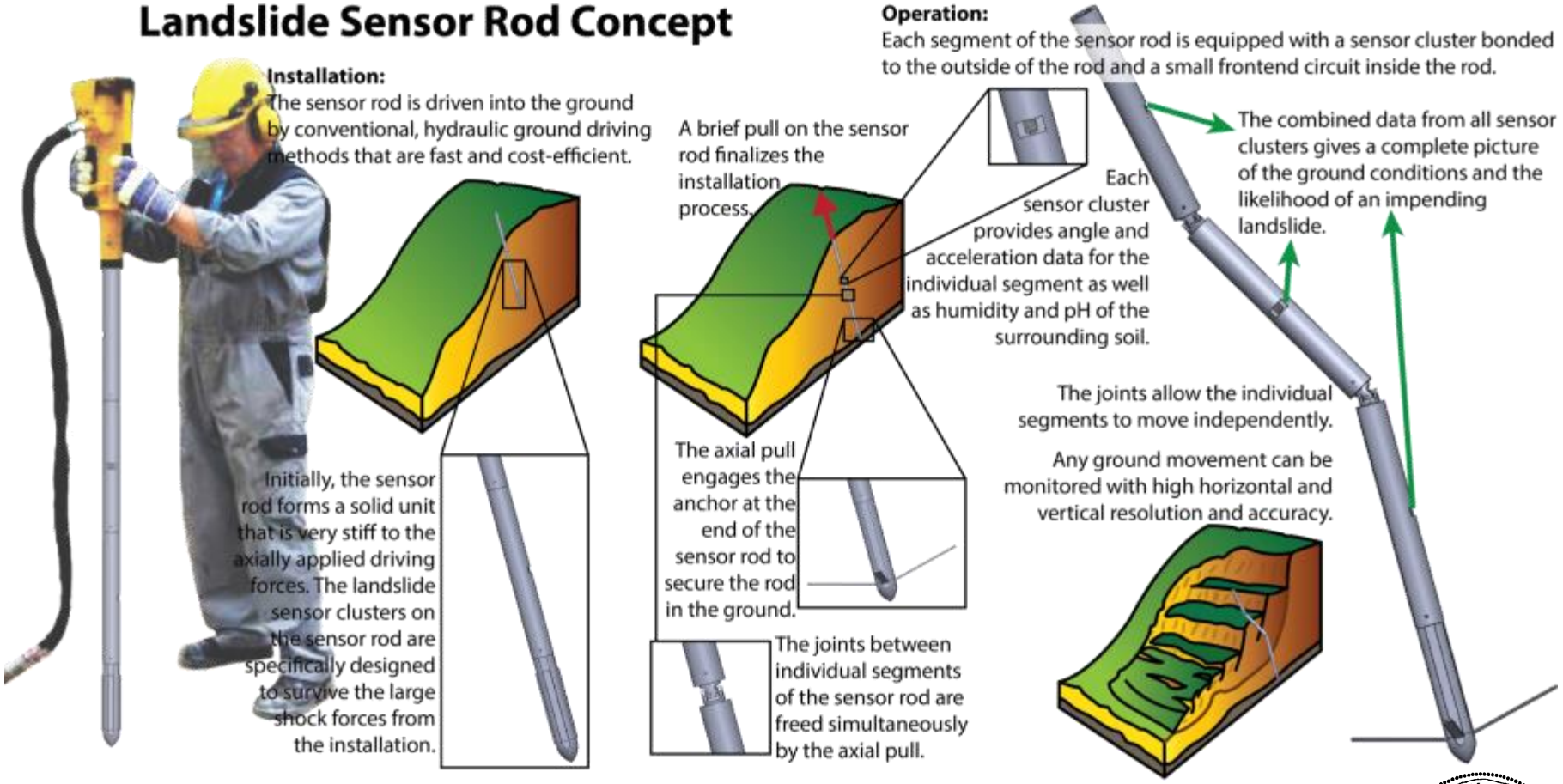
Methane diffusion flame

Prototype fabricated and tested:
- Platinum ink on alumina substrate
- Preliminary tests show geometry has good sensitivity to flames

Next steps:
- Production via MEMS or microprinting technology
- Design and construction of test chamber

Cluster Sensor Landslide Prediction

Harsh Environment Sensor Cluster



Cluster Sensor for Infrastructure

Harsh Environment Sensor Cluster

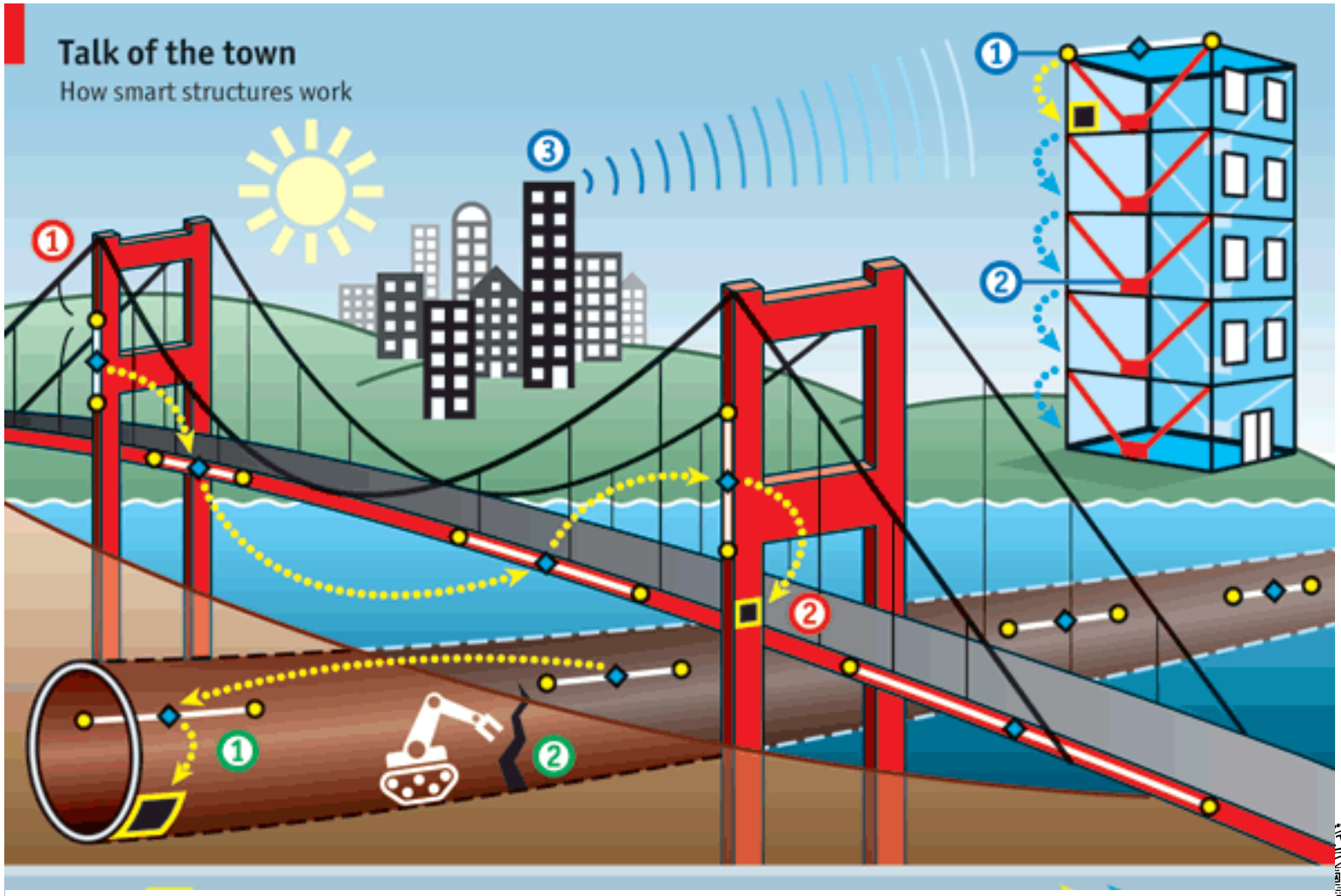
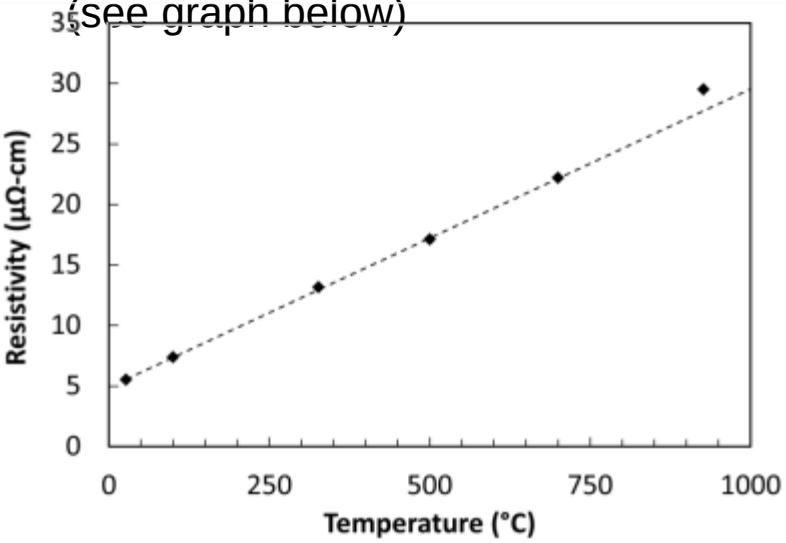


Figure from The Economist Magazine

Sensor Cluster Prototype

Harsh Environment Sensor Cluster

- Temperature sensor is resistive type (resistance changes linearly with temperature)
- Sensor size can be very small (e.g. 200 µm x 200 µm)
- Many temperature sensors can be placed on the sensor cluster chip
- Linearity is very good for Molybdenum in the required temperature range (see graph below)

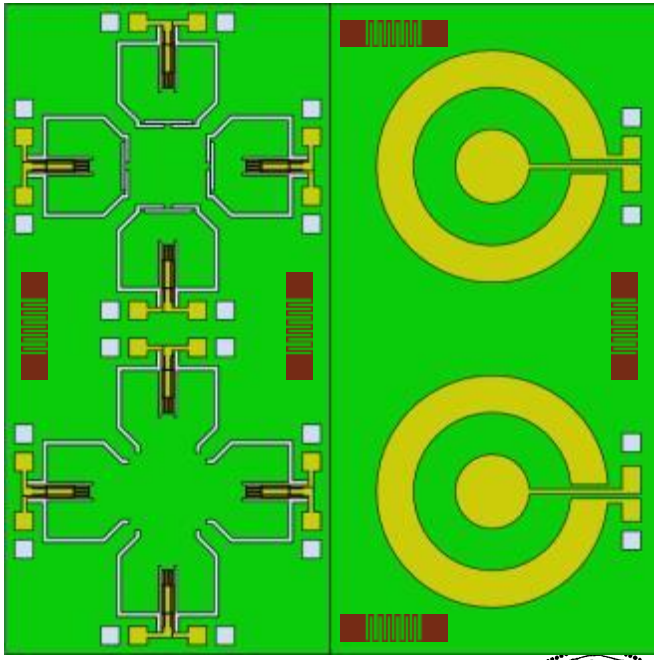


Source: www.elmettechnologies.com

Example of Sensor Design

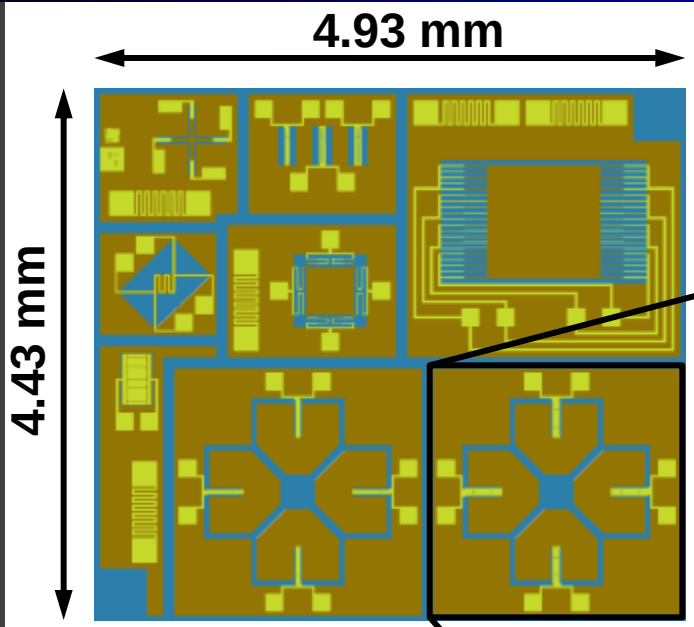
Example of Placement

Note: This is a schematic figure. The actual design of the prototype I chip will be submitted later.

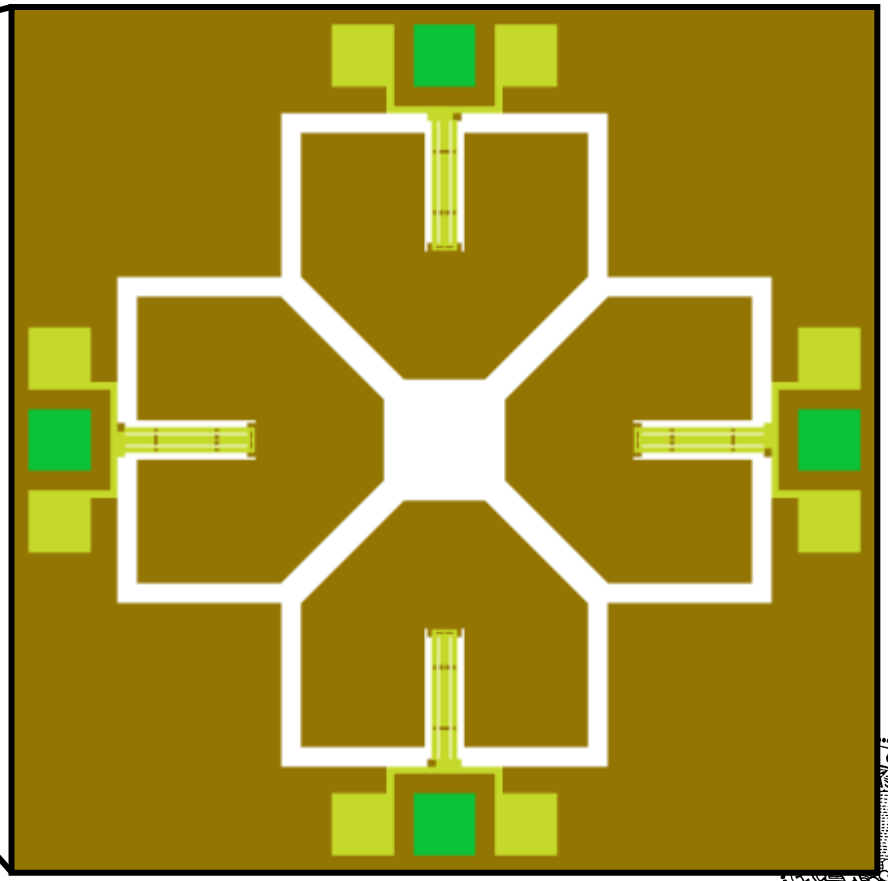


Pre-Prototype Design

Harsh Environment Sensor Cluster



2-Axis Accelerometer

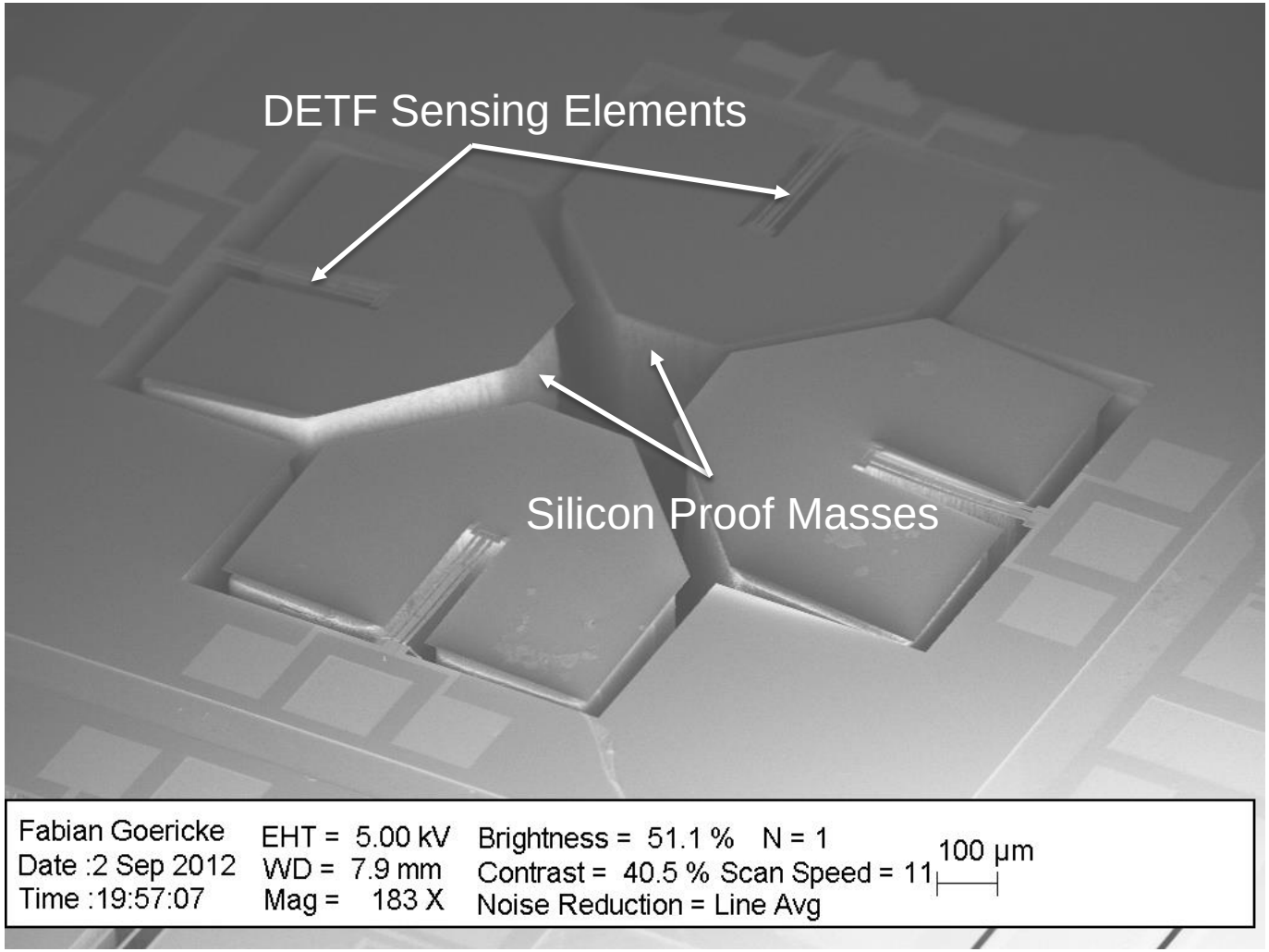


Integrated components:

- 2-axis accelerometer
- Vacuum pressure gauge
- Strain sensor
- Temperature sensor

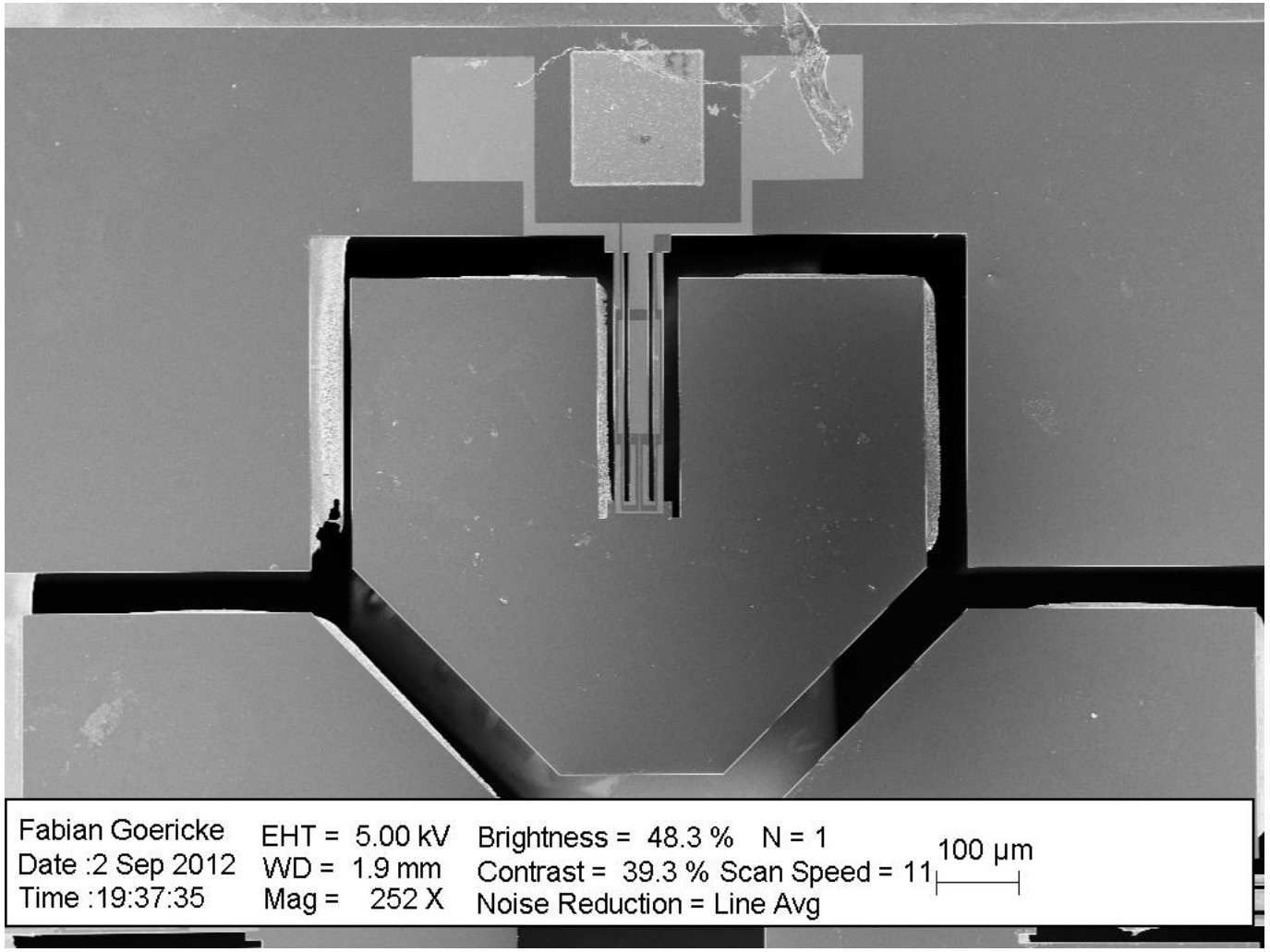
Pre-Prototype Results

Harsh Environment Sensor Cluster



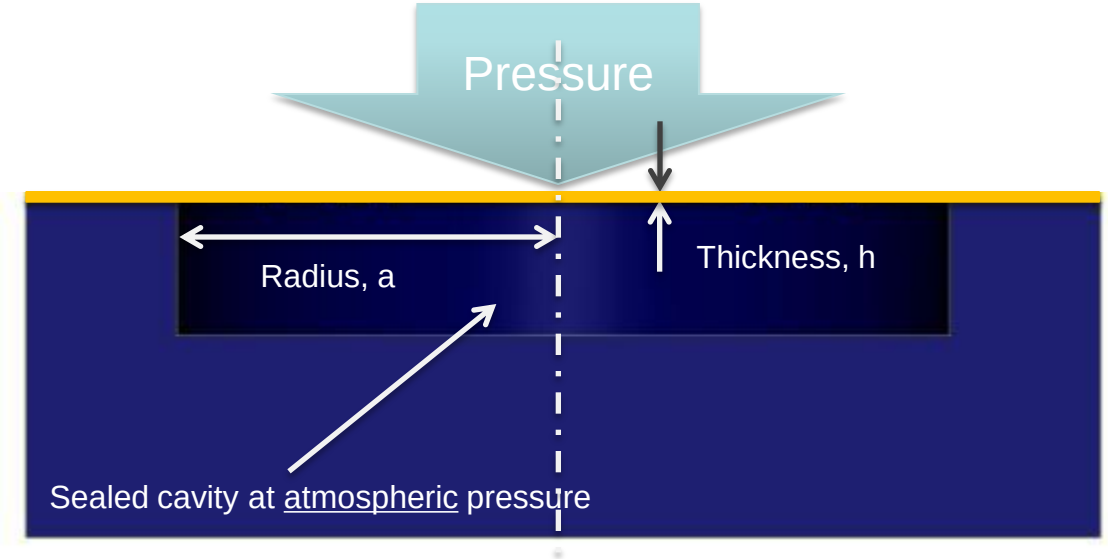
Pre-Prototype Results

Harsh Environment Sensor Cluster



AlN Pressure Sensor Design

Harsh Environment Sensor Cluster



Characteristic Equation for Circular Membrane:

$$\frac{Pa^4}{Eh^4} = 5.86\frac{y}{h} + 3.19\frac{y^3}{h^3}$$

Resonance frequency of membrane:

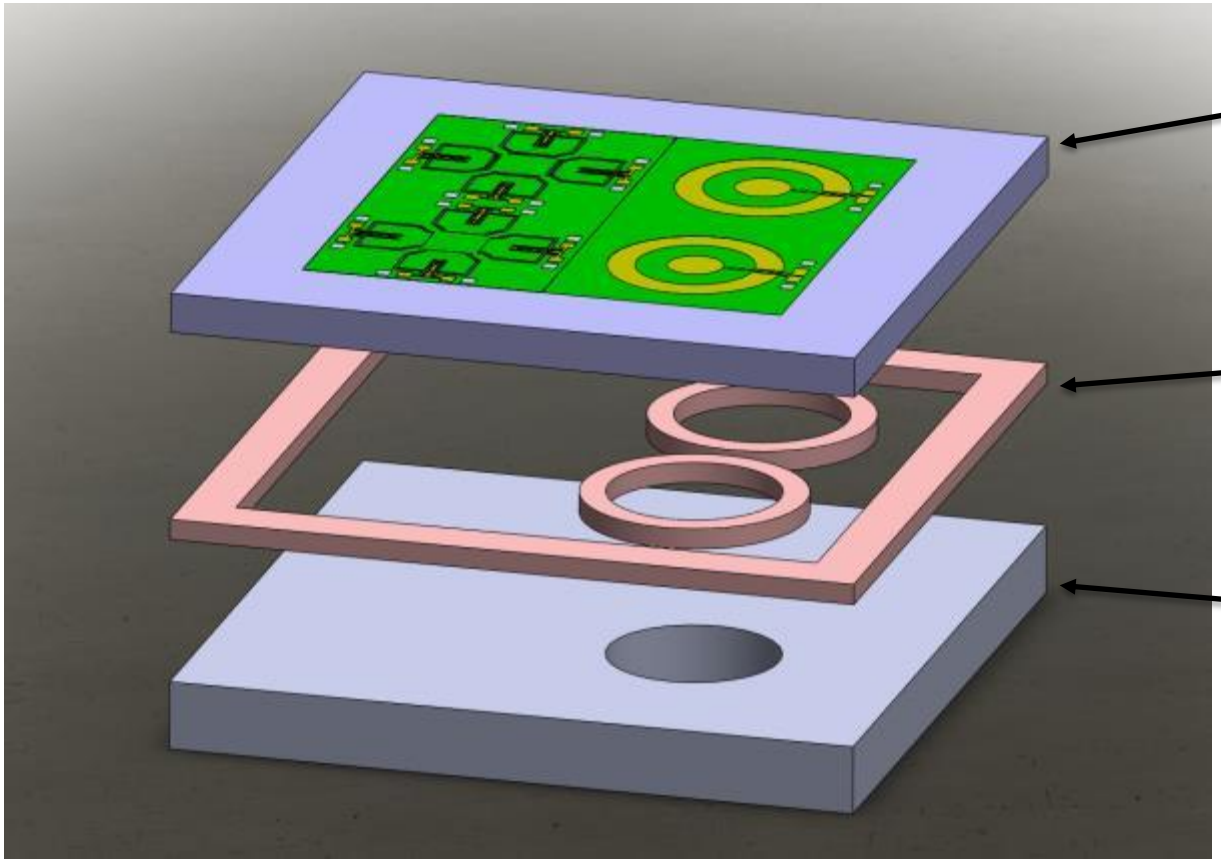
$$\omega = 9.22\frac{h}{a^2}\sqrt{\left[\frac{E}{\rho(1-\mu^2}\right]}$$

a = radius, h = thickness, y = deflection, E = Young's modulus, Ae = effective area of corrugated diaphragm, D = flesural [illegible], Poisson's ratio, ρ=specific weight of membrane material.

Cluster Prototype Assembly

BSAC

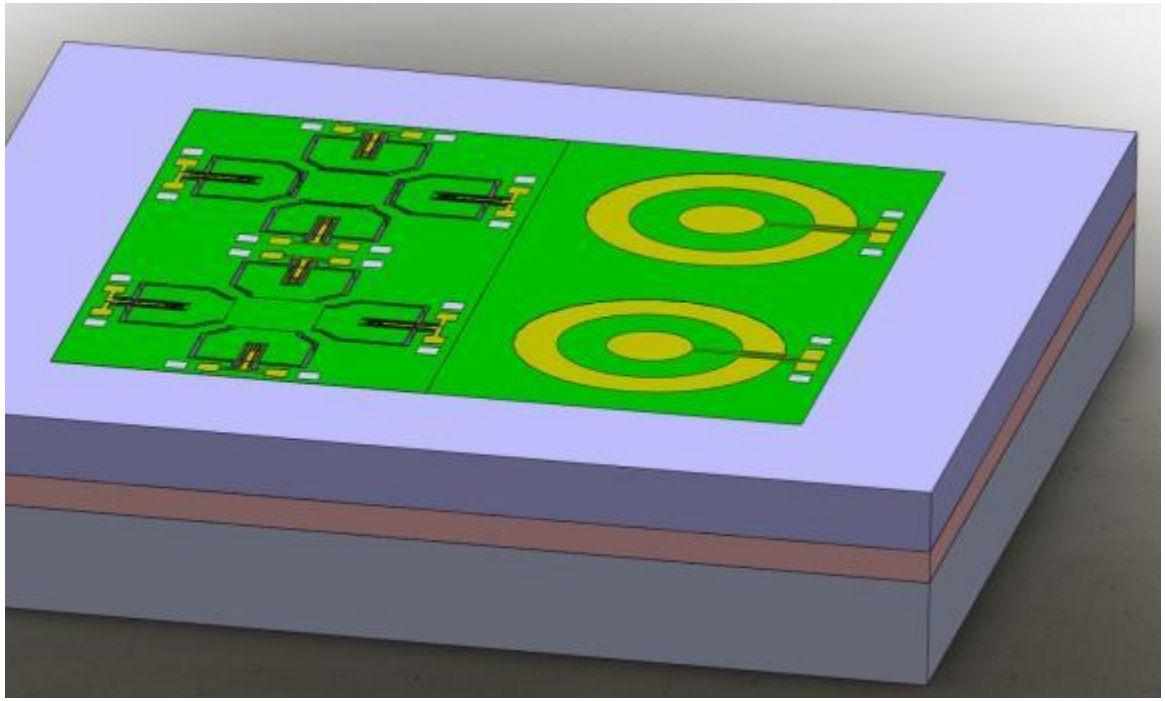
Harsh Environment Sensor Cluster



Cluster Prototype Assembly

BSAC

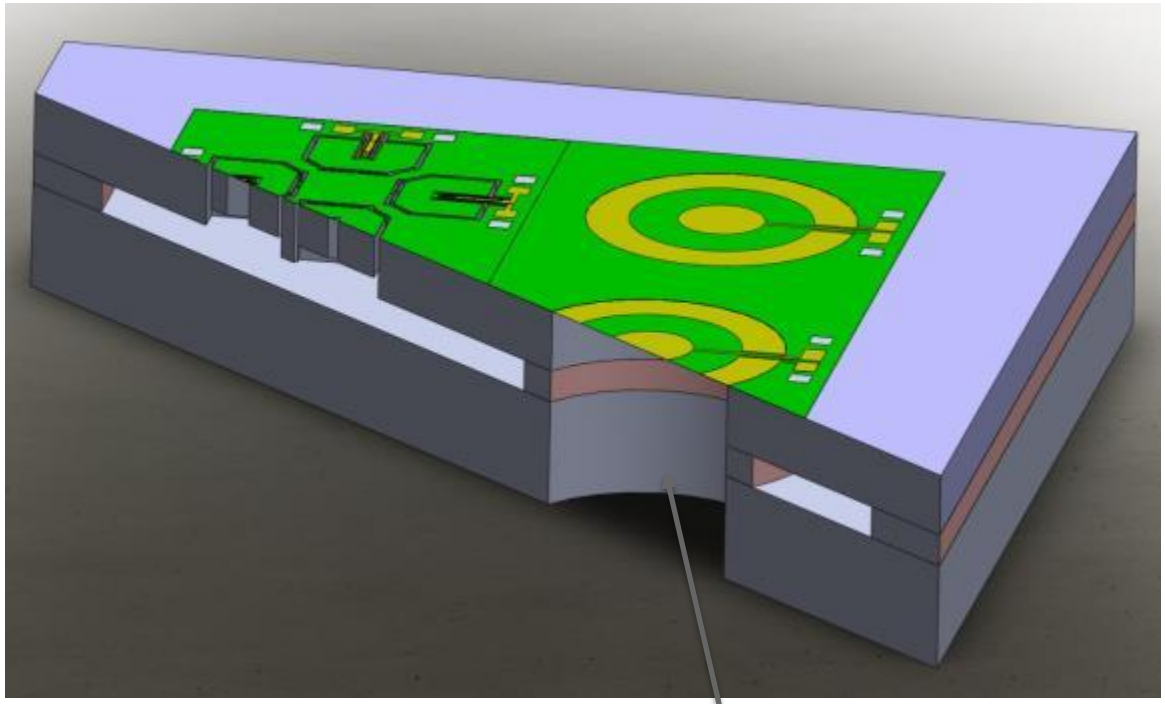
Harsh Environment Sensor Cluster



Cluster Prototype Assembly

BSAC

Harsh Environment Sensor Cluster

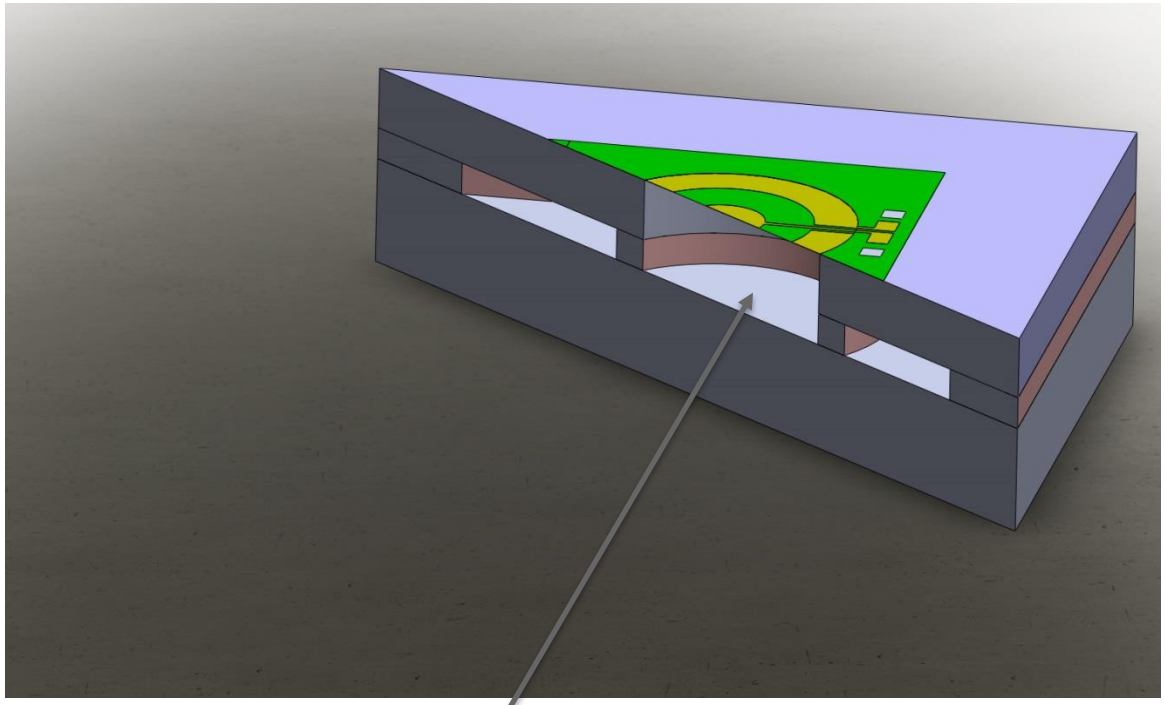


Reference Device Open to Atmosphere on Top and Bottom

Cluster Prototype Assembly

BSAC

Harsh Environment Sensor Cluster



Sealed Cavity of Pressure Sensor

Conclusion

- **Sensor Cluster for**
  - Energy & Power / Gas Turbine
  - Transportation / Automobile Engine
  - Landslide Prediction / Built Infrastructure
- **Common Fabrication Process**
- **Many Sensors on One Chip**
- **Sensor Signal and Packaging are the Next Challenges**
- **Seeking Industrial Collaboration**

Acknowledgements

- BSAC
- UC Berkeley Nanolab
- Prof. Roya Maboudian
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- Mr. David Rolfe
- Mr. Matt Chan
- Ms. Sarah Wodin-Schwartz
- Mr. Fabian Goericke
- Ms. Kirti Mansukhani
- Ms. Yun-Ju “Matilda” Lai
- Mr. Wei-Cheng Lien
- Ms. Nuo Zhang
- Mr. Ting-Ta “Ernest” Yen
- Mr. Chih-Ming “Gimmy” Lin

Conclusion

Thank You!