Integrated SiC Sensors & Electronics

SiC and AlN Material Properties

Property	Silicon Carbide 3C-SiC (6H-SiC)	AlN	Silicon	Diamond
Melting Point (^{o}C)	**2830 (2830) sublimes**	**2470**	**1420**	**4000 phase change**
Energy Gap (eV)	**2.4 (3.0)**	**6.2**	**1.12**	**5.6**
Critical Field (u10^{6} V/cm)	**2.0 (2.5)**	**10**	**0.25**	**5.0**
Thermal Conductivity (W/cm-K)	**5.0 (5.0)**	**1.6**	**1.5**	**20**
Young's Modulus (GPa)	**450 (450)**	**340**	**190**	**1035**
Acoustic Velocity (x10^{3} m/s)	**11.9 (11.9)**			

Material properties of SiC, AlN and other semiconductor materials.

LPCVD Cost Reduction

Precursor	Purity	State	Price per gram	Price per mol of SiC	Deposition Temperature (( )
1,3-Disilabutane*	98%	Liquid	$ 22	$ 990	750-850
Methylsilane**	99.9%+	Gas	$ 17	$ 798	750-850
Methyltrichloro-silane**	99%	Liquid	$ 0.062	$ 9.24	1000-1200

* - Current technology which previously demonstrated low stress, low resistivity films for sensor fabrication.

** - Proposed technology to be developed and characterized for improved cost.

High-T Metallization on 3C-SiC

SiC Resistance Testing

Optical images of (a) SiC-coated and (b) uncoated polysilicon structures following immersion in 65ºC KOH for 1 minute

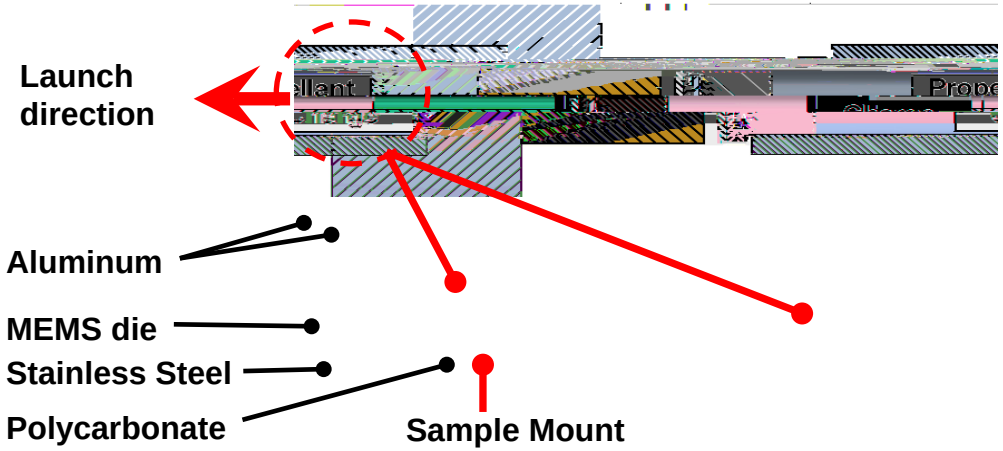
Material	Oxide Thickness after 100 hours in Air at 850^{O}C
Diamond-like Carbon (DLC)	Completely burned out after 24 hours
Si	300 nm
Poly-SiC	50 nm

SiC Sensor Operation at 600°C

- 7KH SROVFUVWDOOLQH6L&VHQVRU&UHVRQDWHV LQ DLU D
  °&

G-Shock Testing at 64,000 g

Gas Gun Schematics



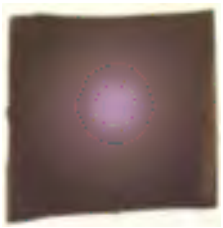
- G-shock Testing carried out at Aerophysics Research Center at University of Alabama in Huntsville
- Hard-launch soft-catch method
- Initial G-load is 64,000 g

Before G-shock
Sample 1 Device 1

After G-shock
Sample 1 Device 1

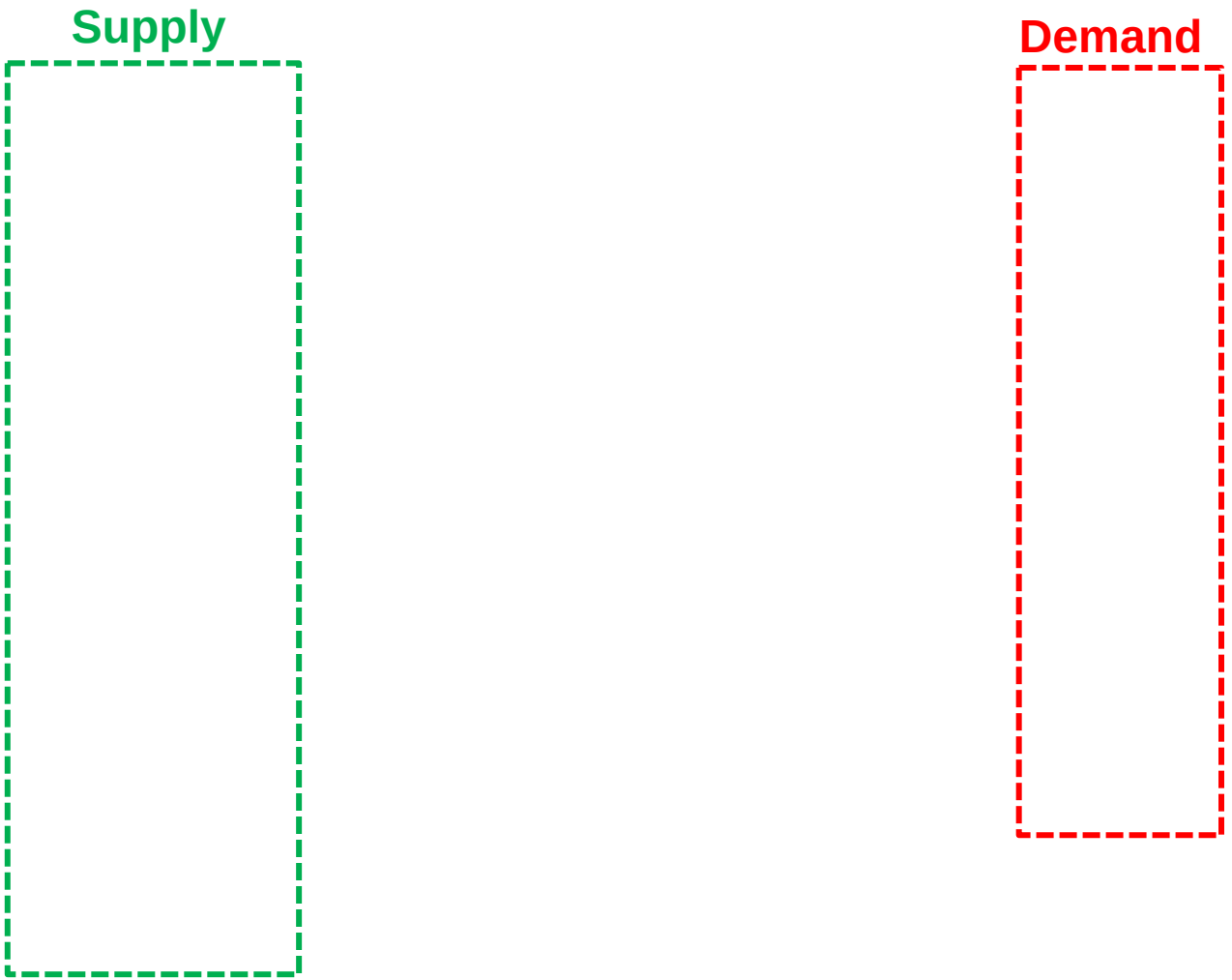
- No structural damage after g-shock at 64,000g
- Successfully operates (resonates) after enduring a 64,000 g shock

Exposure Testing

	Si Die	SiC Die
Before Exposure		
After 20 h Exposure		

Exposure Te/lm2 763mvg 0 Tc 0 Tw ( )T

Energy Flow for USA (circa 2006)



Source: Energy Flow Charts, LLNL, 2006 - https://eed.llnl.gov/flow

Geothermal Energy

U.S. Geothermal Resources

Western United States Geothermal Energy Resources:

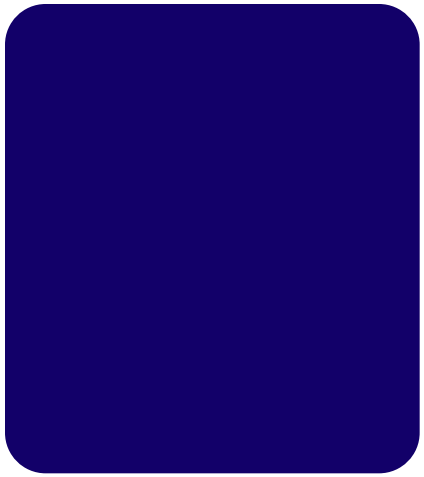
- **Hydrothermal = 30,000 MW**

- **Enhanced Geothermal**

Geothermal Resources in Japan

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

Sensor Cluster in the Ground



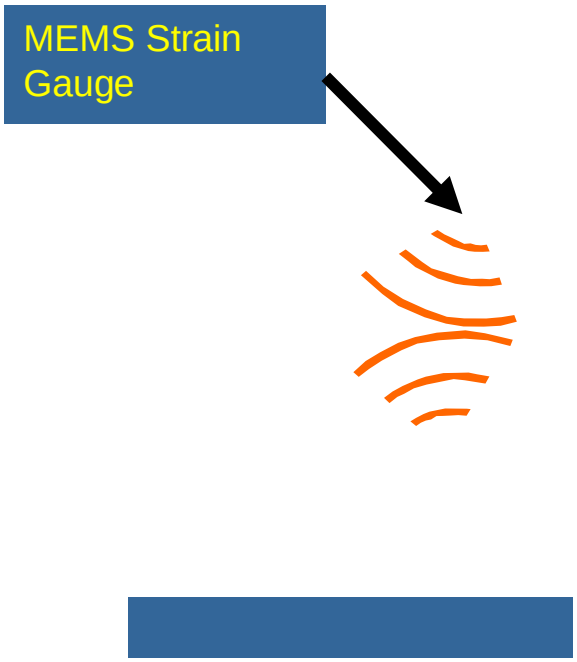
Cluster Sensor in the Ground

- Combustion chamber temperature
- Combustion chamber pressure
- Manifold absolute pressure
- Mass air flow sensor
- Oxygen sensor
- •
  •
- Pressure sensors
- Accelerometer array

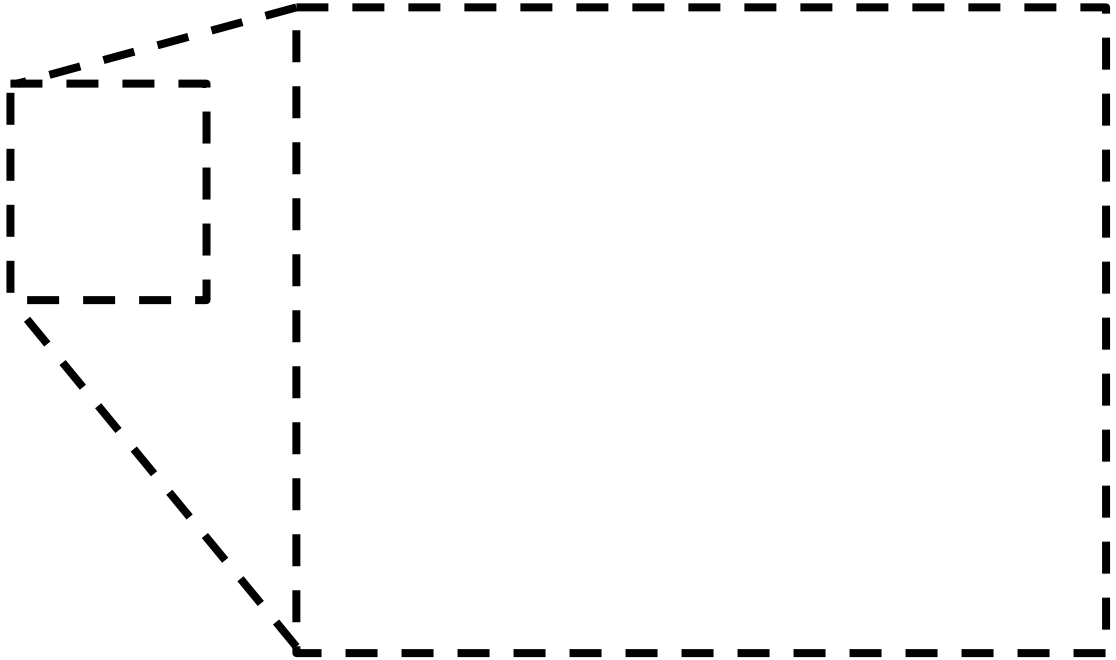
- Airbag accelerometers
- Air quality filtration sensor
- Rain sensor
- Passenger temperature
- Pedal position sensor

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

Sensor Cluster in the Automobile



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



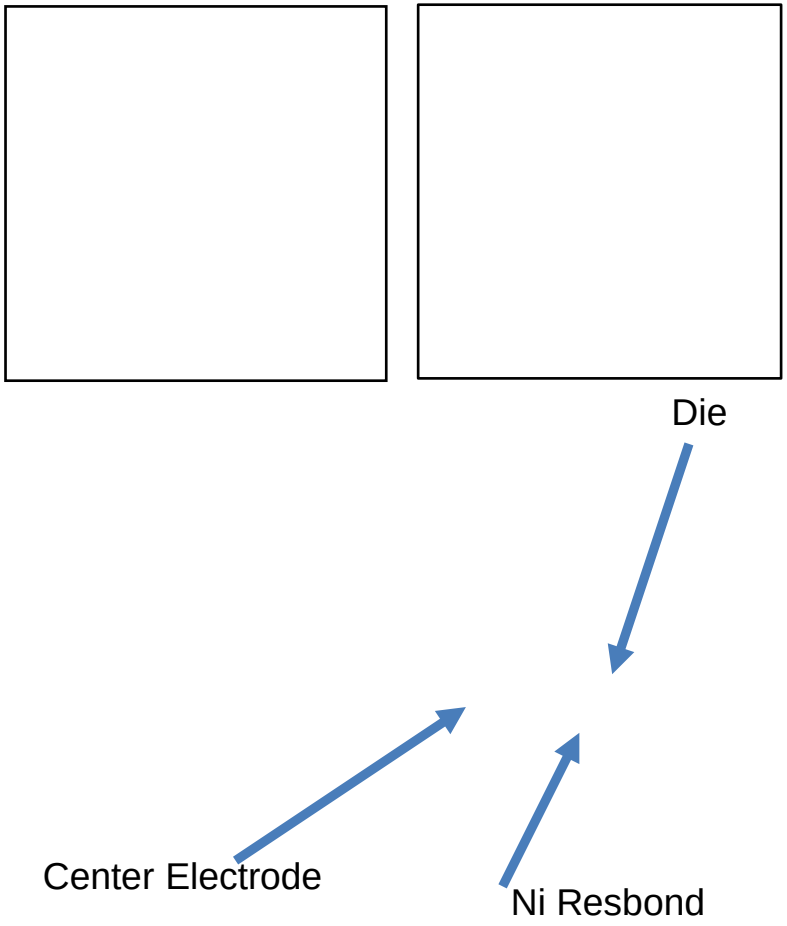
<u>Sensor Types</u>:
Strain Sensors
Pressure Sensors
Accelerometers

Molding & Vulcanization

- **4 embedded samples**
- **5x5mm2 each**

- **Array of SiC**

Cluster Sensor in the Auto Engine



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

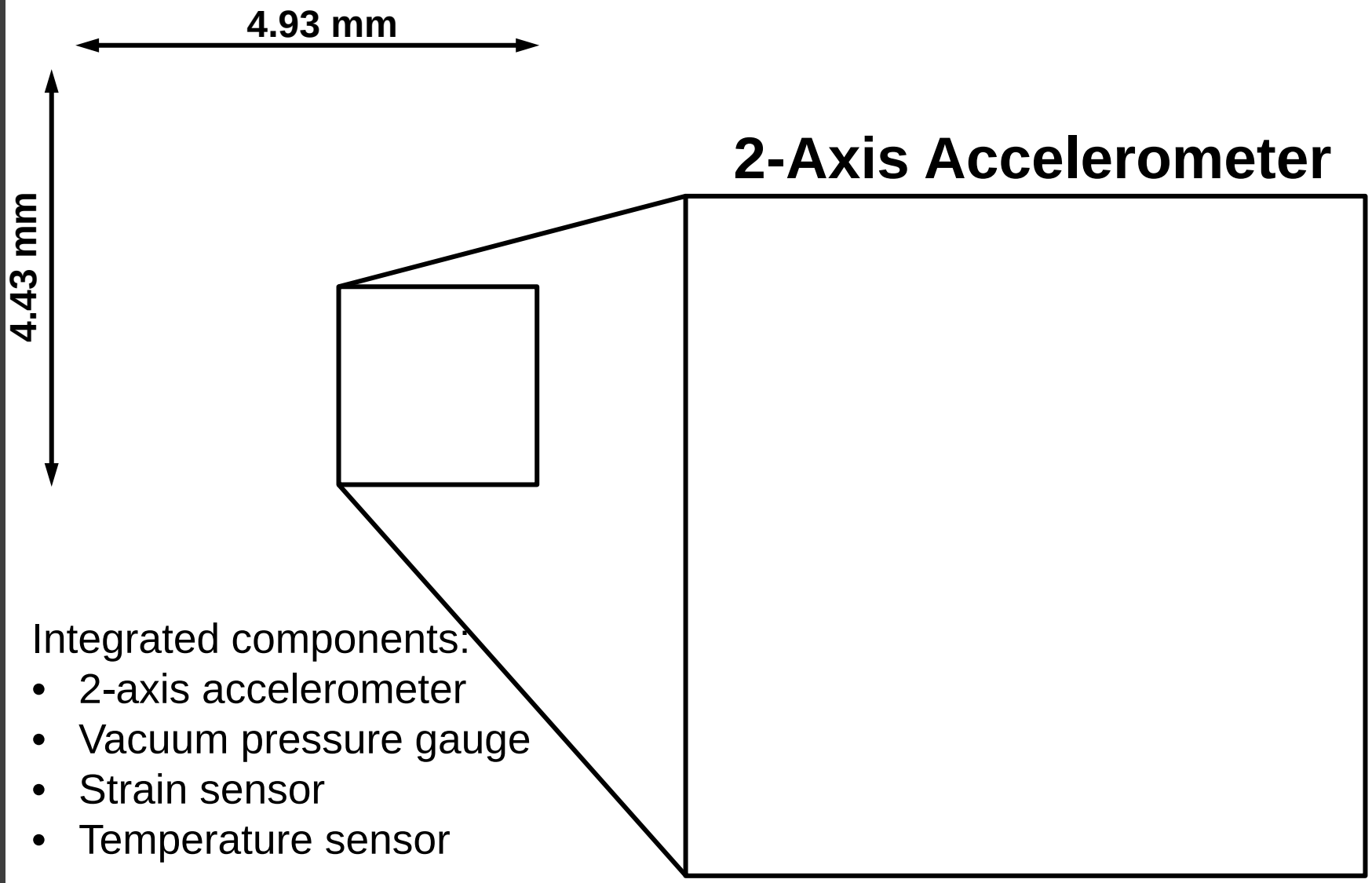
Cluster Sensor in the Infrastructure

Figure from The Economist Magazine

Advanced Sensor Cluster Prototype

- Temperature sensor is resistive type (resistance changes linearly with

Pre-Prototype Design



Integrated components:

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

Pre-Prototype Results

AlN Pressure Sensor Design

a = radius, h = thickness, y = deflection, E = Young's modulus, A_e = effective area of corrugated diaphragm, ρ = density, ν = Poisson's ratio,

Cluster Prototype Assembly

Cluster Prototype Assembly

Reference Device Open to Atmosphere on Top and Bottom

Cluster Prototype Assembly

Conclusion

Acknowledgements

- BSAC
- UC Berkeley Nanolab
- Prof. Roya Maboudian
- Dr. Carlo Carraro
- Dr. Maxime Vincent
- Dr. Ayden Maralani
- Dr. Gabriele Vigevani
- Dr. Debbie G. Senesky
- 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!