Electronic packaging for harsh environments

HiVe – Vestfold University College, Oslofjord Research and Innovation Park

Raveien 197, Borre/ Horten

18. November 2011 by SINTEF and HiVe

9:30 - Welcome (Nils Høivik, HiVe)

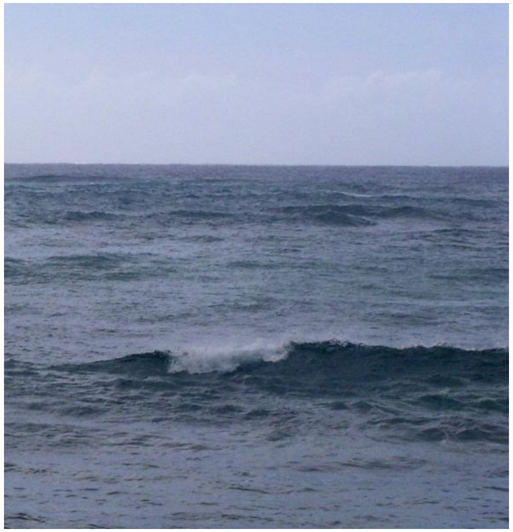
- ReMi (Fine Pitch Interconnect of Microelectronics and Microsystems for use in Rough Environments) – overview (Maaike MV Taklo, SINTEF)
- MEMS and microelectronics for ammunition, Isotropic Conductive Adhesive as interconnection (Jakob Gakkestad, FFI)
- Fingerprint sensor, Anisotropic Conductive Adhesive as interconnection (Øyvind Sløgedal, IDEX)

Break w/ fruit

11:00-

- HTPEP (High Temperature Power Electronics Packaging) – overview (Andreas Larsson, SINTEF)
- Unconventional oil exploration in hot environments (Truls Fallet, Badger Explorer)
- SiC MEMS for harsh environments (Matt Chan, UC Berkeley)
- Final remarks (Knut Aasmundtveit, HiVe)

12:30 End of seminar



2008–2012 (Q1)
8.5 MNOK

Forskningsrådet

Seminar HiVe 2011-11-18

ReMi (Fine Pitch Interconnect of Microelectronics and Microsystems for use in Rough Environments) – overview

SINTEF: Frøydis Oldervoll, Andreas Larsson, Astrid-Sofie Vardøy, Maaike M.V. Taklo
HiVe: Hoang Vu Nguyen, Lars Hoff, Knut Aasmundtveit
Conpart: Helge Kristiansen

Companies: FFI, Nammo, IDEX, WesternGeco, OSIO

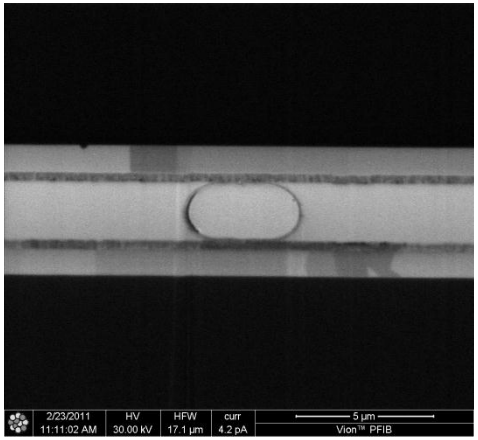
Project content

- Motivation: Reliability challenges of interconnects in harsh environments
- Technical solution: Mechanical compliance of metal coated polymer spheres

- Variants:
  - Isotropic conductive adhesive
  - Anisotropic conductive adhesive
  - Ball Grid Array assembly

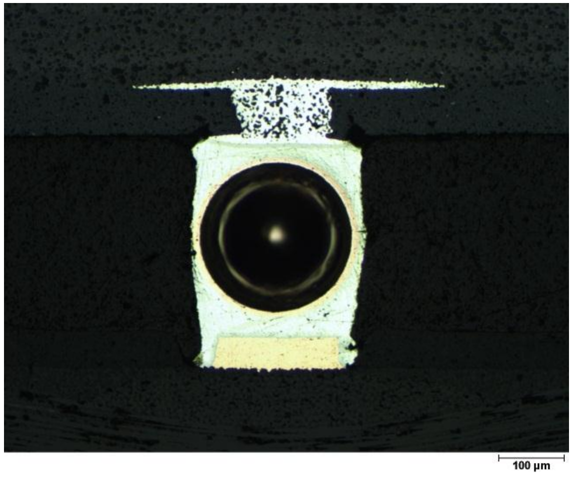
- With three case studies
  - Fuse, Finger print reader,
    Ceramic carrier

4 µm, Au coating
Several spheres
per interconnect



Metal coated polymer spheres. Various sizes for various applications.

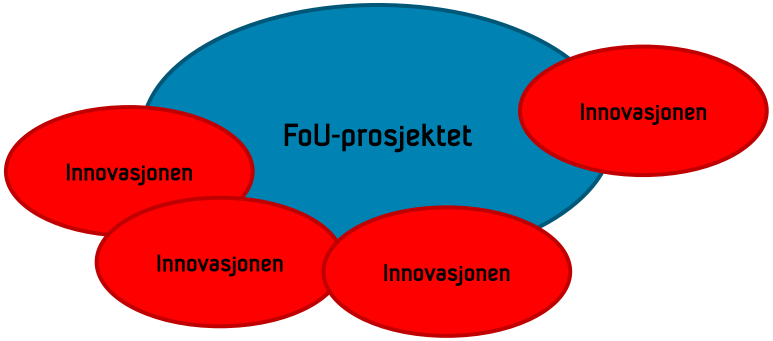
310 µm, Sn coating
One sphere
per interconnect



The presented project, ReMi, is a KMB sponsored by the BIA program of The Norwegian Research Council

Increased value for the industry

User-driven Innovation Projects (BIP) and **Knowledge-building Projects with User Involvement** (**KMB**) are the key instruments employed by the BIA programme, and funding will be awarded to ambitious projects that place great demands on the implementation capacity of the project participants. Importance is attached to **encouraging cooperation** among companies and between companies and research groups, both nationally and internationally. Innovative and experimental methods will be applied under programme as part of the effort to find optimal instruments for realising the potential for value creation in Norwegian trade and industry. Emphasis will also be given to **disseminating research findings** and increasing **awareness of the significance of user-driven research**. The programme's communication measures will include newsletters, websites with web casts, reports, media contact and the annual BIA day.



Today's message

ReMi has created value for the partners

- and beyond

And will create more for the future

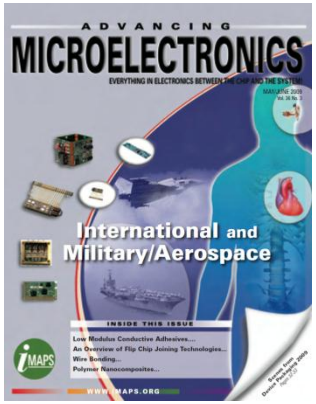
Possible next step: "Innovasjonsprosjekter i næringslivet"

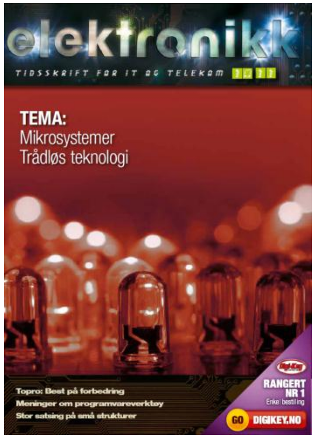
NEW MAJOR FUNDING OPPORTUNITY FOR INDUSTRY:

NOK 450 million in funding for innovation projects

This autumn's call for proposals under the Programme for User-driven Research-based Innovation (BIA) is the largest ever of its kind.

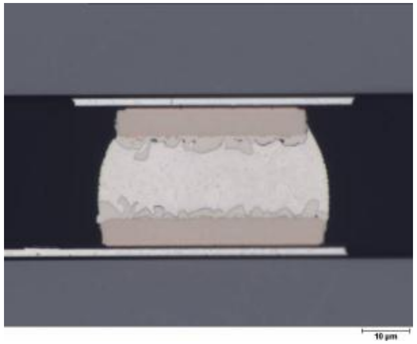
Dissemination of the project





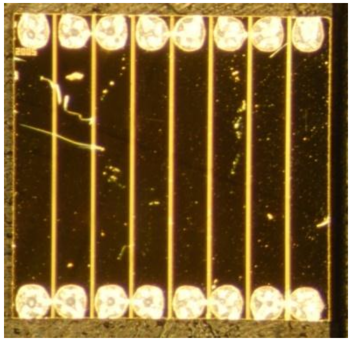
- Presentations of the **overall project**:
  - Seminar "Bonding technology for rough environments" 3. Dec 2010
  - Smart System Integration in Dresden 2011
  - Article in "Elektronikk": http://viewer.zmags.com/publication/56fdbb68#/56fdbb68/30
  - The seminar today
- **Examples** of presentations of detailed project results
  - Case Fuse: Journal of Micro/Nanolithography, MEMS, and MOEMS, Advancing Microelectronics
  - Case Finger print reader: MME 2011
  - Case Ceramic Carrier: To be presented at ECTC 2012
  - PhD study: ECTC 2011
  - Related work: Device Packaging Conference 2011, Chip Scale Review 2011 (JEMSiP_3D, ENIAC)

The technical challenge



Brittle IMC formed in a SnAg microbump (Johannessen et al., IEEE Trans. Adv. Packag. 2009)

- Thermo mechanical stress in substrate, chip, interconnect and fill materials
  - Mismatch in coefficient of thermal expansion
  - Large differences in Young's modulus
  - Built in stress from assembly at elevated temperature
  - Stress from external load or thermo mechanically during storage, transport and application
- Brittle intermetallic phases in interconnects
  - Mechanical stress leads to failures
- Fine pitch
  - Lack of process control leads to failures
- **How can reliability be improved by introducing metal coated polymer spheres?**



Ag Epoxy dispensed on fine pitch MEMS device

How do we understand reliability?

"Knuten" 1882, virtualtourist.com

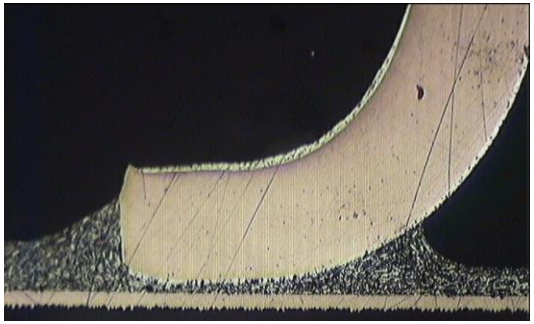
- For a product in industry
  - Survive a range of standardized tests
- For research
  - **Stress until failure**
    - Go beyond the standardized tests when needed
    - Perform accelerated tests
    - Perform relevant tests
  - Understand the physics of the observed failures
    - Otherwise hard to know that acceleration is correct
      - E.g. phase changes in polymers must be known

fasdprevention.wordpress.com

- **Overall target: Understand how to predict lifetime for a given application**

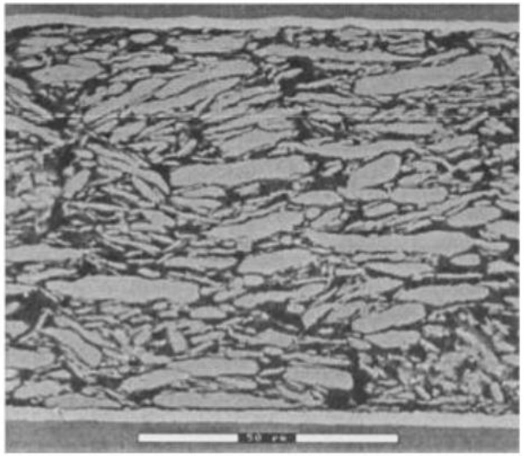
Three variants and three case studies

Isotropic conductive adhesives (ICA)

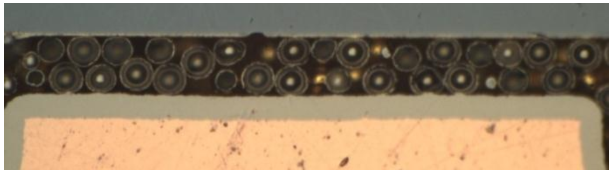


Silver epoxy, a traditional ICA

- Used in electronics packaging and interconnect for decades
  - Composite material
    - Adhesive resin
    - Conductive particles (metals)
- Typically known as silver epoxies
  - Epoxy adhesive loaded ≈ 30% Ag (volume %)
  - Matrix and fillers are very different materials
    - E-modulus ratio: 2-orders of magnitude
    - Large CTE miss-match
  - **Micro-cracking between filler and matrix**
- Brittle behaviour
  - Introduce plasticisers, reduce T_g of matrix
    - Increases CTE miss-match
- **Replace Ag with MPS to improve reliability**



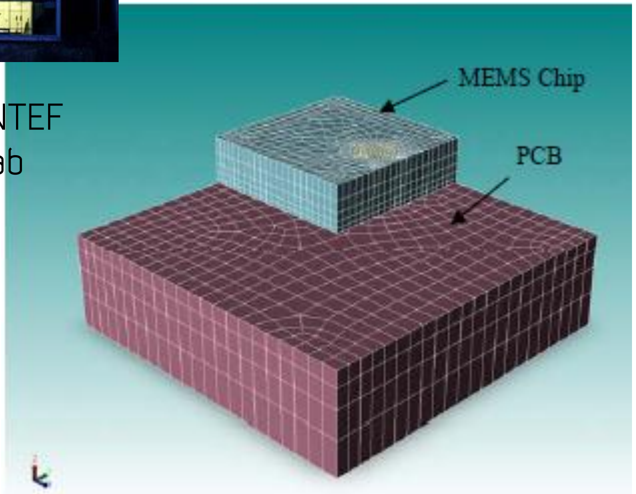
Kristiansen et al., Pan Pacific 2009



LM image of ICA with MPS, H-V. Nguyen, Seminar at HiVe., Vestfold University College, Des 03 2010

MEMS from SINTEF MiNaLab

ICA case study: MEMS fuse

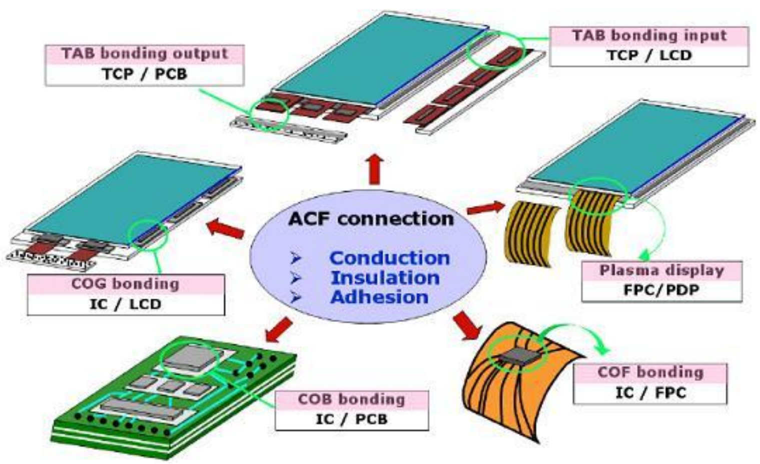


- Silicon MEMS device
- Assembly directly on PCB
  - A severe CTE mismatch challenge
- ICA with 3-4 and 30 µm MPS, Ag epoxy as reference
- Stencil printing

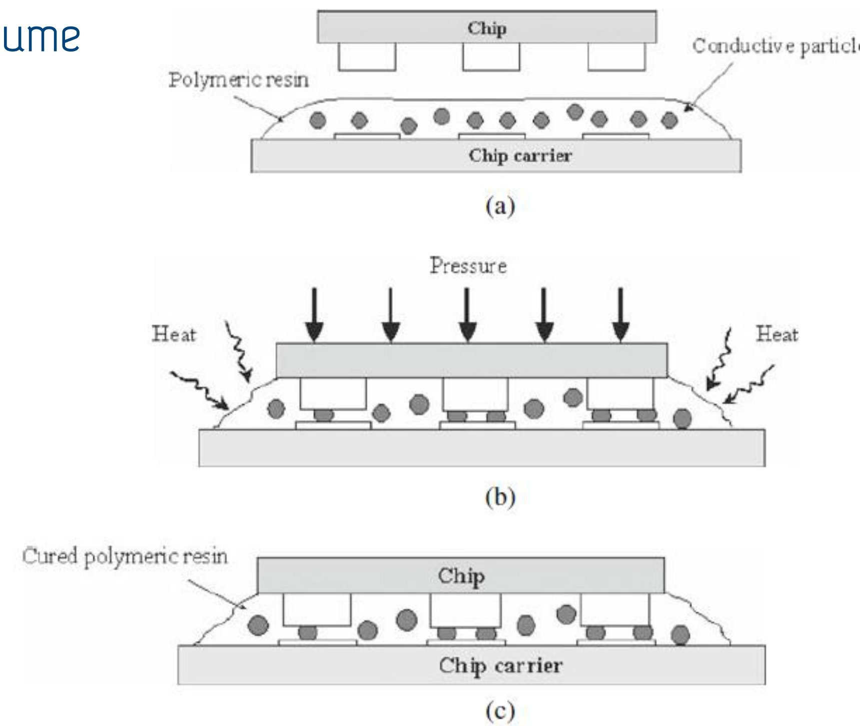
- **Thermal cycling** of chips assembled in parallel on large test boards
- **Thermal cycling followed by firing tests** of chips assembled on smaller boards
- **Characterization**: Electrical, shear strength measurements and cross section inspection
  - Viable technology for the purpose, as to be presented by FFI

Anisotropic conductive adhesive/film (ACA/ACF)

- Provides unidirectional electrical conductivity
- The directional conductivity → relatively low volume loading of conductive filler (5-20 vol%)
- Fine pitch implementation
- ACF is commonly used in LCD screens

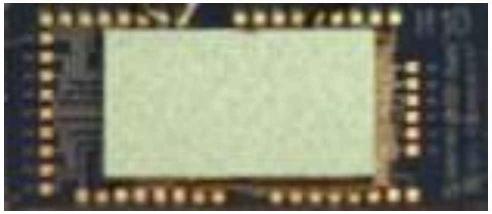


http://www.acffilm.com/



ACF case study: Fingerprint sensor

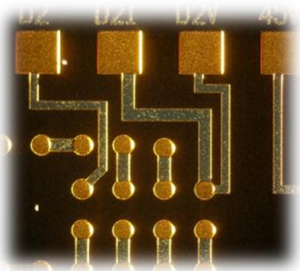
- MEMS onto ASIC, fine pitch
- Anisotropic conductive film (ACF)
  - Film from subcontractor (using MPS from Conpart)
  - Assembly (VUC/Tampere)
    - Lamination (below T_g)
    - Bonding (above T_g)



Assembly at Tampere University of Technology (pressure needed)

Wafers from SINTEF MiNaLab

- "**Reflow**" repeated for higher level assembly tests
- **Thermal shock cycling, storage and humidity** for application tests
- **Characterization:** Electrical, cross-section, surface analysis, Thermal analysis (T_g) with DSC
  - Viable technology for the purpose, as to be presented by IDEX

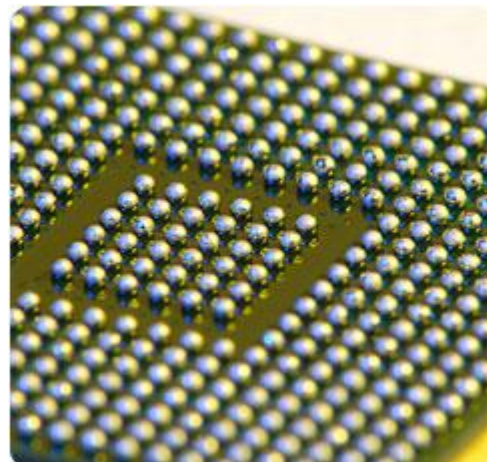


Pads for daisy chains and 4-ponit probing

Ball Grid Array balls (BGA)

- Transition from SnPb to SAC has resulted in reduced cycles to failure
- Combination of
  - Thermal expansion miss-match
  - Non-compliant ball
- Causes reliability issues
  - Severe cyclic strain in solder
  - Severe stress in component
- Limits maximum size of component / Number of I/O's

Whalley, HDP Feb 2010



http://www.bga.net/

RoHS, since 1. July 2006

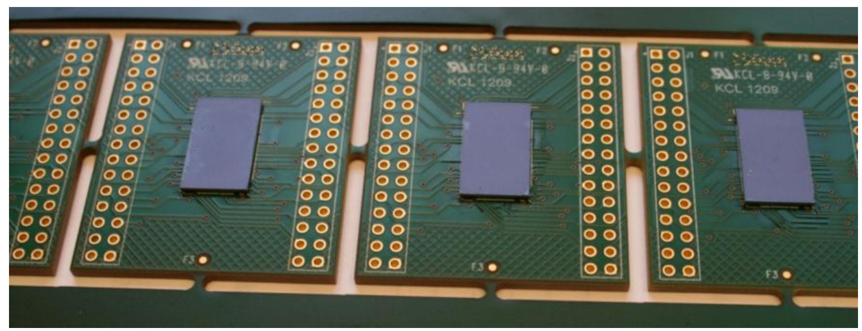
http://www.sekisui-fc.com/

- **Replace SnPb/SAC with MPS to improve reliability**

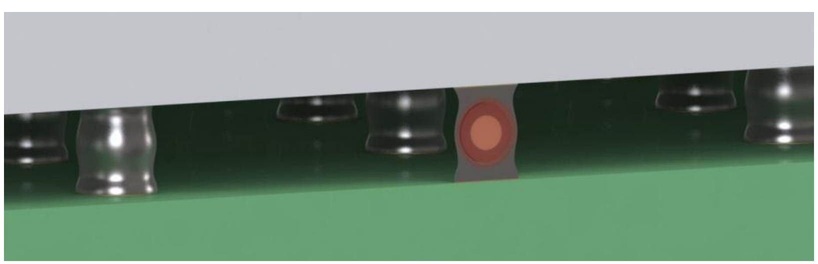
BGA case study: Ceramic carrier

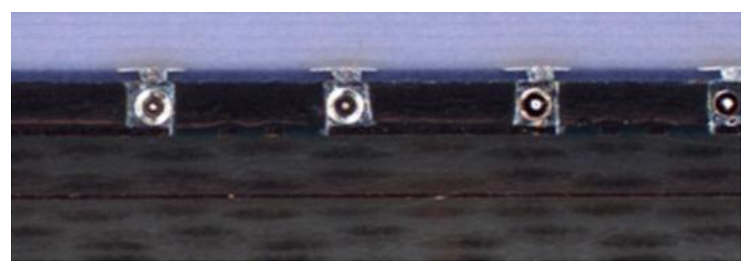
Assembly of LTCC onto PCB

- LTCC carrier onto PCB
- MPS with solder as BGA to avoid underfill, called Plastic Core Solder Balls (PCSB)
  - Spheres from Sekisui
- References: SnAgCu BGAs



- Mounting onto PCB
- Reliability studies

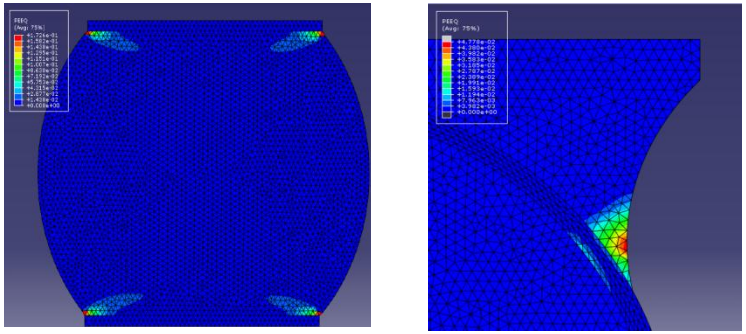




Increased value for the industry

- Stencil printable **ICA** with a larger tolerance for thermo mechanical stress
- **ACF** for Fingerprint sensor, beneficial for both silicon and polymer based solutions
- **PCSB** assembly feasible for a ceramic carrier (reliability tests to be performed)

- All results achieved so far support the theory about increased reliability, in particular with regard to shock and thermal cycling, due to the **increased compliance** of a system with MPS



F. Guillén Marín, D.C. Whalley, H. Kristiansen and Z. Zhang "Mechanical Performance of Polymer Cored BGA Interconnects" Proceedings of the 10th IEEE Electronics Packaging Technology Conference, EPTC, Singapore, Dec 2008, 316-321, DOI: 10.1109/EPTC.2008.4763454

Nammo
IDEX
WesternGeco
conpart®
MOSAIC solar technology
VESTFOLD UNIVERSITY COLLEGE
OSI Optoelectronics AS
An OSI Systems Company

SINTEF

Technology for a better society

FFI Forsvarets forskningsinstitutt

ICA as interconnection for MEMS and Microelectronics in Ammunitions

J.Gakkestad,
FFI

Electronics Packaging for Harsh Environment

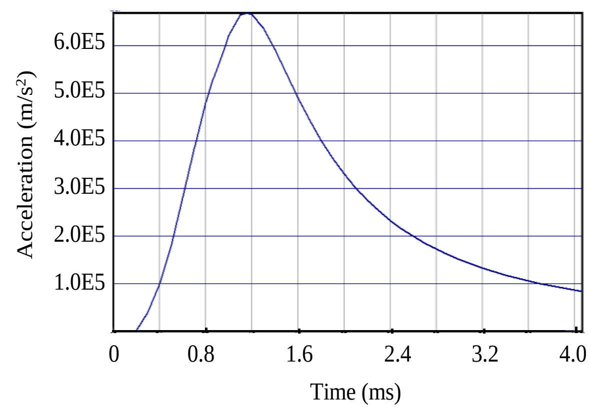
Vestfold University College
18. Nov 2011

Outline

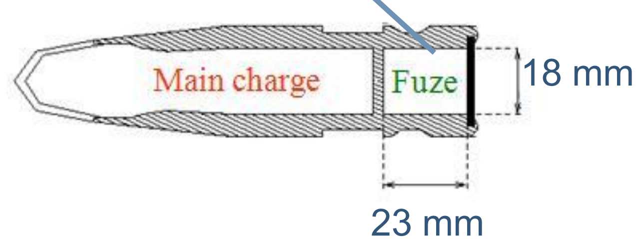
- Background and motivation.
- Experiments.
- Characterization.
- Conclusion.

Background and motivation

- The electronic components in a fuze are exposed to severe mechanical forces during firing.
- For 30 mm ammunition, setback acceleration exceeds 60 000 g and the centripetal acceleration is 9000g/mm out of center.
- In 30 mm ammunition, the electronic components should not occupy more than 1-3 cm^3.

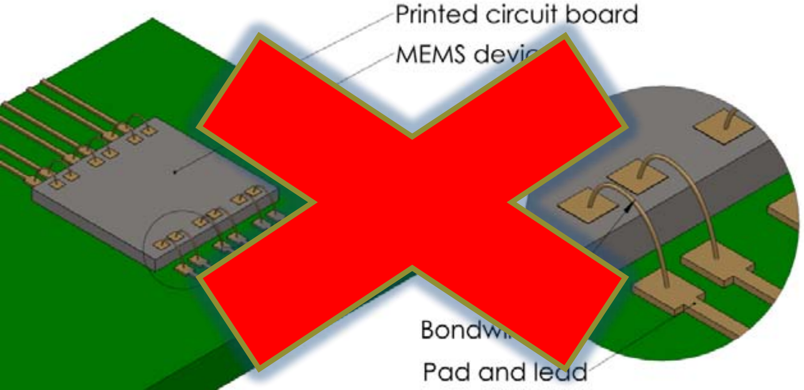


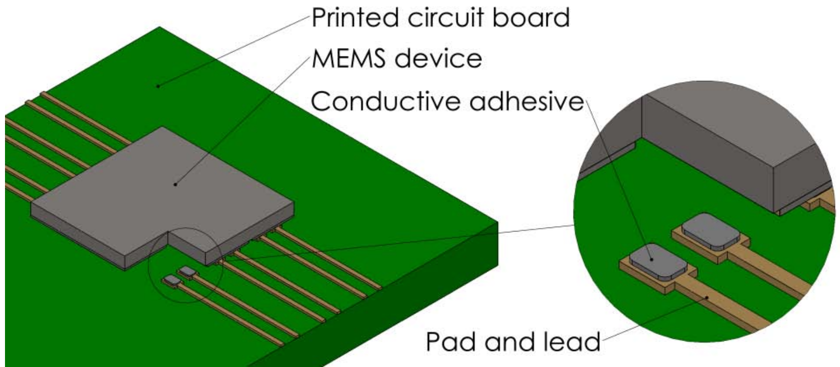
MEMS & electronic components e.g. programmable unit, power supply ++



Mounting of MEMS to PCB

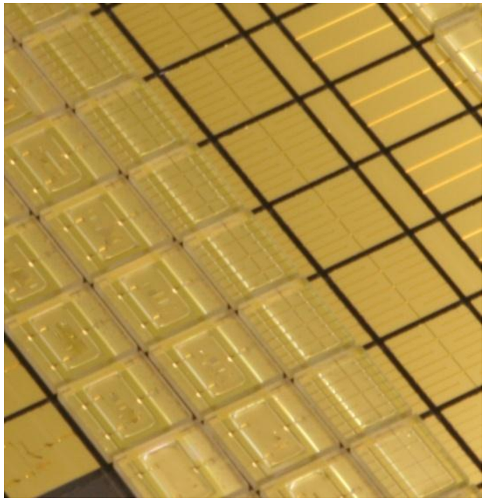
- It is advantageous to mount the MEMS chip directly to PCB omitting extra packaging level. This will require less space and cost saving is possible.
- Using bondwires for direct contact between MEMS and PCB is not a favorable option.
- Using isotropic conductive adhesive (ICA) for interconnection between MEMS and PCB could be a possibility. However, performance of ICA this demanding environment must be investigated.

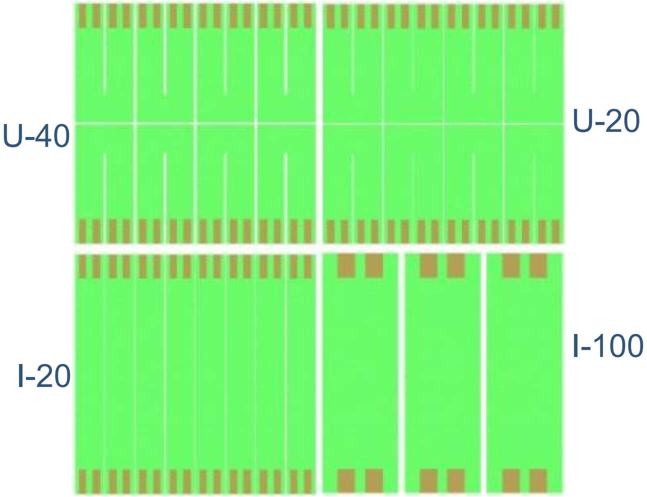




Test structures

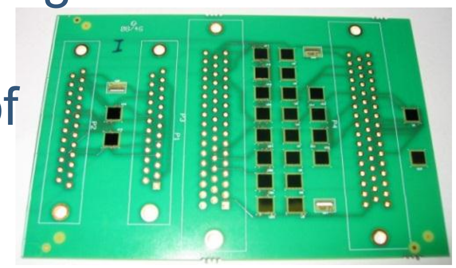
- MEMS test structures for interconnect testing were designed and fabricated on the same SOI wafers as the real MEMS devices.
- Cr, Ni, Au is sputtered onto the wafer and used as conductive layer
- Size of each structure is 3.5 X 3.5 mm.
- Pad size is 250X350 µm (I-100) and 100X350 µm for the other test structures.

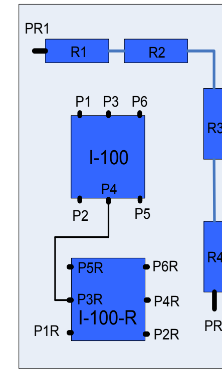




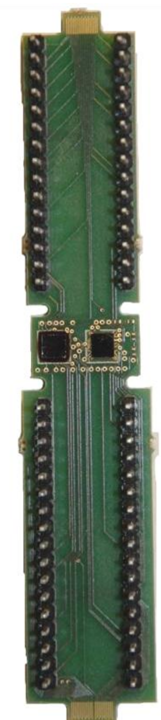
Test boards for environmental testing

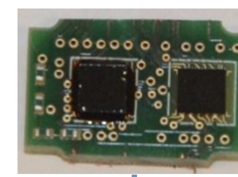
- Board used mainly for temperature cycling test contains daisy-chain structures an structures for Kelvin measurement of contact resistances.





- Board used for firing test. Possible to mount 2 I-100 test structures and 2 U-40 test structures. Contains also 4 pcs of 0402 resistances on each side. Possible to do Kelvin measurement before and after firing test.



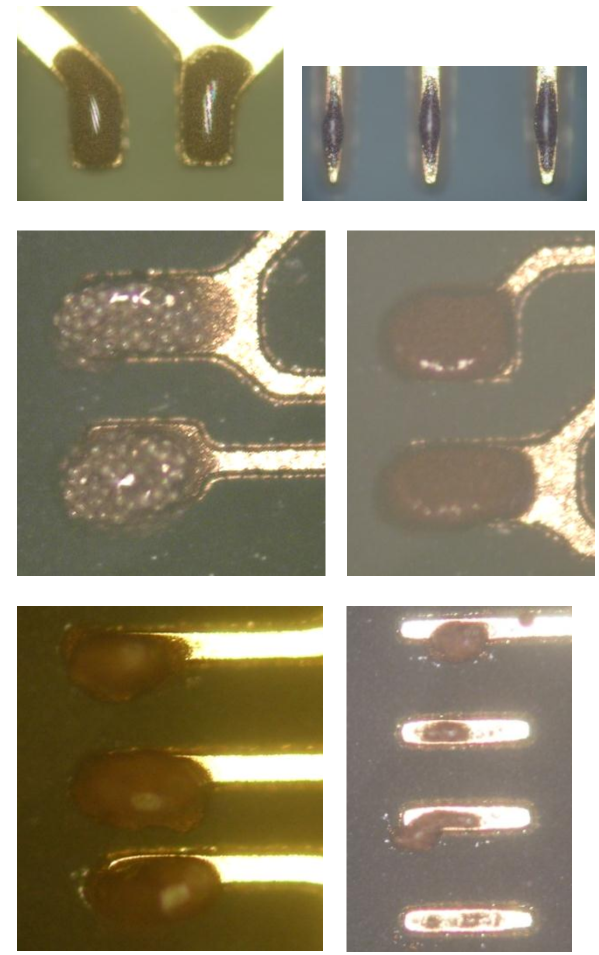


Size: $9X16\ mm^2$

- Test structures placed on the board using a MY9 pick & place machine.

Stencile printing of ICA

- Used ICA with different sized polymer spheres.
  - 30 µm : silver coated.
  - 4µm : gold coated.
- ~50% volume fraction of spheres is used.
- Printing results dependent upon many factors such as:
  - Viscosity
  - Shear thinning
  - Stencile +++
- Pad with size 100X350 µm not suitable for ICA with 30µm spheres.



Experimental setup

- Temperature cycling test according to MIL-STD-883 G method 1010.8 test condition B (-55°C - 125°C).
  - 10 cycles
  - 100 cycles

- Recovery firing tests. Temperature cycled samples were used in this experiment.

Initial measurement of contact resistances

- I-100 contact resistances

ICA with:	Mean value (Ω)	Std. Dev (Ω)
30 µm silver coated spheres	0.317	0.149
4 µm gold coated spheres	0.103	0.030

  – Difference mainly caused by thin silver coating & silver delaminating.

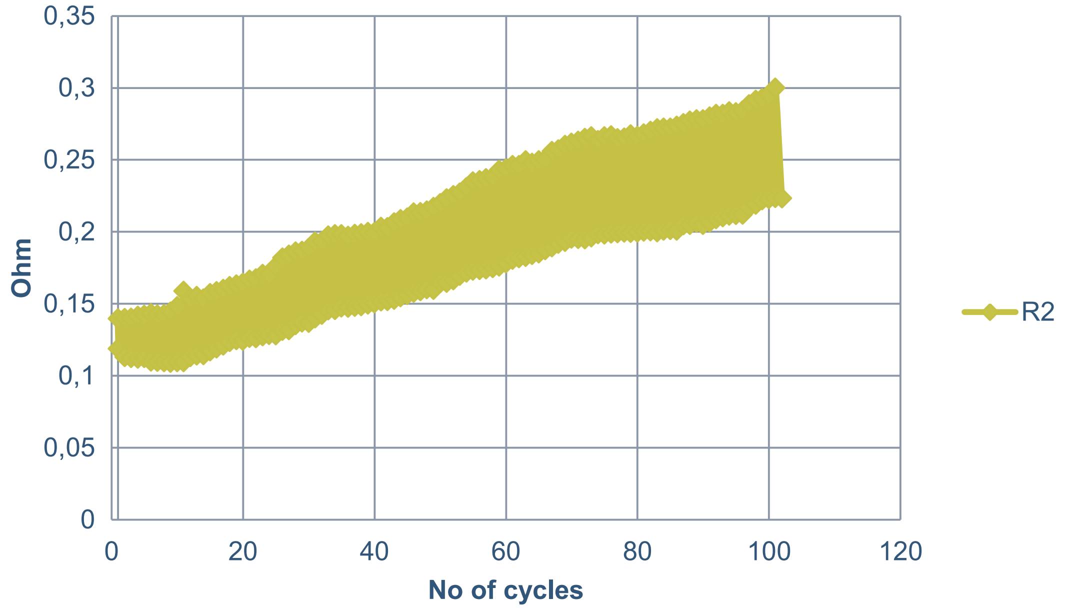
Results – temperature tests

- No resistances failed for the I-100 test structures (coarse pitch).

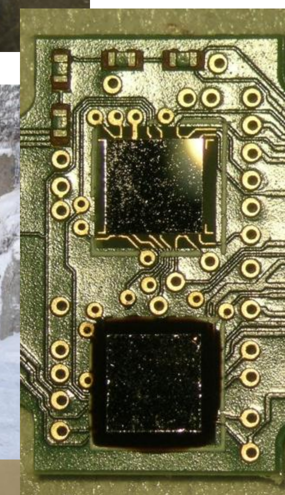
	ICA with	No of cycles	Ω before	Ω after	% change
I-100	30 µm spheres	10	0.317	0.366	15.5
	4 um spheres	10	0.091	0.079	-13.2
	30 µm spheres	100	0.361	0.675	87
	4 um spheres	100	0.112	0.217	93.7

Results – temperature tests

- No resistances failed for the I-100 test structures (coarse pitch).



Firing test



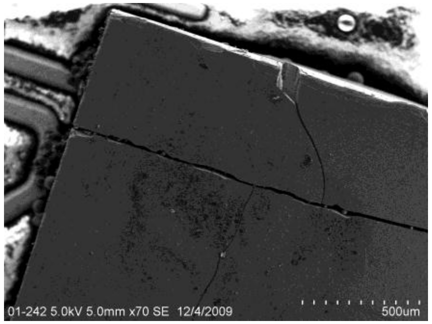
Firing test results for I-100 test structures

- All fired test structures have been exposed to temperature tests.
- 31 out of 36 contact resistances passed recovery firing test
- Two test structures without underfill cracked.

ICA with	No of cycles	Ω before	Ω after	% change
30 μm spheres	10	0.224	0.205	-8.5
4 um spheres	10	0.082	0.097	18.3
30 μm spheres	100	0.675	0.733	8.6
4 um spheres	100	0.217	0.257	18.4

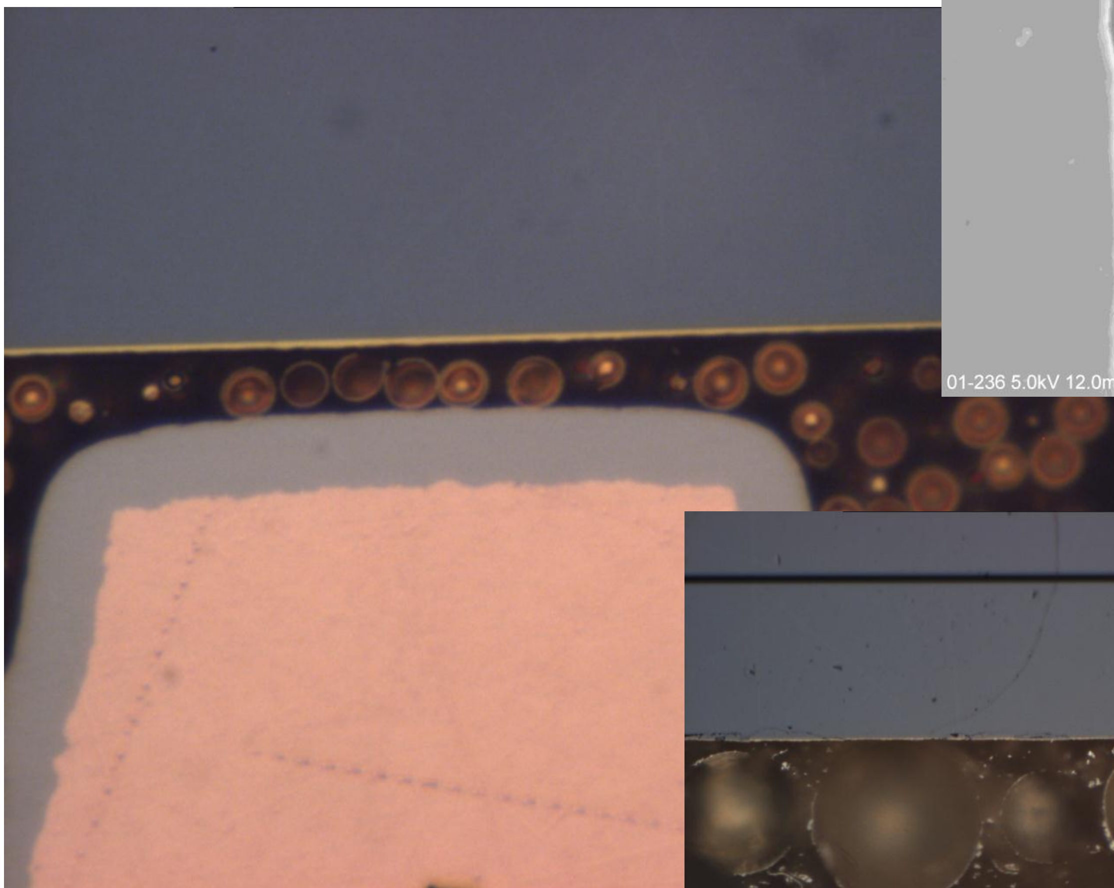
Firing test results for I-100 test structures

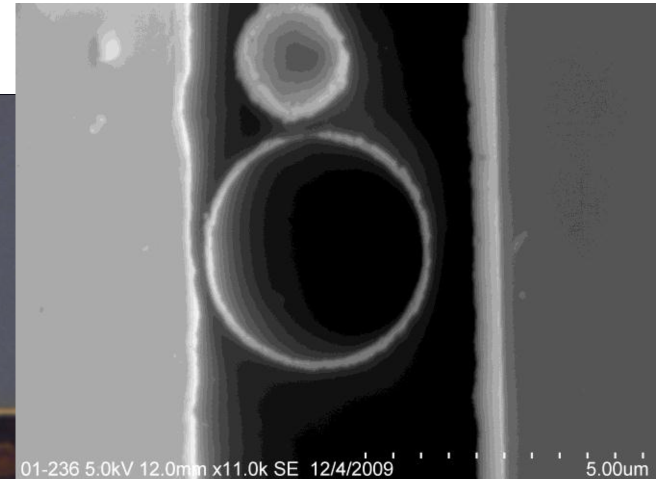
- All fired test structures have been exposed to temperature tests.
- 31 out of 36 contact resistances passed recovery firing test
- Two test structures without underfill cracked.

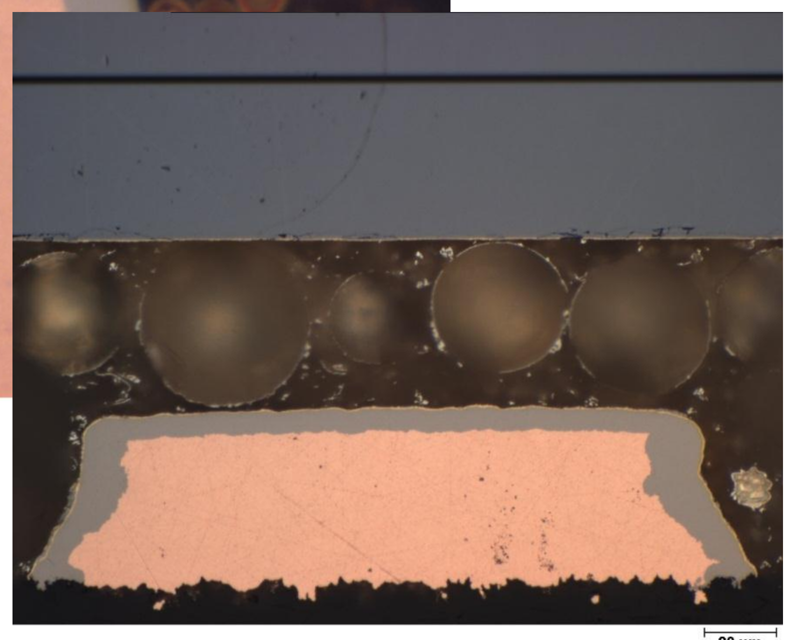


ICA	Board no	Underfill	Raverage after temp cycling (Ω)	Raverage after firing (Ω)	% change
30µm	I1	yes	0.561	0.544	-3.0
30 µm	I1	no	0.788	0.923	17.1
4 µm	I3	yes	0.197	0.210	6.6
4 µm	I3	no	0.236	0.305	29.2

Cross sections

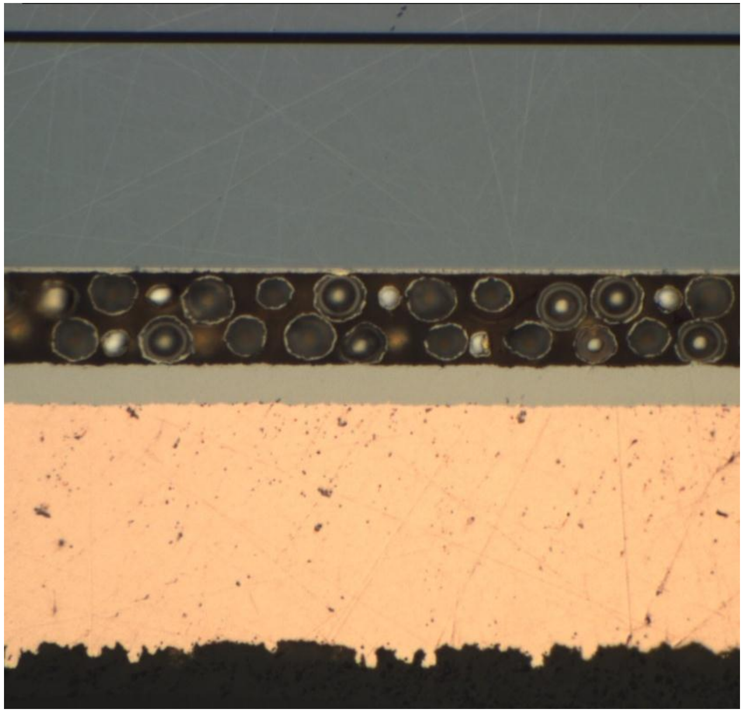






Conclusion

- Stencil printing process must be improved.
- ICA based on highly uniform metal coated polymer spheres seems to be a viable technology for mounting MEMS devices directly to PCB.
- Using this ICA technology may give higher packaging densities and reduced cost in future fuze applications. However, more testing must be carried out.



FINGERPRINT SENSOR PACKAGING

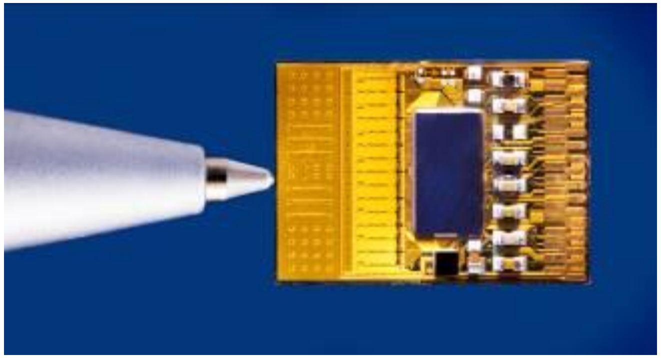
Øyvind Sløgedal
Business Development Manager
Idex ASA
HIV 18112011

Navigating Unknown Terrain

http://youtu.be/x8q9_oMji5Y

Our business

IDEX develops and delivers world leading swipe fingerprint sensor technology, products and authentication solutions

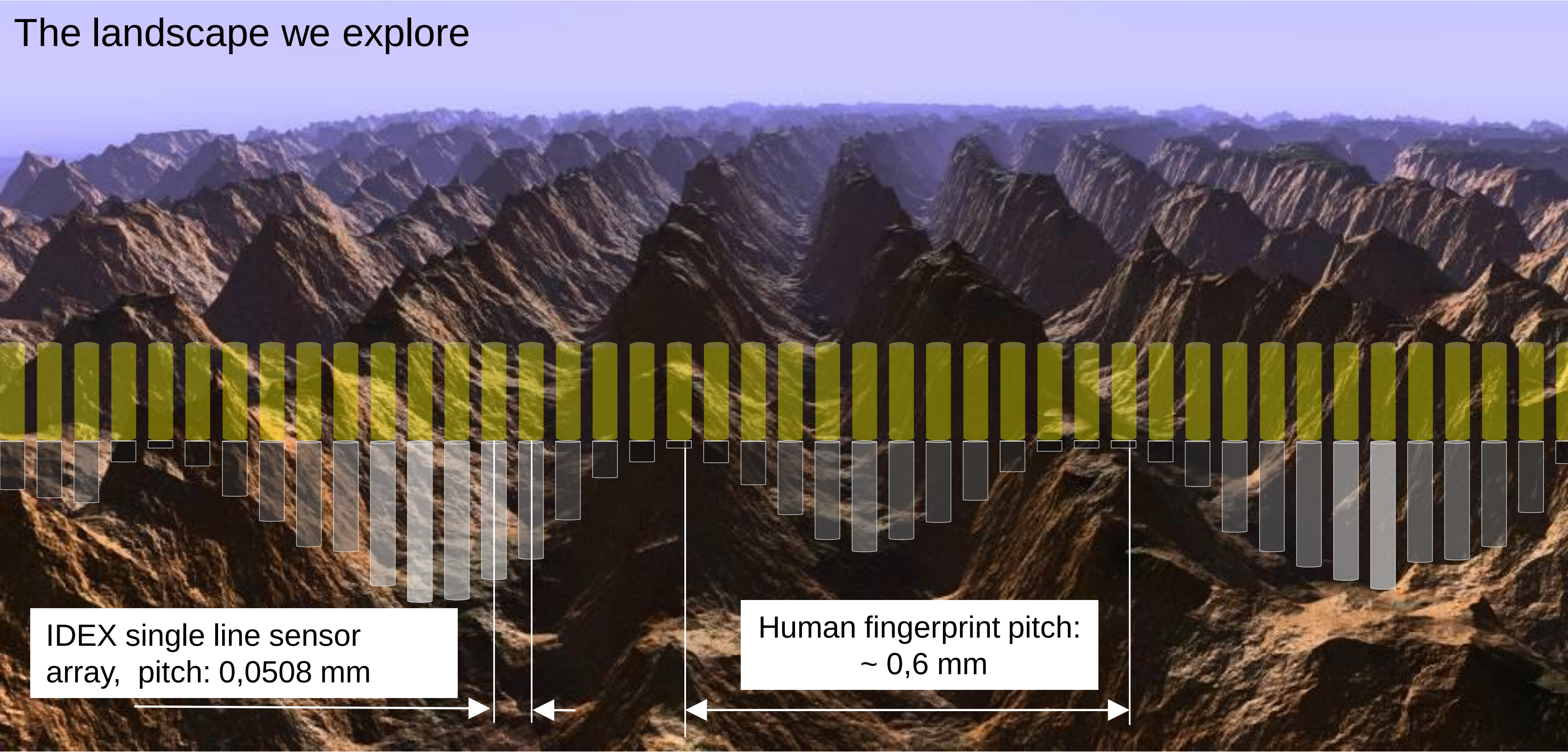


IDEX

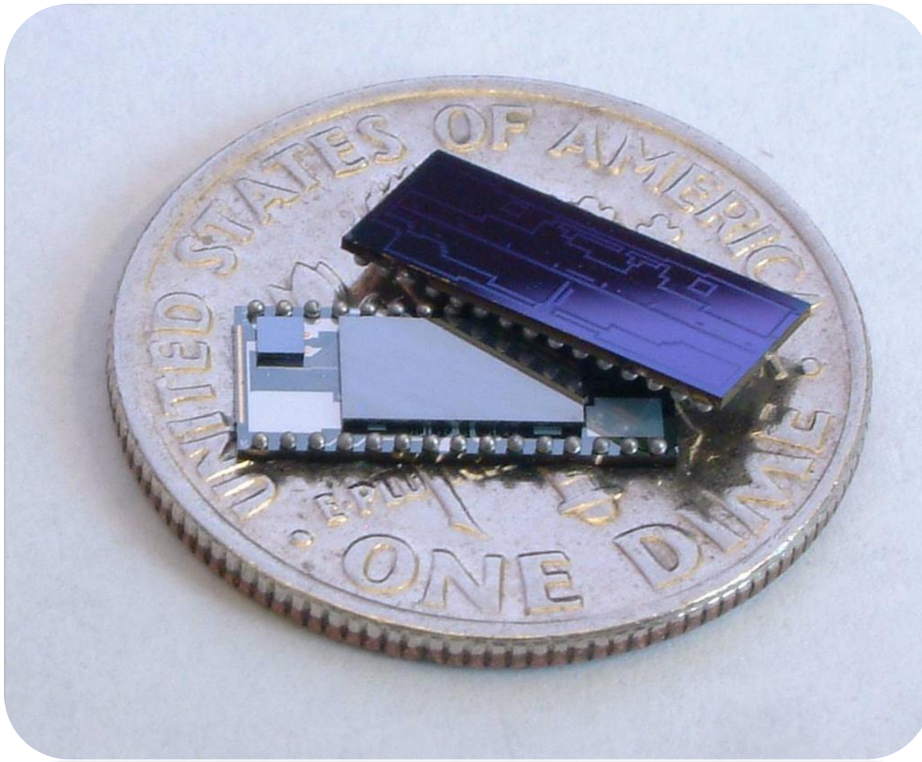
About IDEX ASA

- IDEX is headquartered at Fornebu (Oslo), Norway with representative offices in Philippines (Far East).
- 21 employees
- IDEX is a public company and shares trade at the Oslo Axess list at Oslo Børs (Oslo Stock Exchange)
- Full focus on volume ramp-up manufacturing
- More than 10 companies are designing SmartFinger® Film into demonstrators, prototypes or products

Swipe sensing

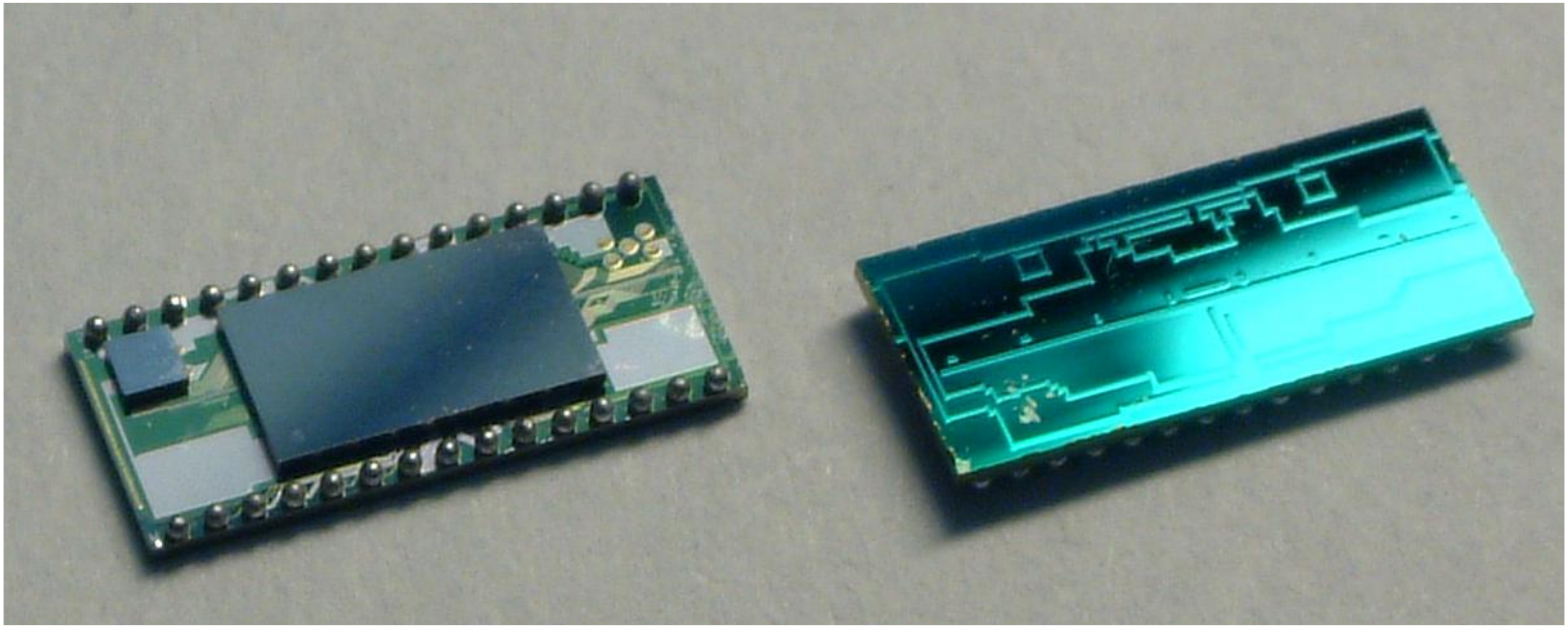


SMARTFINGER® Sensor Components

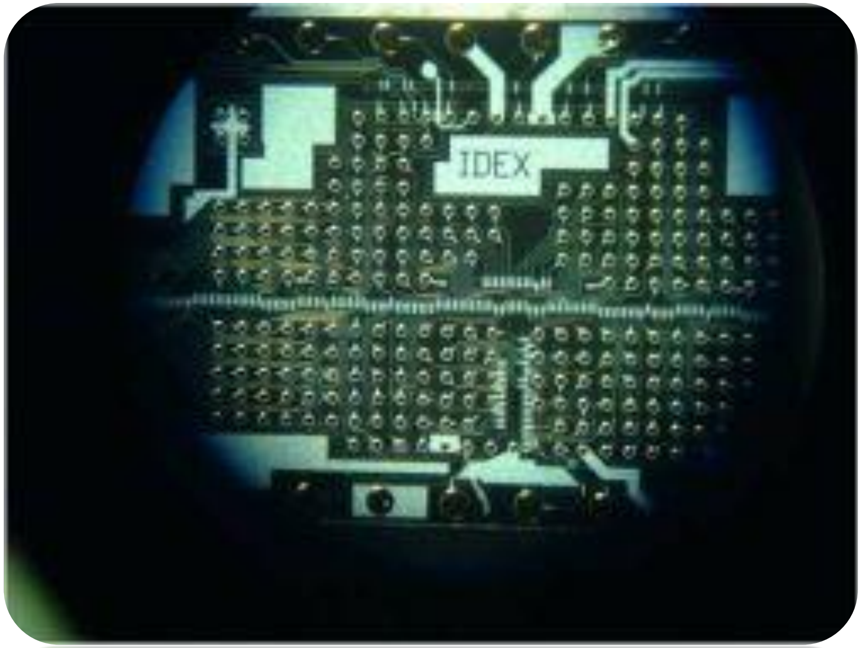


- Sensor Substrate 5x10 mm
- Analog Front End ASIC
- Bare Die ESD Diode
- 2nd Level Interconnects

Chip Scale Configuration

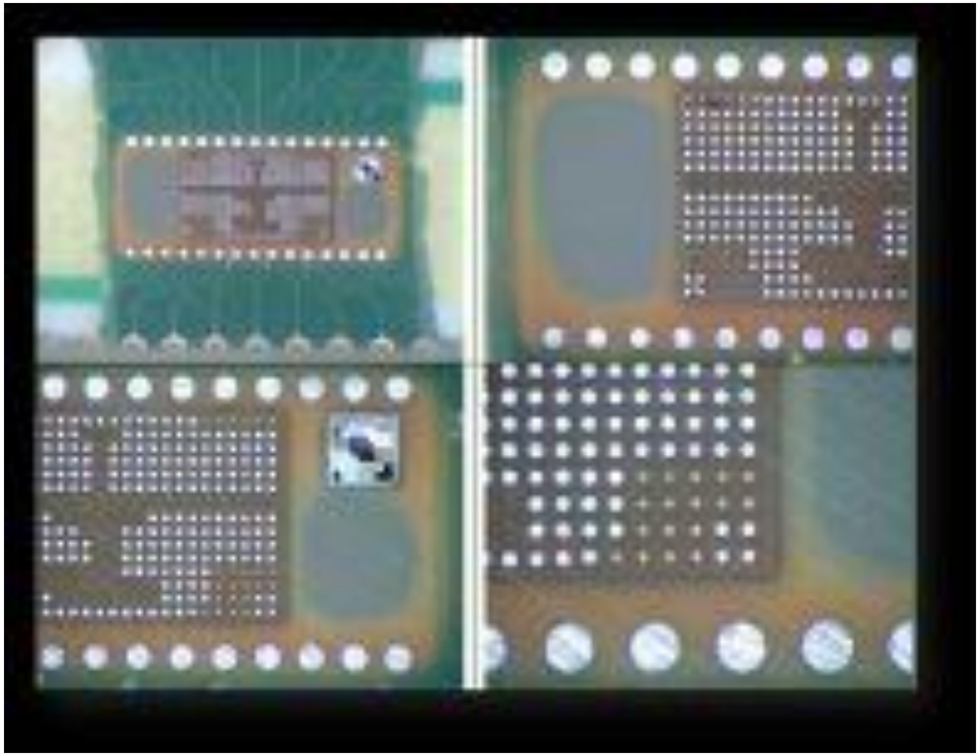


The Challenge

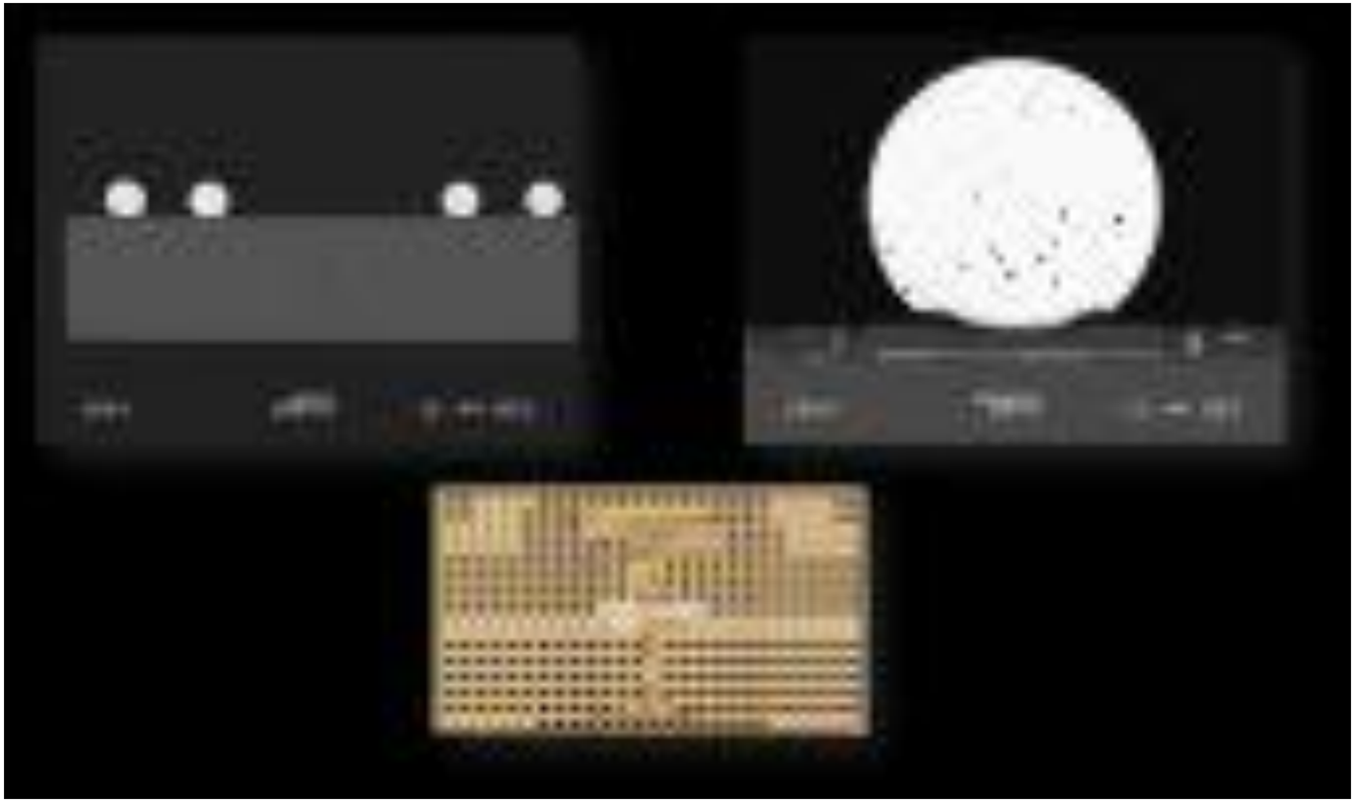


- Silicon – Silicon FC
- Large IO Count 300+
- Exposed Geometry
- Manufacturability

Solder Based Solutions



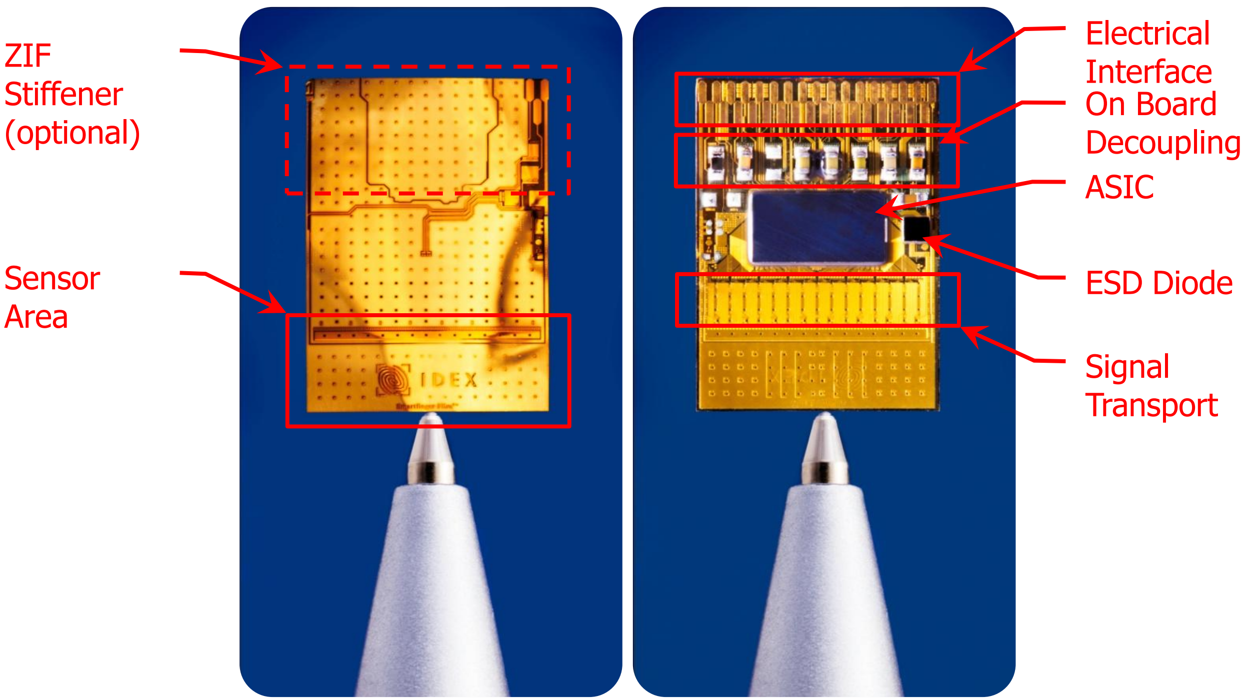
Standard Pad Design & Layout



REMI Lessons Learned

- Raised Pad Design Needed
- Large Pin Count = Large Forces
- Very Thin Bond Layer Possible
- Reduced Pitch Possible
- Flexibility Possible
- Underfill Included

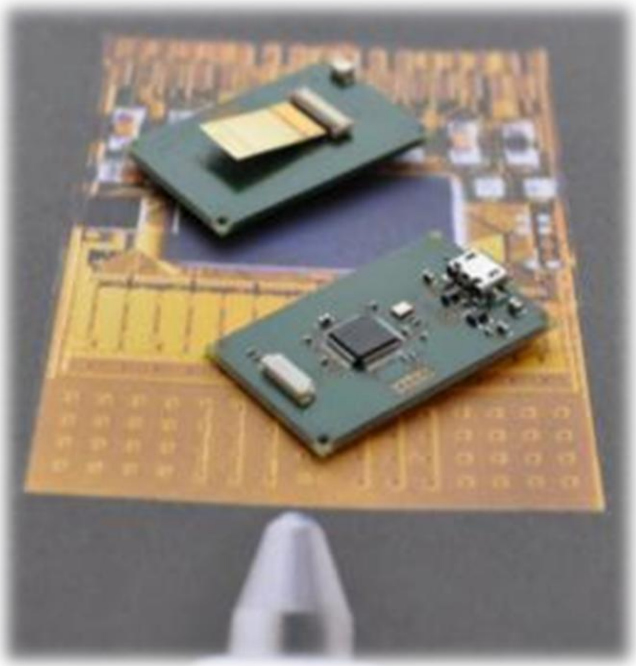
Moving to Polymer



Finger Interface Side

Circuit Interface Side

Example Implementations



Eight Cooperation Agreements announced

- Committed implementation plans
- Specific milestones for entering into commercial agreements
- Customers' targeted application markets represent volume applications
- SmartFinger Film sensors currently designed into customers biometric cards and devices

Pierson Capital Technology

Identita

Future Electronics

Validus Technologies

UINT

S·I·C Biometrics

深圳市华旌科技有限公司
Huaking Shen Zhen Huajing Technology Co.,Ltd

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PO BOX 88467 ATLANTA GA 30356
www.embedx.com 770 475 0075

High Temperature Power Electronics Packaging

HTPEP

HiVe 18.11.2011

Outline

- The HTPEP project
- High temperature power electronics and SiC technology
- Some projects results
- Summary

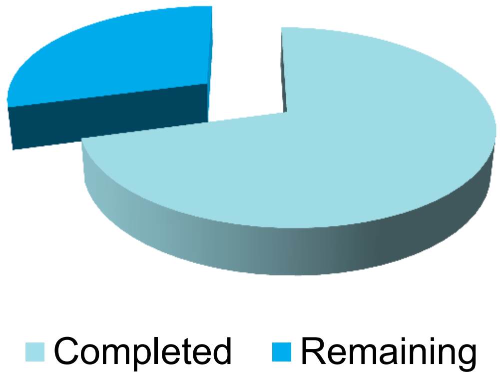
The HTPEP project – funding and partners

Norwegian research project

- PETROMAKS program
  - 2009 – 2012
  - 6,4 MNOK

Partners

- 1,6 MNOK

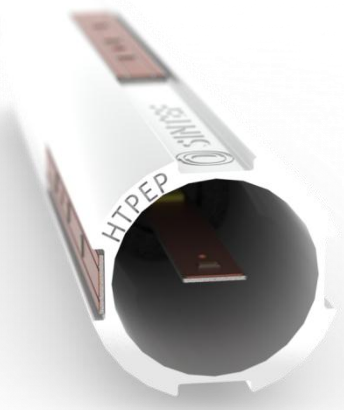


SINTEF
BADGER EXPLORER
SmartMotor Energy Efficient Technology
roxar MAXIMUM RESERVOIR PERFORMANCE
FAIRCHILD SEMICONDUCTOR
NORBITECH
VESTFOLD UNIVERSITY COLLEGE

The HTPEP project – objectives

Develop a reliable packaging technology for power electronic systems operating at temperatures up to 250 ℃.

- Know-how on SiC component technology.
- Processes for packaging of SiC and passive components for HT application.
- Knowledge on failure mechanisms occurring in interconnects and materials during HT operation.
- Demonstrator.

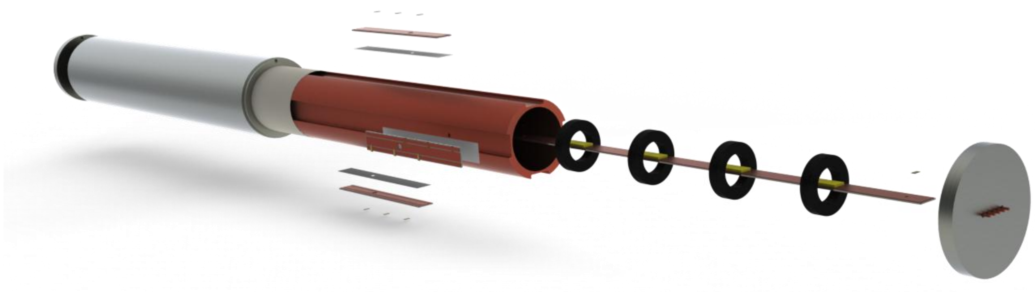


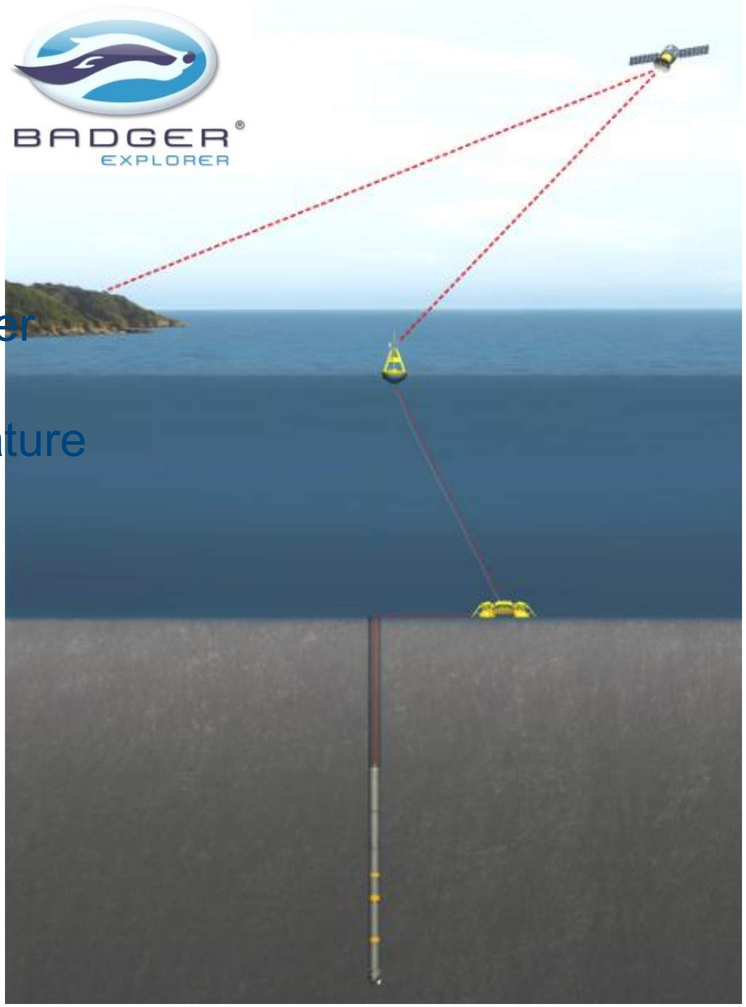
Why 250 °C?

- Today's petroleum wells have HT:
  - 150 – 230 °C
- Geothermal wells:
  - 200 – 500 °C
- Locally generated over-temperatures due to power loss in components.

Application

- Demonstrate the packaging technology in a power controller for a brushless DC motor for downhole applications.
- Packaging solution should enable the controller to operate for at least 6 months at an ambient temperature of 200 °C and a junction temperature of 250 °C.





www.bxpl.com

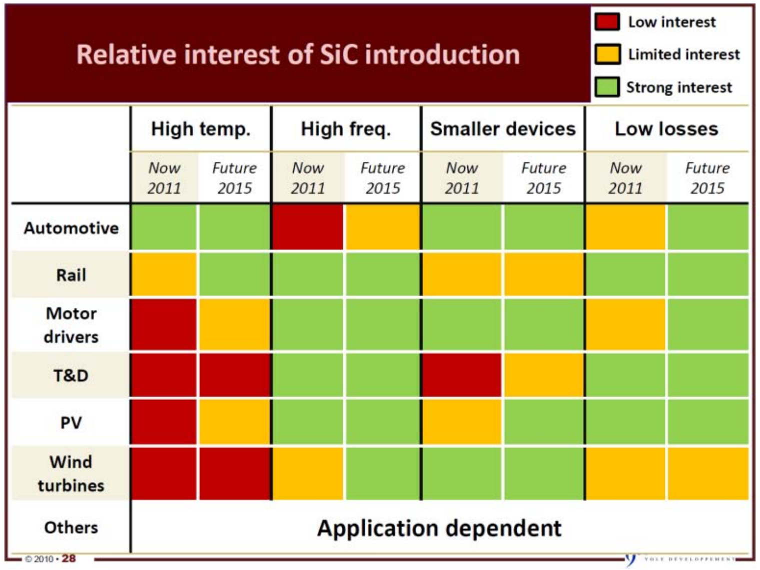
State of the Art and Trends

- Minimizing power losses and high power/temperature compliance is key for power electronics development.
- Compliant packaging is perhaps the major limitation today together with availability of commercial capacitors and advanced MEMS and IC's for high temperature applications.

Comparison Si, SOI, SiC and GaN in Power Electronics

	Silicon	SOI	SiC	GaN (on silicon)
Max. junction T°	125 °C	225 °C	400°C	350°C
Power range	Several 100's kW	< 100W	Several 100's kW	Few kW
Max. Vb	6.5 kV	600 V	10 kV	1.2 kV
4" price range	$20	$70	$1,000+	< $250
6" price range	$35	$170	N/A	< $400
# of companies developing devices	100+	~40	~25	~15

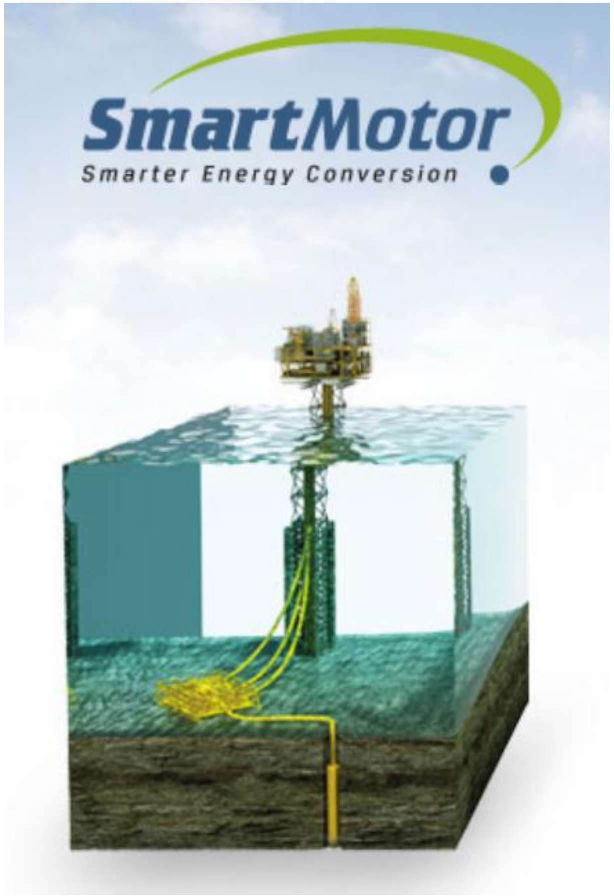
© 2010 • 26



A. Avron, "*New strategies for thermal management of high power modules and systems*", 2011

Added value of SiC electronics

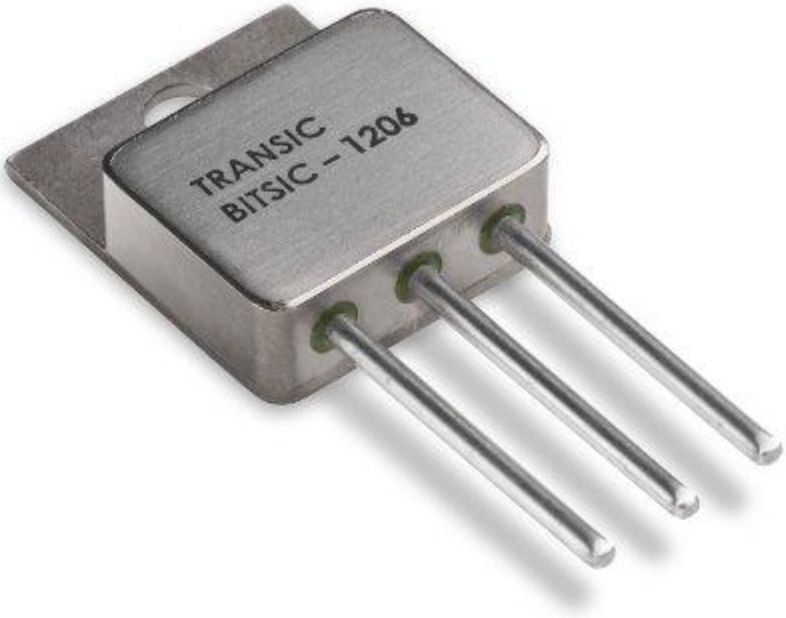
- Higher switching frequencies
- Higher voltage operation
- Higher junction temperatures
  - >250 °C operation
  - Increased reliability
  - Reduced cooling system
- Reduction in power losses



www.smartmotor.no

Silicon carbide BJT transistor

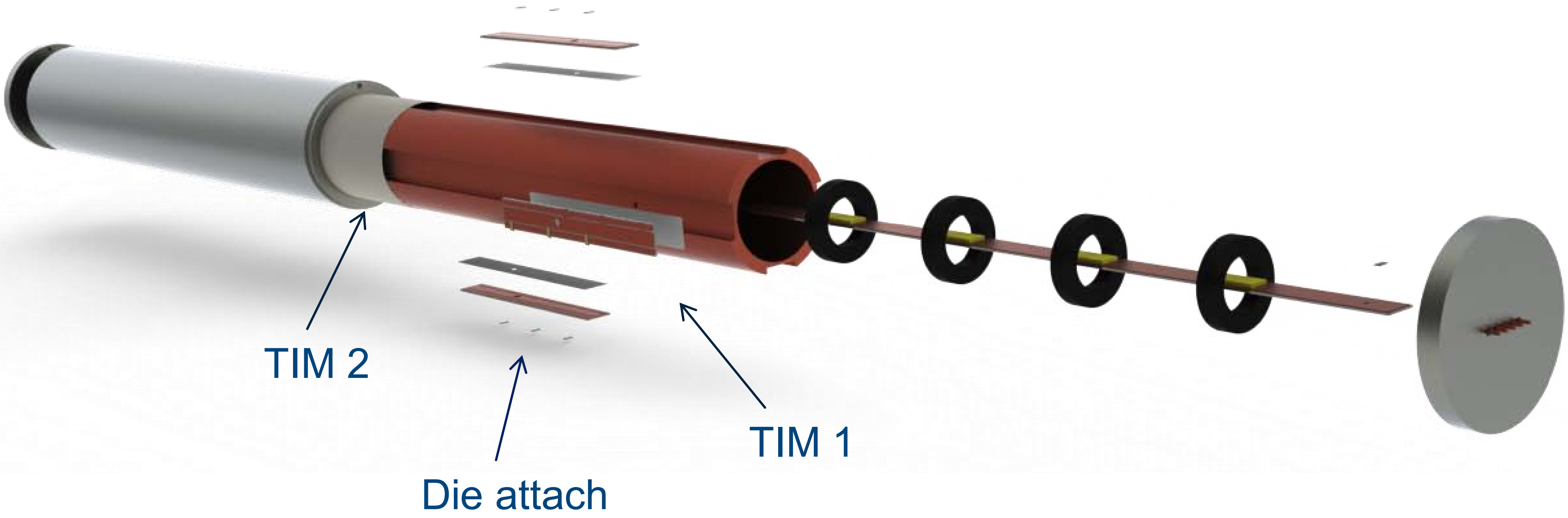
- Bipolar Junction Power Transistors in Silicon Carbide.
  - 1200 Volts 6 Amperes BitSiC®
  - 900 Volts 20 Amperes BitSi
- Tested from -80 to 250 °C



FAIRCHILD SEMICONDUCTOR®

www.transic.com

Die attach and Thermal interface materials (TIM)



Die attach: Fix components to substrate, low thermal resistance, electrically conductive.

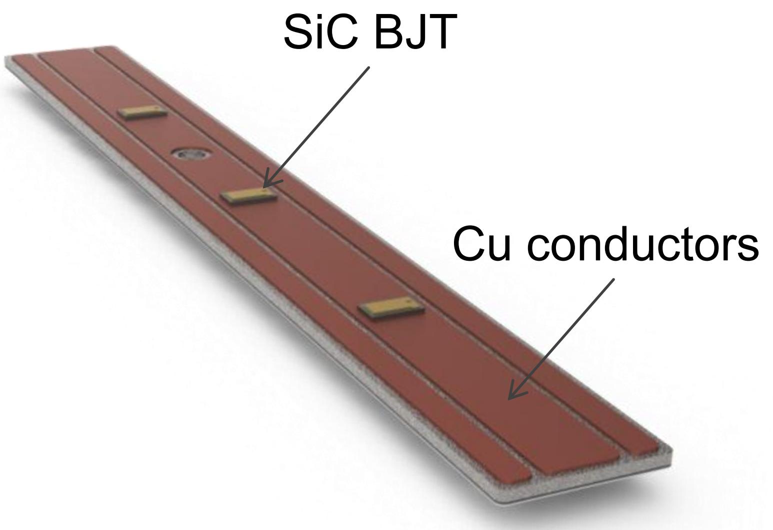
TIM 1: Fix substrate mechanically to support structure (avoid screws/clamps), ensure low thermal resistance.

TIM 2: Low thermal resistance between support structure and external housing.

Substrate technology

Silicon nitride, Si_3N_4

- Thermal conductivity: 20 – 90 W/mK
- CTE: ~3.2 ppm/K
- Flexural strength: 750-900 MPa
- Durable and robust during thermal cycling

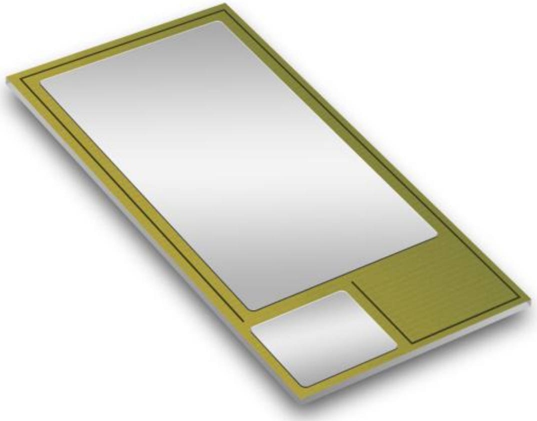


Die attach/interconnect technology: SLID

SLID – Solid-Liquid Inter-Diffusion

Gives a bond that is stable at higher temperature than the initial process temperature

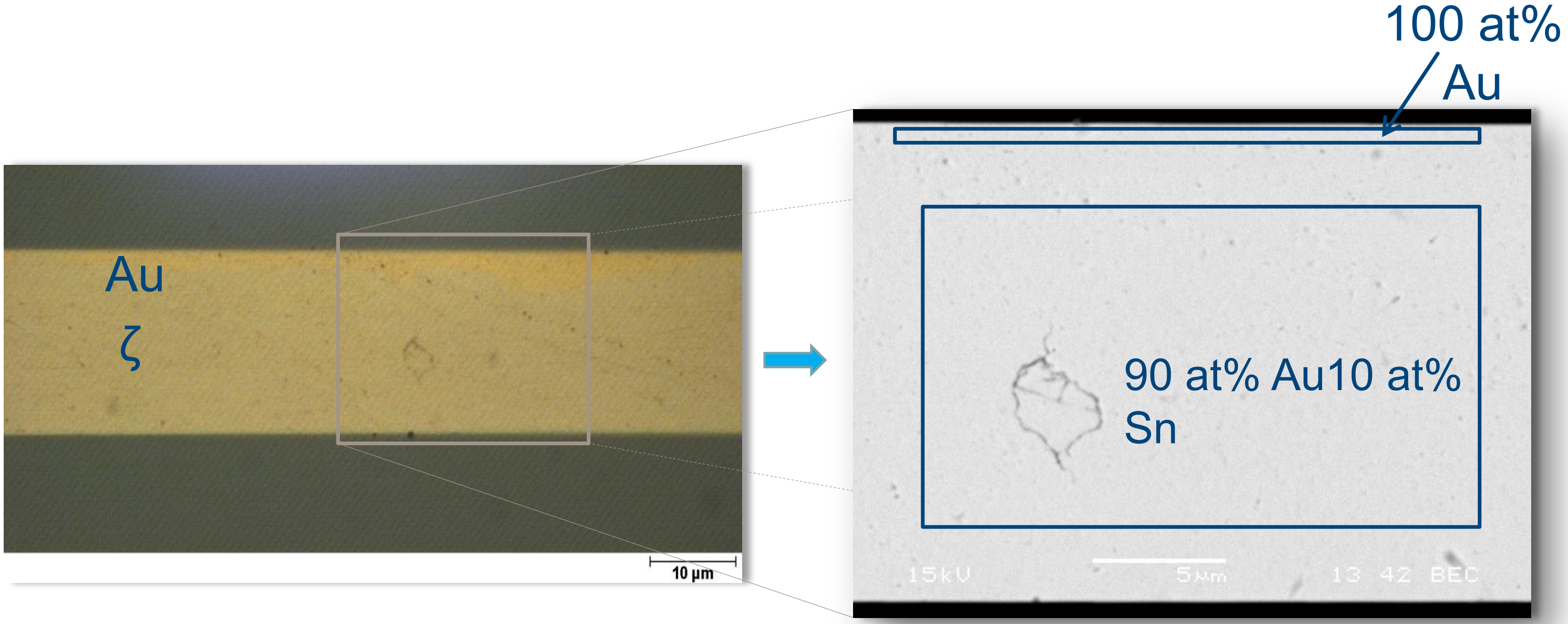
- Au-Sn SLID: up to 500°C
- Cu-Sn SLID: up to 670°C



BitSiC BJT1206AA/P1,
Gold backside metallization

Die attach processing – Bond Characterization

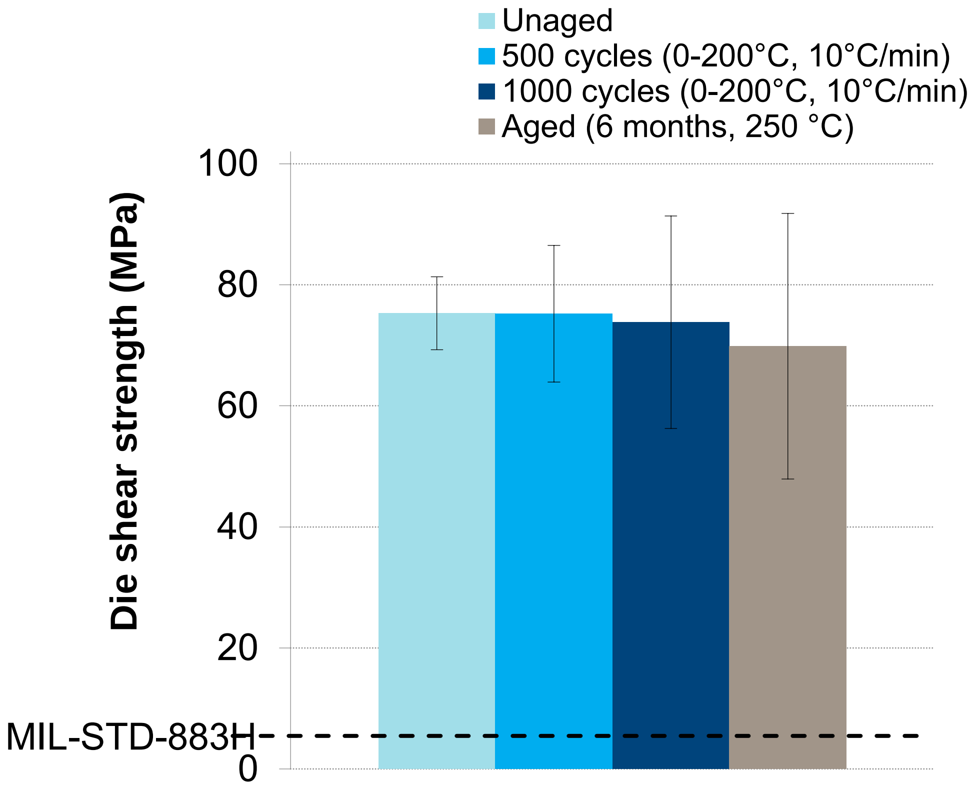
The bond interface is a uniform Au-rich phase, identified by EDS to be the ζ phase (with a melting point of 522°C).

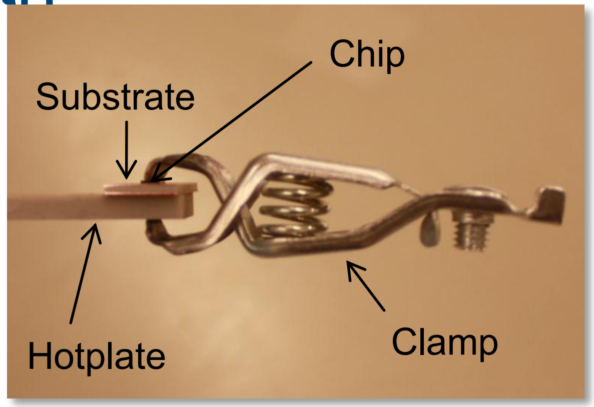


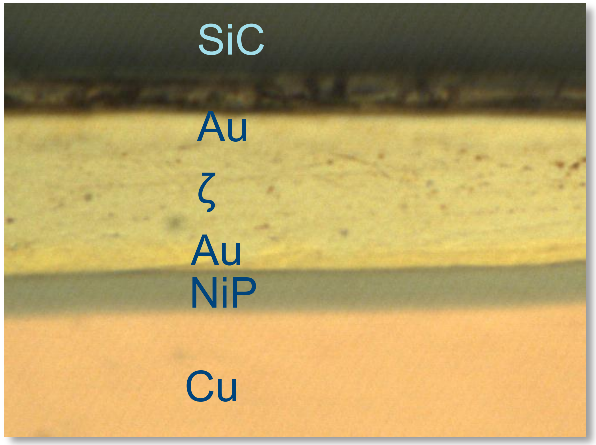
T.A. Tollefsen et al., "*Au-Sn SLID bonding for high temperature applications*", HiTEN 2011

Reliability testing – Die shear strength

Superb bond strength: >78 MPa.





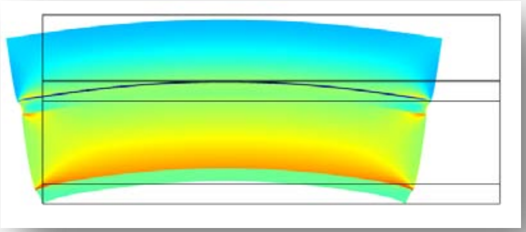


X-section

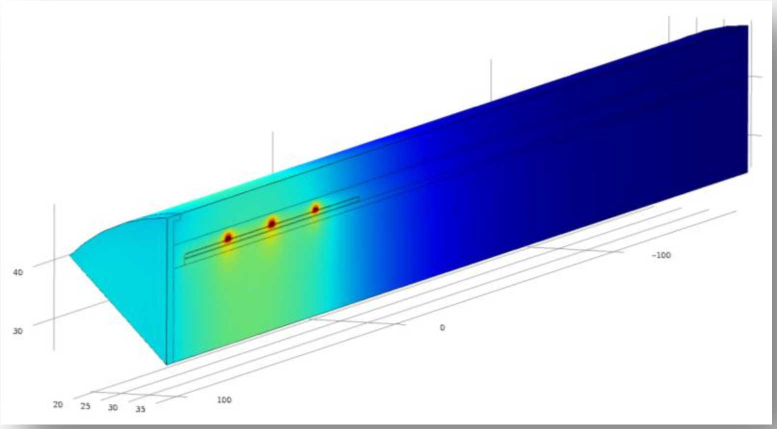
T.A. Tollefsen et al., "*Au-Sn SLID bonding for high temperature applications*", HiTEN 2011

Simulation aided design

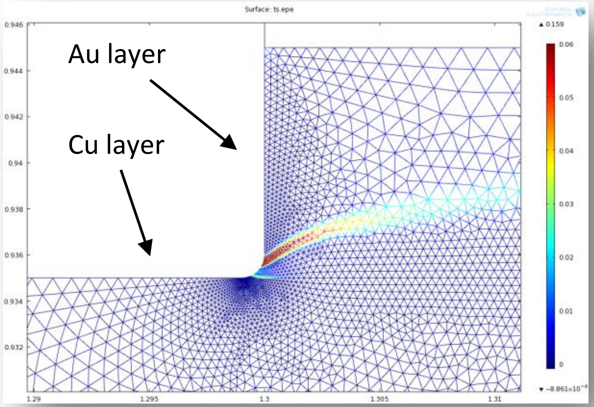
COMSOL Multiphysics



Warpage



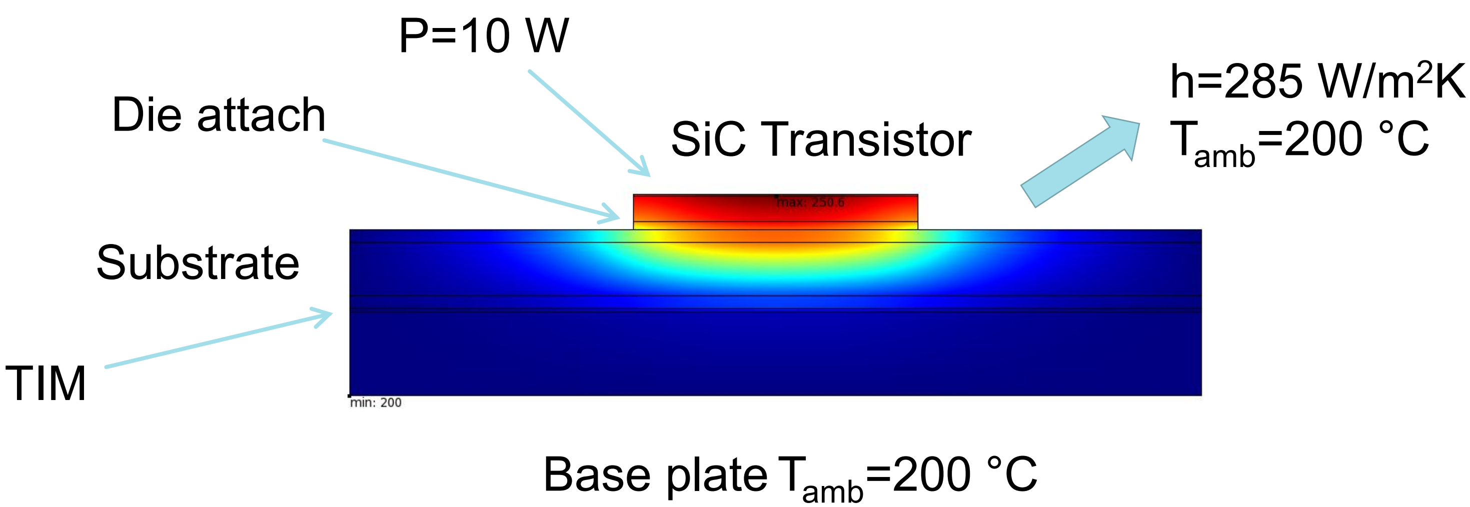
Thermal (E.g. convection)



Plastic strain & fatigue

Thermal management example – System

AlSiC/NanoFoil based system vs. std. component system

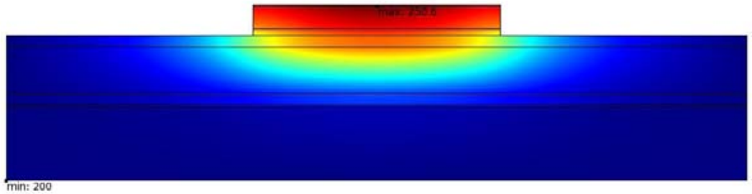


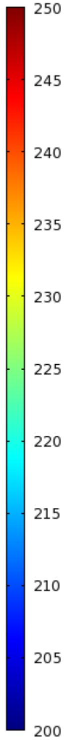
A. Larsson et al. "*High power module packaging design for harsh environments*", Device Packaging 2011

Thermal management example – Results

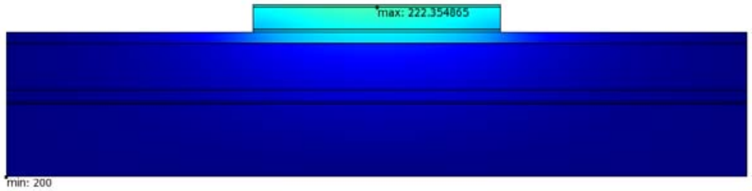
AlSiC/NanoFoil based system vs. std. HT component system

T_j=251°C





T_j=222°C



Ref. system with std. HT technology

- Die attach: Au-In solder
- Substrate: Alumina
- TIM: Ceramic graphite

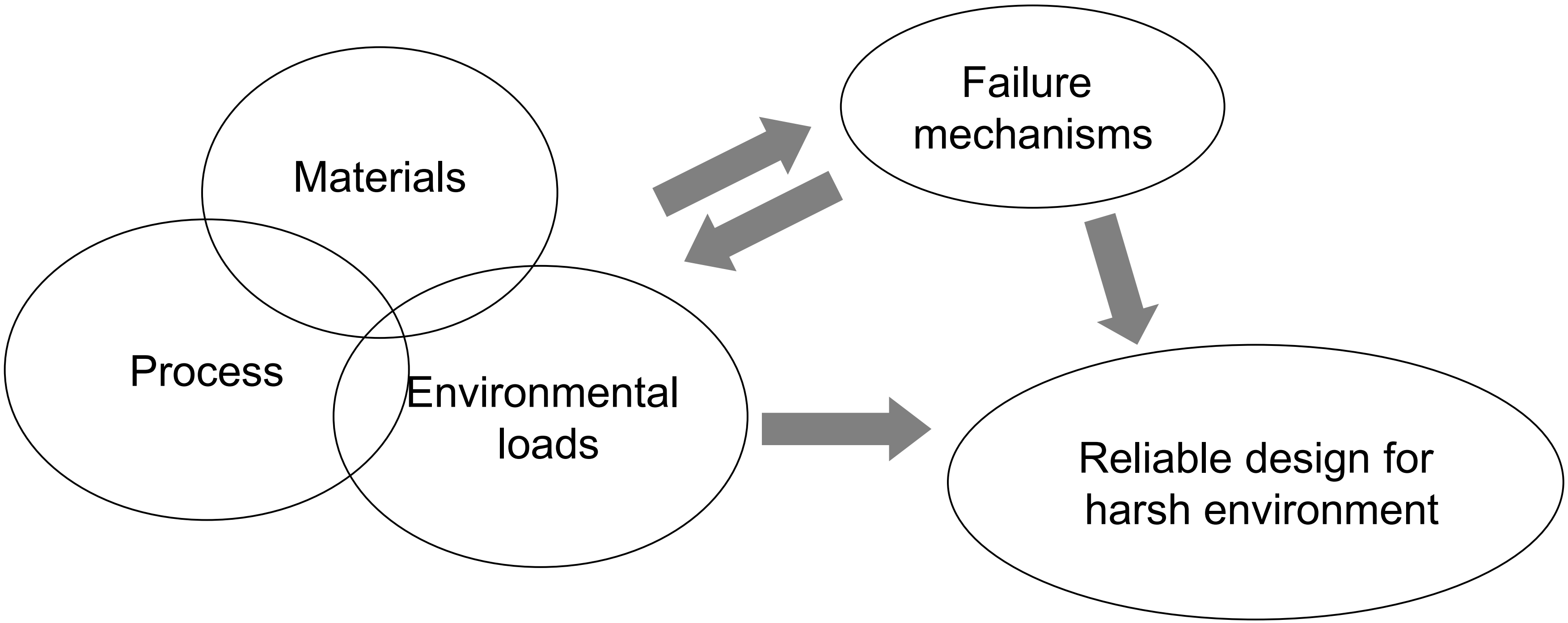
NanoFoil and AlSiC system

- Die attach: NanoFoil
- Substrate: AlSiC
- TIM: NanoFoil

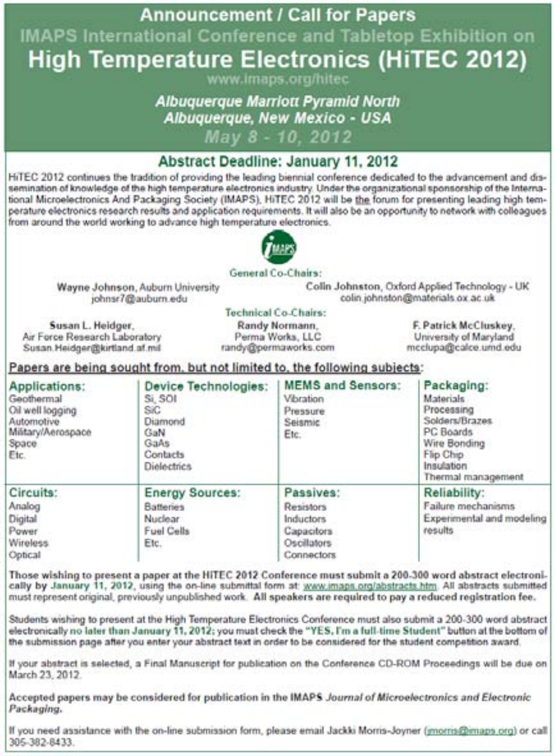
A. Larsson et al. "*High power module packaging design for harsh environments*", Device Packaging 2011

Summary

HTPEP – High temperature power electronics **packaging**



High temperature electronics conferences



Announcement / Call for Papers

IMAPS International Conference and Tabletop Exhibition on

High Temperature Electronics (HiTEC 2012)

www.imaps.org/hitec

Albuquerque Marriott Pyramid North
Albuquerque, New Mexico - USA
May 8 - 10, 2012

Abstract Deadline: January 11, 2012

HiTEC 2012 continues the tradition of providing the leading biennial conference dedicated to the advancement and dissemination of knowledge of the high temperature electronics industry. Under the organizational sponsorship of the International Microelectronics And Packaging Society (IMAPS), HiTEC 2012 will be the forum for presenting leading high temperature electronics research results and application requirements. It will also be an opportunity to network with colleagues from around the world working to advance high temperature electronics.

General Co-Chairs:

Wayne Johnson, Auburn University
johnsr7@auburn.edu

Colin Johnston, Oxford Applied Technology - UK
colin.johnston@materials.ox.ac.uk

Technical Co-Chairs:

Susan L. Heidger,
Air Force Research Laboratory
Susan.Heidger@kirtland.af.mil

Randy Normann,
Perma Works, LLC
randy@permaworks.com

F. Patrick McCluskey,
University of Maryland
mcclupa@calce.umd.edu

Papers are being sought from, but not limited to, the following subjects:

Applications:	Device Technologies:	MEMS and Sensors:	Packaging:
Geothermal Oil well logging Automotive Military/Aerospace Space Etc.	Si, SOI SiC Diamond GaN GaAs Contacts Dielectrics	Vibration Pressure Seismic Etc.	Materials Processing Solders/Brazes PC Boards Wire Bonding Flip Chip Insulation Thermal management
Circuits:	**Energy Sources:**	**Passives:**	**Reliability:**
Analog Digital Power Wireless Optical	Batteries Nuclear Fuel Cells Etc.	Resistors Inductors Capacitors Oscillators Connectors	Failure mechanisms Experimental and modeling results

Those wishing to present a paper at the HITEC 2012 Conference must submit a 200-300 word abstract electronically by January 11, 2012, using the on-line submittal form at: www.imaps.org/abstracts.htm. All abstracts submitted must represent original, previously unpublished work. **All speakers are required to pay a reduced registration fee.**

Students wishing to present at the High Temperature Electronics Conference must also submit a 200-300 word abstract electronically no later than January 11, 2012; you must check the "YES, I'm a full-time Student" button at the bottom of the submission page after you enter your abstract text in order to be considered for the student competition award.

If your abstract is selected, a Final Manuscript for publication on the Conference CD-ROM Proceedings will be due on March 23, 2012.

Accepted papers may be considered for publication in the IMAPS *Journal of Microelectronics and Electronic Packaging*.

If you need assistance with the on-line submission form, please email Jackki Morris-Joyner (jmorris@imaps.org) or call 305-382-8433.

Final Program

IMAPS International Conference on

High Temperature Electronics Network (HiTEN 2011)

July 18 - 20, 2011
St. Catherine's College Oxford
Oxford, United Kingdom

Conference Chairs:

Colin Johnston
Materials KTN
colin.johnston@materials.ox.ac.uk

R. Wayne Johnson
Auburn University
johnsr7@auburn.edu

Organizing Committee

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Bringing Together The Entire Microelectronics Supply Chain™

Program Overview

Session 1: Passives
Chairs: Steve Riches, GE Aviation Systems - Newmarket; Liang-Yu Chen, Ohio Aerospace Institute/NASA Glenn Research Center

Session 2: Packaging
Chairs: Joseph A. Henfling, Sandia National Laboratories; Robert Estes, Baker Hughes

Session 3: SiC
Chairs: F. Patrick McCluskey, University of Maryland - CALCE; David Shaddock, General Electric Global

Session 4: Power
Chairs: Randy Normann, Perma Works LLC; Milton Watts, Quartzdyne, Inc.

Session 5: Test & Characterization
Chair: Hector Torres, Texas Instruments, Inc.

Session 6: Packaging Materials
Chair: R. Wayne Johnson, Auburn University

Session 7: Si Devices
Chairs: Laurent Martinez, CISSOID, S.A.; Ovidiu Vermesan, SINTEF

Corporate Sponsors:

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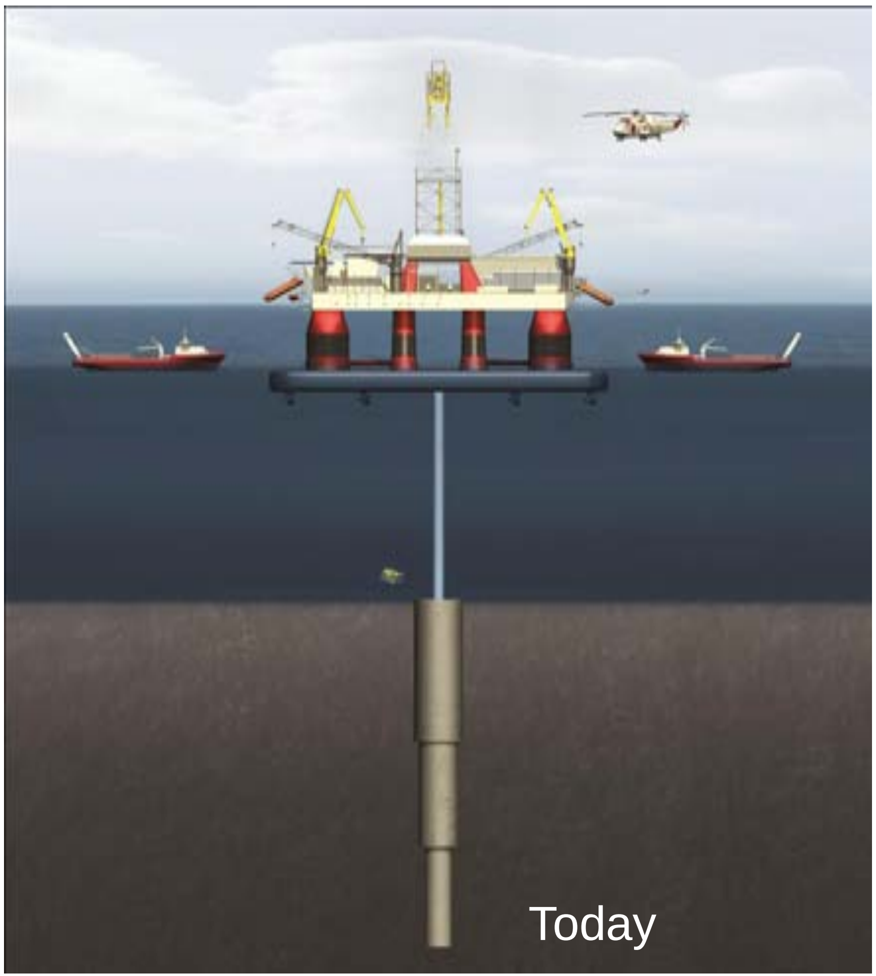
Thanks for your attention!
HTPEP

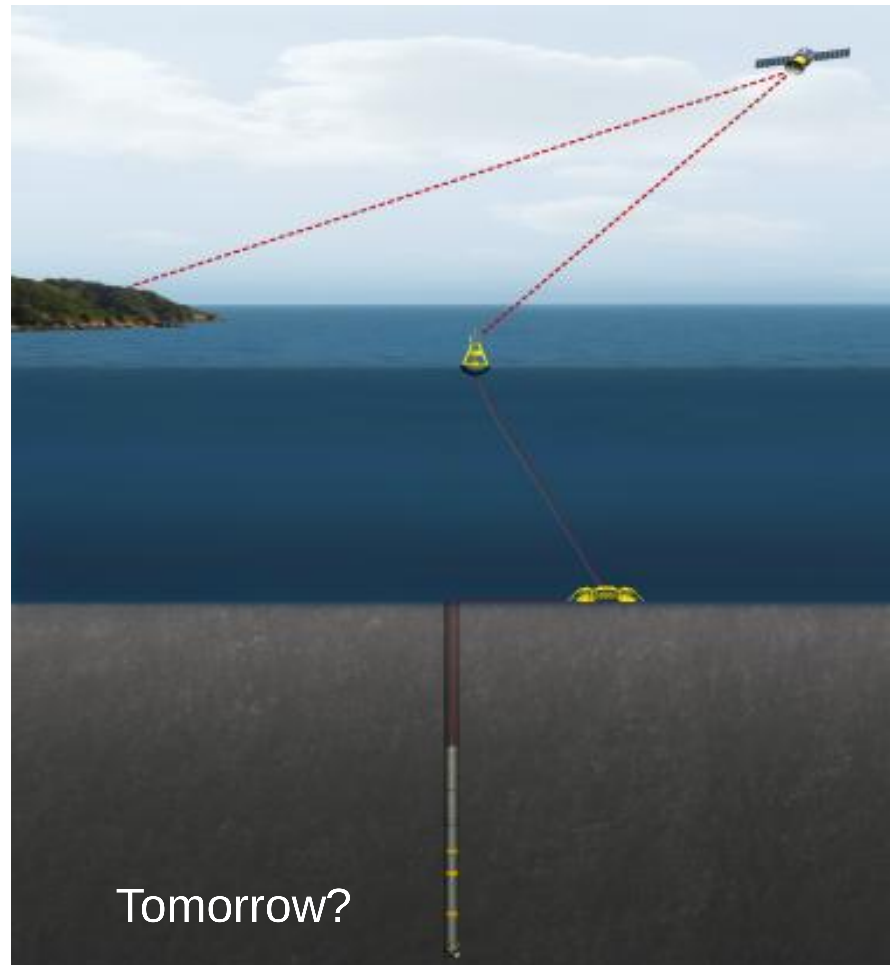
Andreas Larsson
SINTEF ICT, Instrumentation dept.
andreas.larsson@sintef.no

BADGER® EXPLORER

Unconventional oil exploration in hot environments

Truls Fallet





Drivers: Environment and money

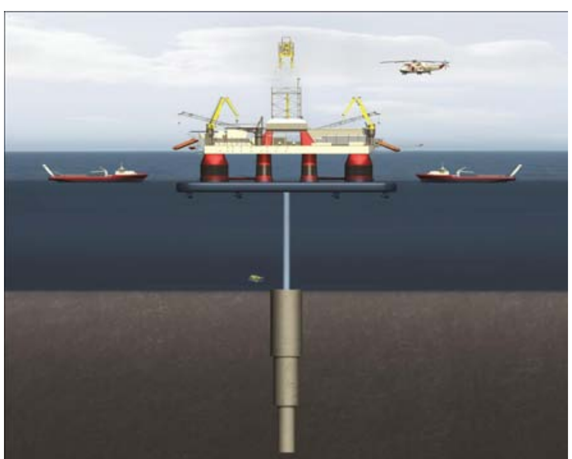
Conventional drilling

Currently the only available drilling technology, environmentally risky

Up to USD 700 million rig and 120 man crew required to drill a well

Tight supply market with all time high day rates

Exploration wells are rarely used for production



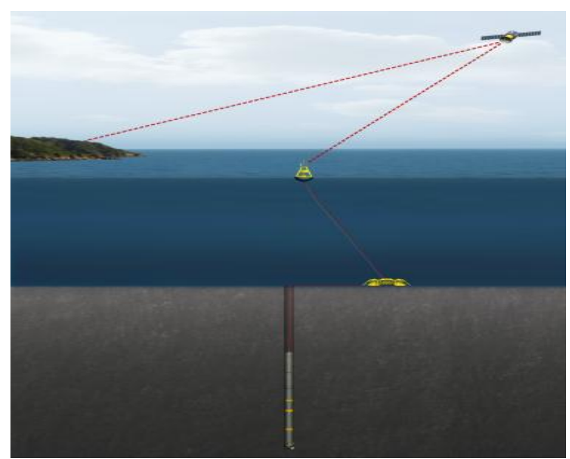
Badger Explorer

An alternative way, no hole in the ground

No need for drilling rig means reduced cost

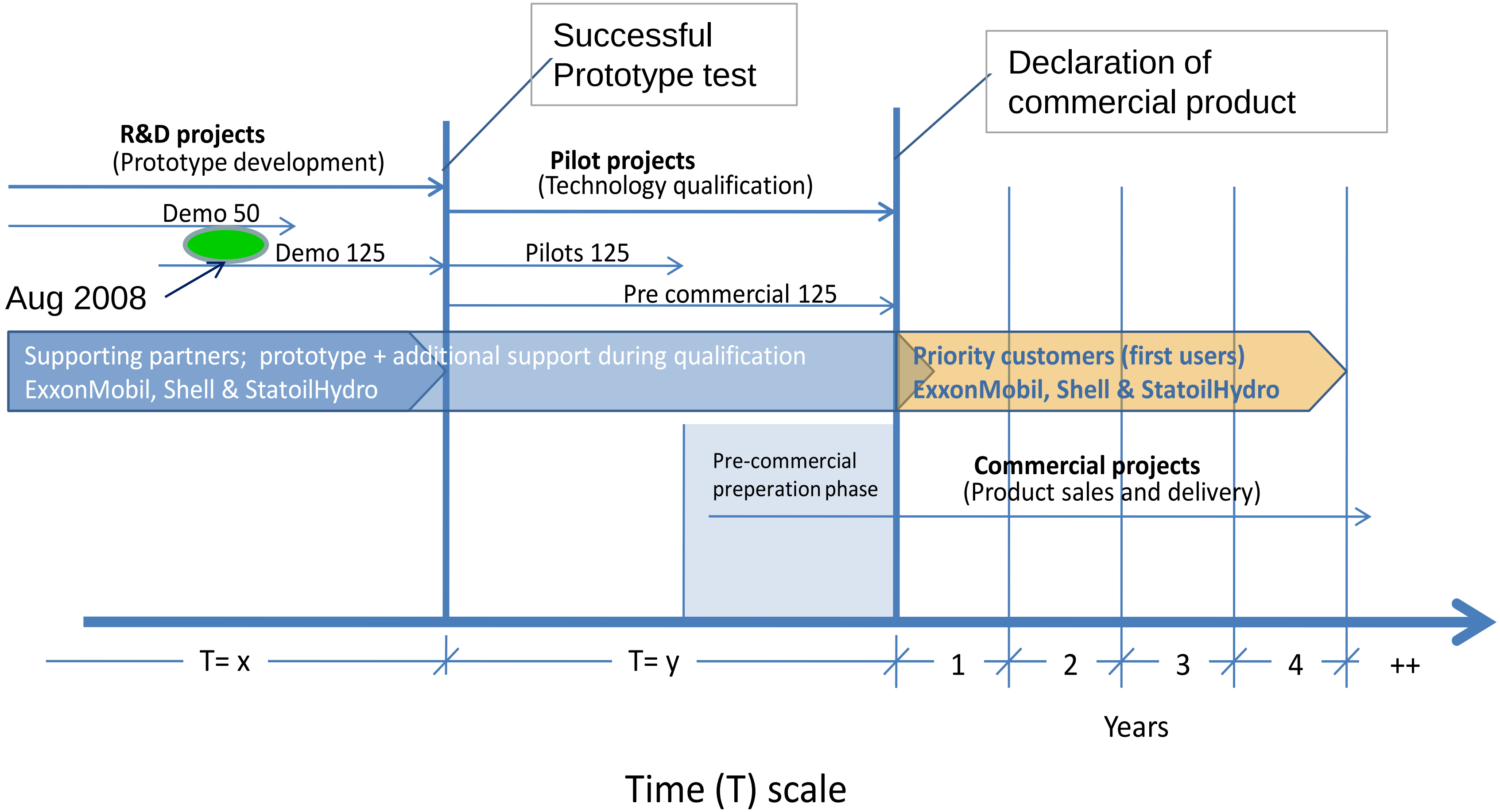
Provides detailed formation data and verifies the presence of hydrocarbons

Leaves a permanent test point in formation



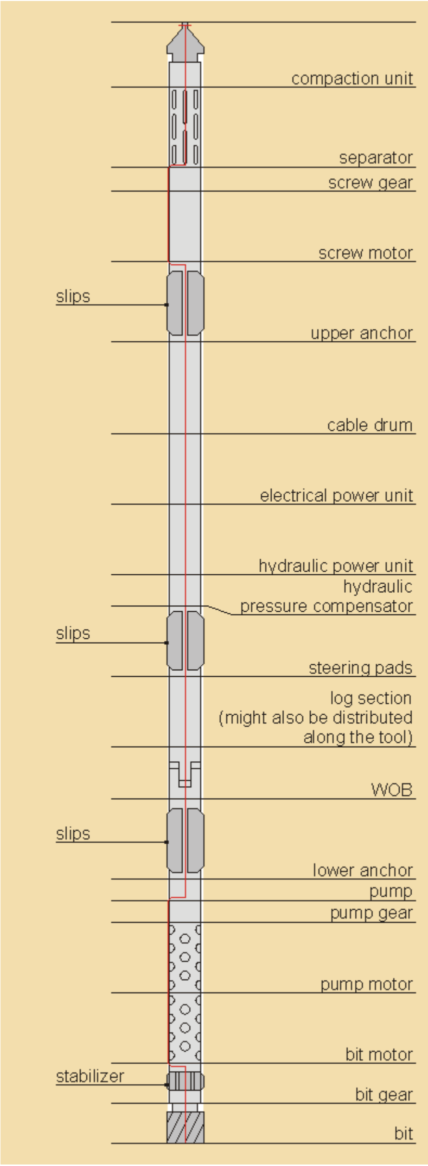
Strategy Product Development

And when the 125 version is done, the fun continues with versions for deeper reservoirs and extended features.

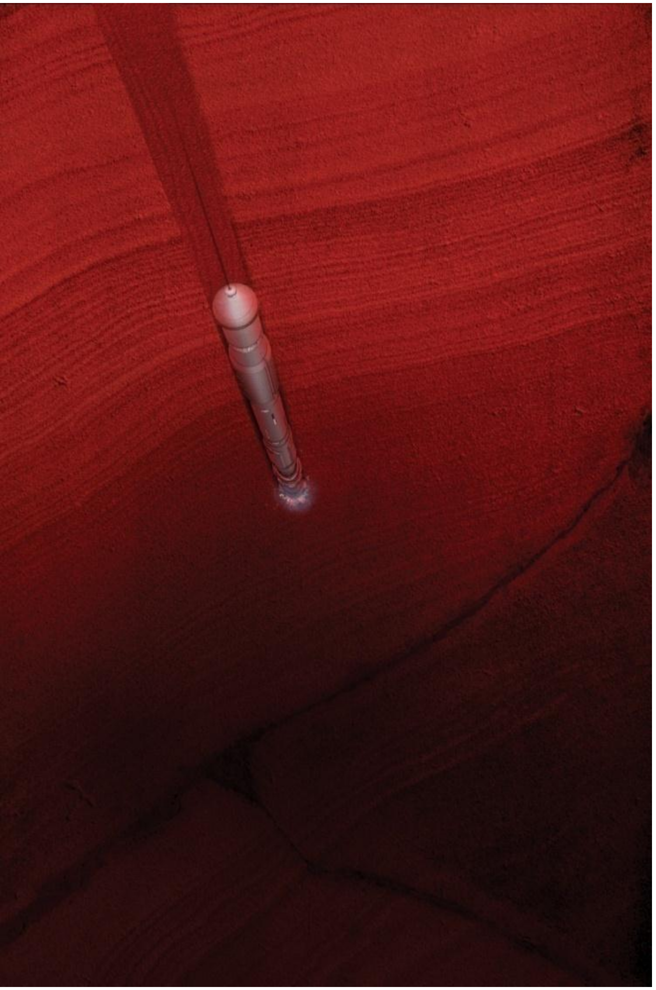


Tool Concept

- Compaction Module
- Separation Module
- Upper Anchor
- Cable-drum / unwinding / power transformation / communication
- Log Module
- Steering Pads
- Electrics/Hydraulics
- Weight on Bit Module
- Lower Anchor
- Pump Module
- Drilling Module



HT-power electronics needed



The Badger will operate in formation temperatures up to150^{o}C in order to reach deep reservoirs

The tool it self dissipates up to 10kW heating the formation 25-35^{o}C

The inside components, motors, pumps cable storage and power electronics will have to be warmer than their environment in order to get rid of dissipated heat

Even with high performance cooling concepts we may experience junction temperatures >200^{o}C

Power electronics offer the largest challenges:

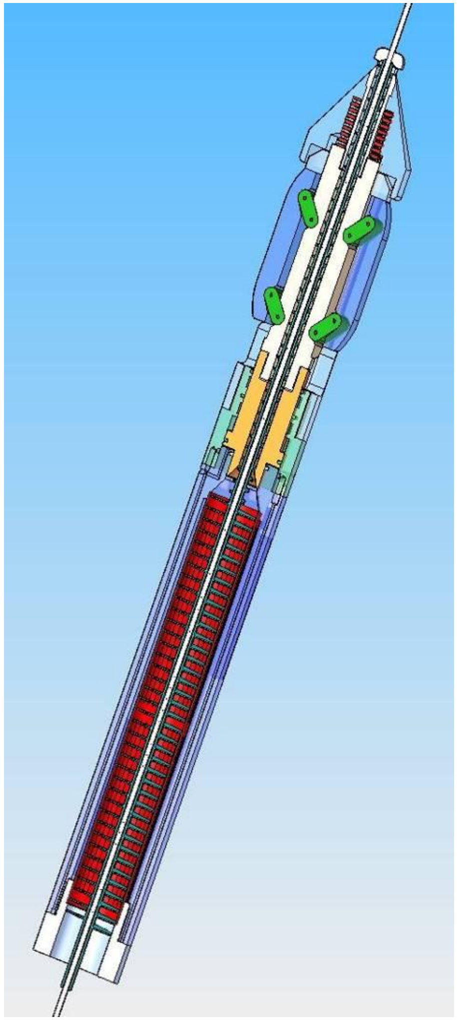
- DC/DC converter 1000V to 400V, 10kW
- Motor controllers   5kW/300V, 3ph.AC variable frequency

Environmental issues

In addition to the high temperature, the Badger parts will have to cope with:

- Completely immersed in hot salt water with high contents of highly abrasive stone particles (slurry)
- Available room inside tool limited to 120mmØ and should typically be much slimmer in order to save room for slurry and cooling water transport pipes
- Heavy outside steel jacket needed for structural integrity

Total lifetime: 5000 hours, temperatures slowly increasing from 50 to 200^{o}C as we move downwards



Some issues for Badger HT-electronics

- High efficiency switched motor controller and DC/DC converter
- Avoid large capacitors as much as possible, no electrolytes!
- Design for junction temperatures of power switches up to >200^{o}C
- Design for large currents and voltages (20A, 1000V)
- Efficient cooling of high dissipation components

Arguments for SiC technology:

- High operating temperature
- Fast switching leads to lower switching losses/and total losses
- Fast switching allows high frequency operation and reduction in needed capacitor volume

Testing in Denmark

UC Berkeley's SiC MEMS for Harsh Environments

Matthew Chan

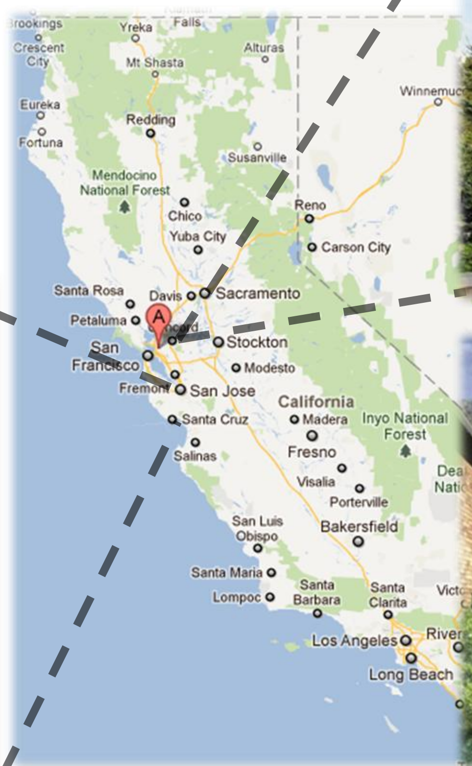
Professor Albert P. Pisano

18 November 2011

University of California, Berkeley

San Francisco

Silicon Valley



http://nanolab.berkeley.edu

Berkeley Sensor & Actuator Center (BSAC)

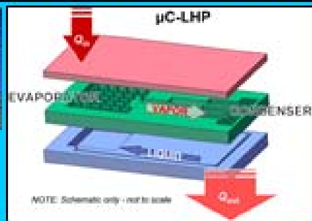
http://bsac.berkeley.edu

- Professor Albert P. Pisano's BMAD Lab

BMAD Lab, picture from 2009

Quantum Energy Systems

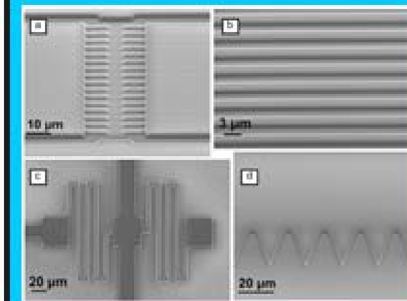
Thermal & Energy Solutions



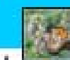
µColumnated - Loop Heat Pipe: Advanced Cooling, Compact Form Factor

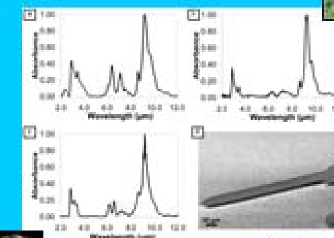
Nanocomposite Energy Storage: High Power & Energy Densities

Polymers & Bioinspired Devices

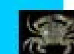


Chitosan & Chitin as Engineering Materials



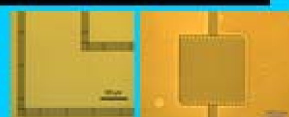


Bioinspired, Polymer-based Infrared Sensors



Nanomanufacturing

High Aspect Ratio, Low Pressure Micromolding for Reel-to-Reel Processing

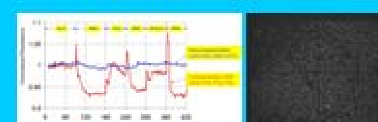


Microfluidic Reactor for Continuous, Controlled Nanoparticle Synthesis

Droplet Assembly of Nanoparticles for 3D Microstructures

BioMEMS

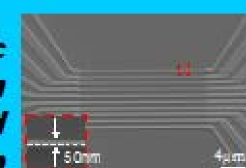
Continuous Flow Lysometry



Single Cell Analysis

Nanowire BioDiagnositcs

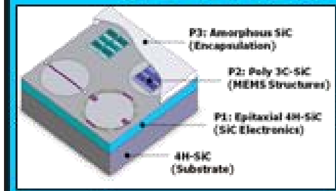
Plastic Injection Molded Lab-on-a-Chip

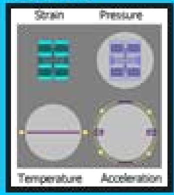


Harsh Environment & Telemetery Systems

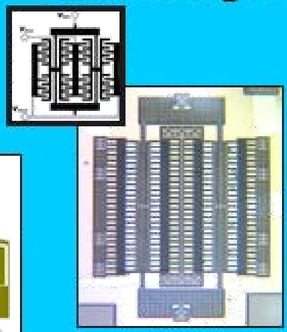
Sensors

SiC TAPS Sensors

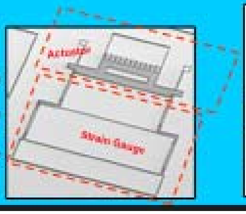


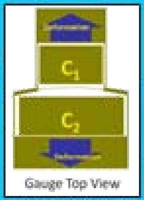


Resonant Strain Gauge



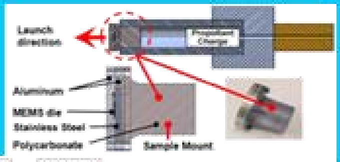
Capacitive Strain Gauge

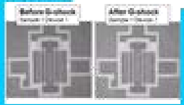




Harsh Environments

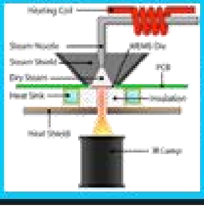
Subsurface & Combustion

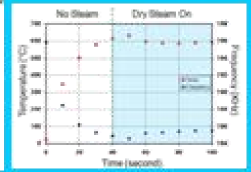




64000 g Exposure (Shock!)

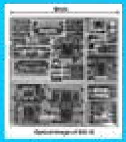
600°C Exposure (Thermal Shock!)

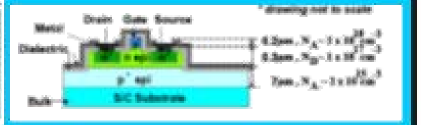




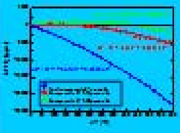
RF Telemetry

Silicon Carbide (SiC) Electronics



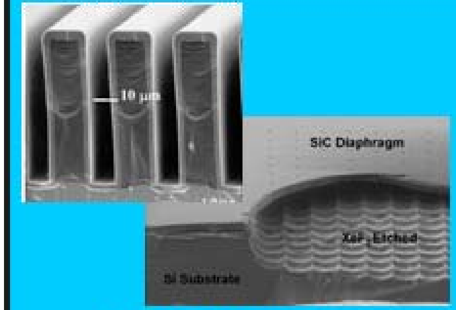


Aluminum Nitride (AlN) Resonator Technology



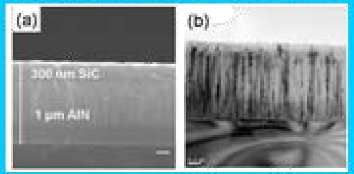
Temperature Compensation

Fabrication & Materials



Amorphous & Polycrystalline SiC Thin Films

AlN/SiC Composite



Plasma Etching

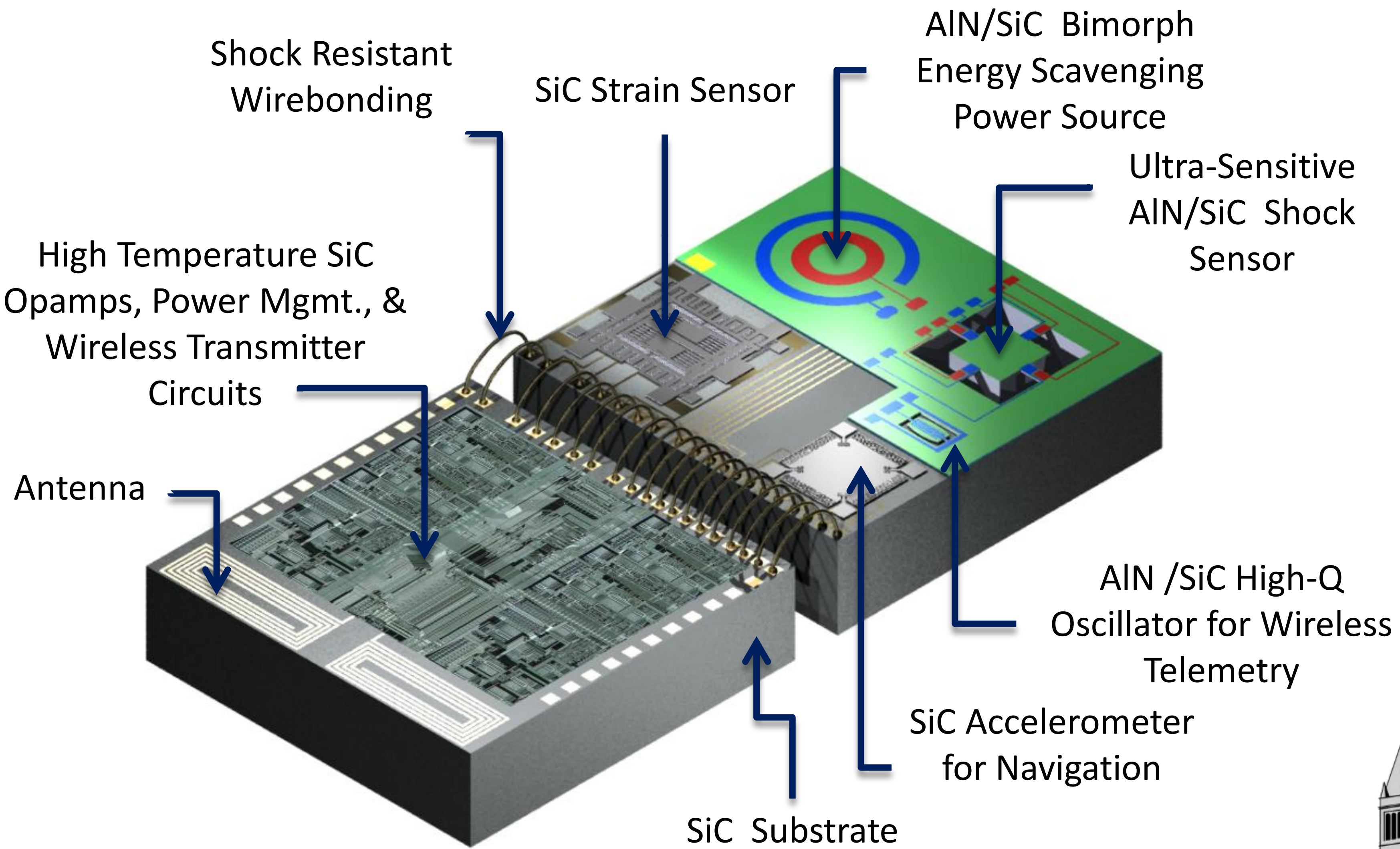
BSAC

Harsh Environments

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 and improved efficiency

Integrated SiC Sensors & Electronics



Harsh Environment Materials

	Silicon	Gallium Arsenide	Diamond	Aluminum Nitride	Silicon Carbide
Electrical	Good below 150 °C	Good to 350 °C	Difficult to make circuits	Difficult to make circuits	Good through 600 °C
Mechanical	Softens at high temp.	Weaker than silicon	Burn above 700 °C in air	Stable past 700°C	Stable past 700 °C
Chemical	Can be etched	Several wet etchants	Robust	Can be etched	Robust

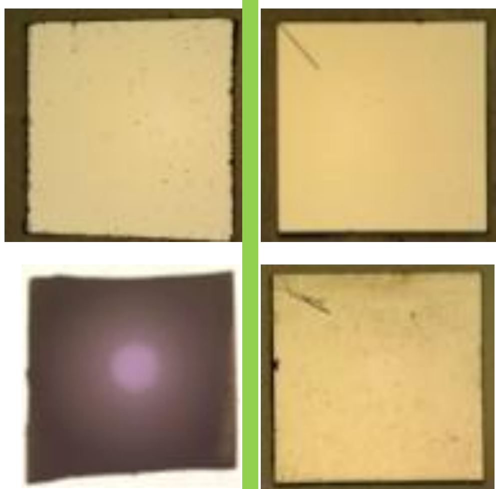
References:
- K. Hjort et al. "Gallium arsenide as a mechanical material" Journal of Micromechanics and Microengineering. 4 (1) pp. 1-13, 1994.
- Slack and Bartram. "Thermal expansion of some diamondlike crystals"[sic] Journal of Applied Physics. 46 (1) pp.89-98, 1975.
- Mehregany, M. "Silicon carbide MEMS for harsh environments" Proceedings of the IEEE. 86 (8), pp. 1594-1610. 1998.

Supercritical Water Exposure Testing

Si Die | SiC Die

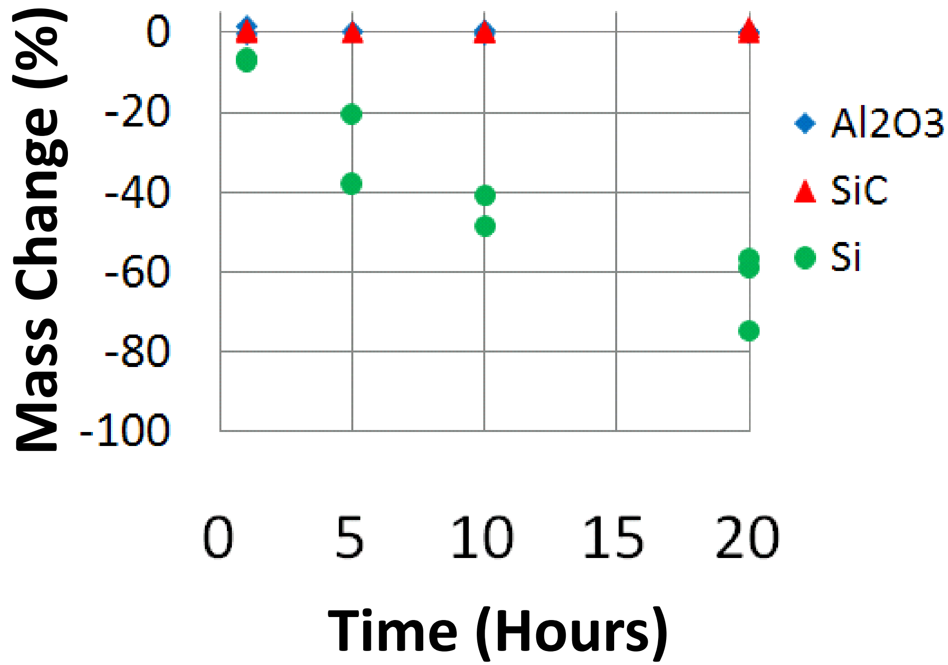
Before Exposure

After 20 h Exposure



Sample size = ~ 5 mm x 5 mm

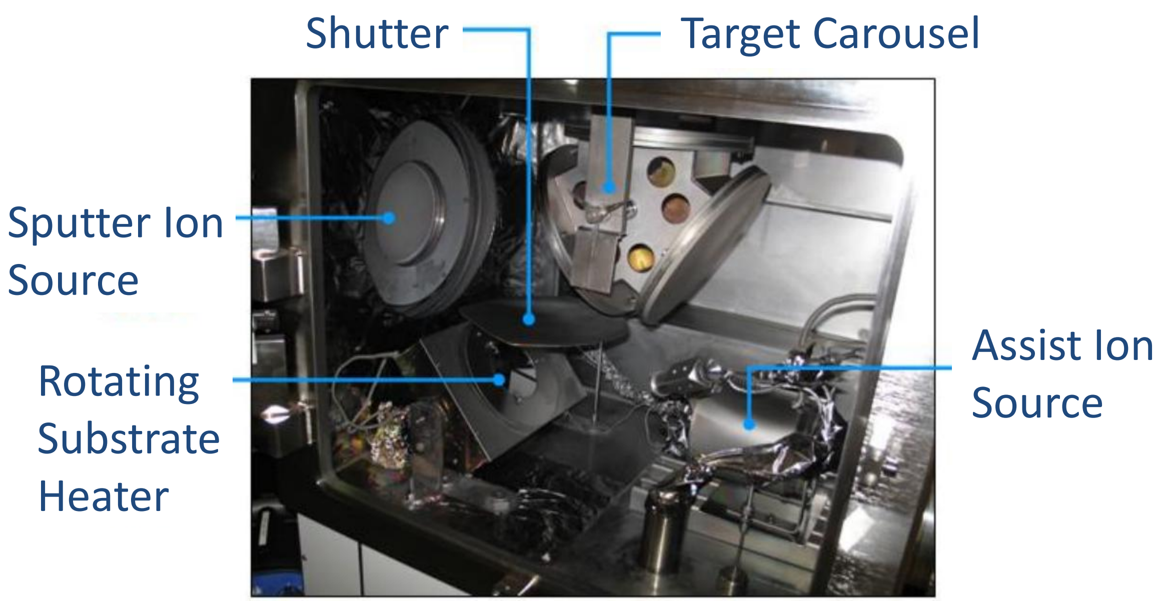
% Mass Change of Substrate versus Exposure Time

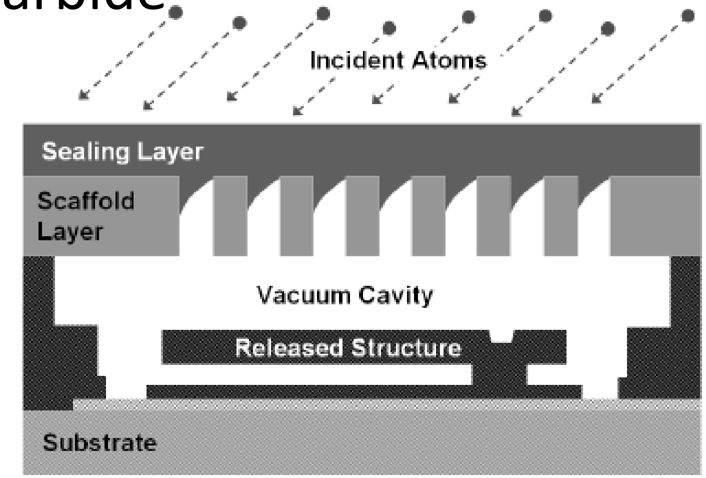


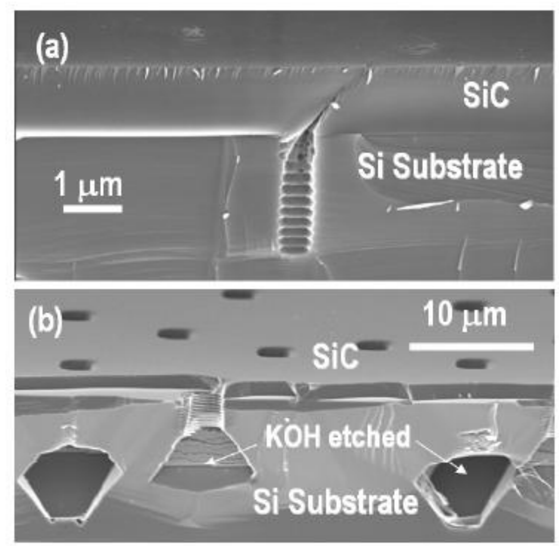
Exposure testing of sensor materials in supercritical H_2O (with Ni ions) environments (P = 100 MPa, Temperature = 427˚C) with Tuttle pressure vessel.

SiC Thin Film Encapsulation

- Line-of-sight sputter deposition of silicon carbide
- Ion Beam Assisted Deposition (IBAD) enables vacuum encapsulation



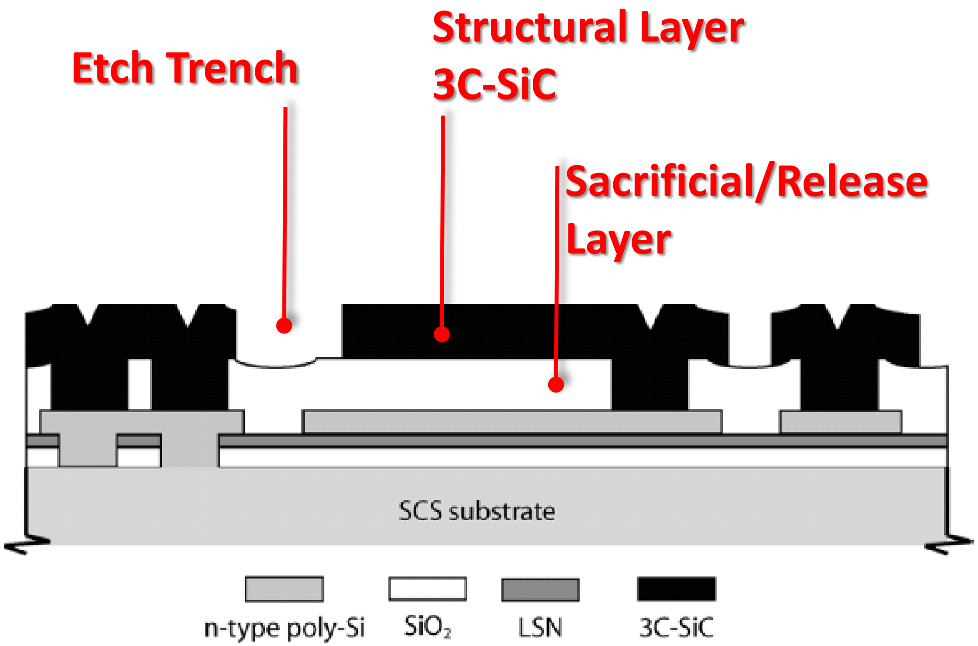




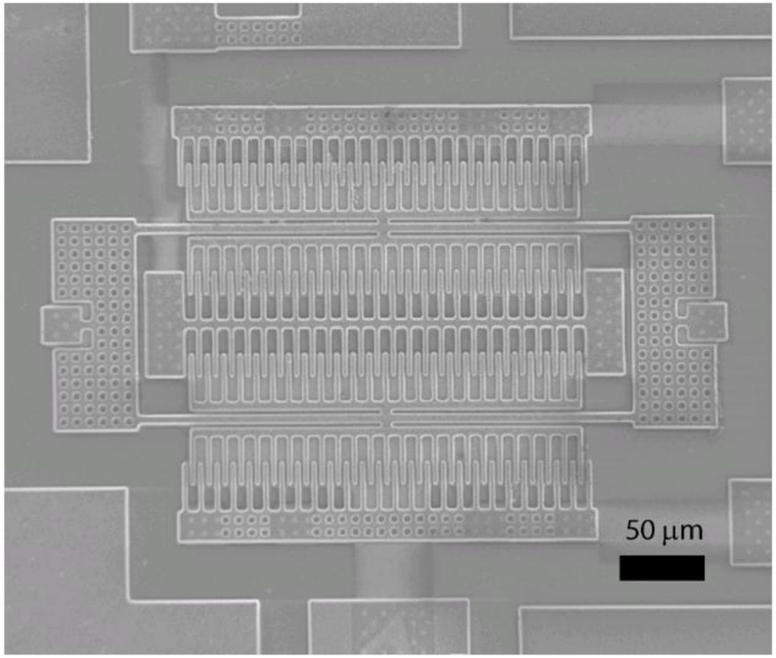
D.G. Jones (Senesky), R.G. Azevedo, M.W. Chan, A.P. Pisano, & M.B.J Wijesundara. MEMS 2007

SiC Resonant Strain Gauge

- Balanced-mass double ended tuning fork (BDETF) strain gauge
- Designed for high-shock resistance



Cross-sectional image of the SiC strain sensor fabrication process.

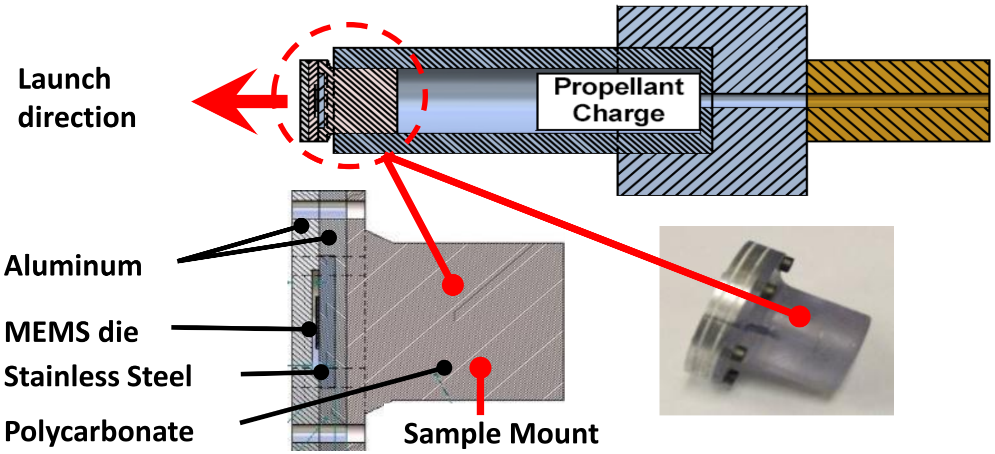


SEM image of polycrystalline 3C-SiC (7um thick) resonant strain sensor.

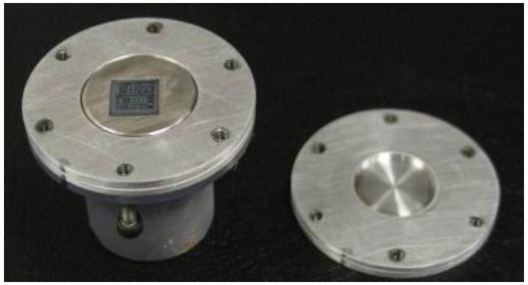
R.G. Azevedo, D.G. Jones (Senesky), A. V. Jog, B. Jamshidi, D. R. Myers, L. Chen, X. Fu, M. Mehregany, M. B. J. Wijesundara, & A.P. Pisano, IEEE Sensors Journal (2007)

64,000 G-Shock Testing of SiC Resonator

Gas Gun Schematics

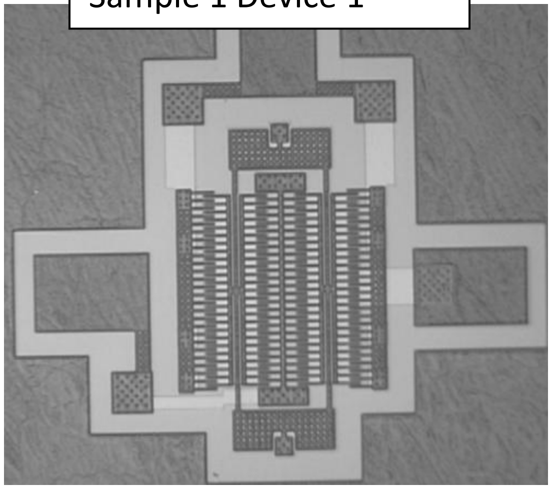


- **G-shock Testing carried out at Aerophysics Research Center at University of Alabama in Huntsville**
- **Hard-launch soft-catch method**
- **Initial G-load is 64,000 g**

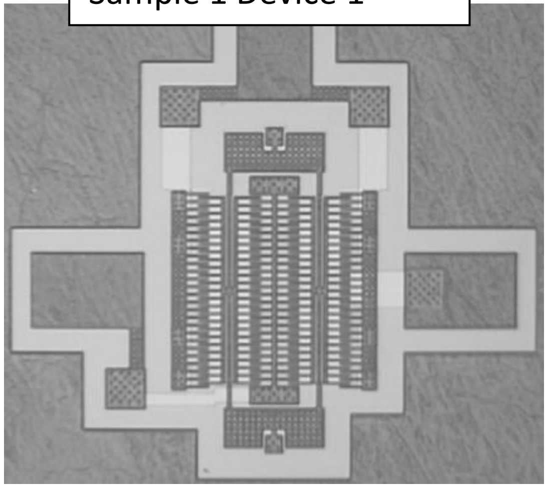


- **No structural damage after g-shock at 64,000g**
- **Successfully operates (resonates) after enduring a 64,000 g shock**

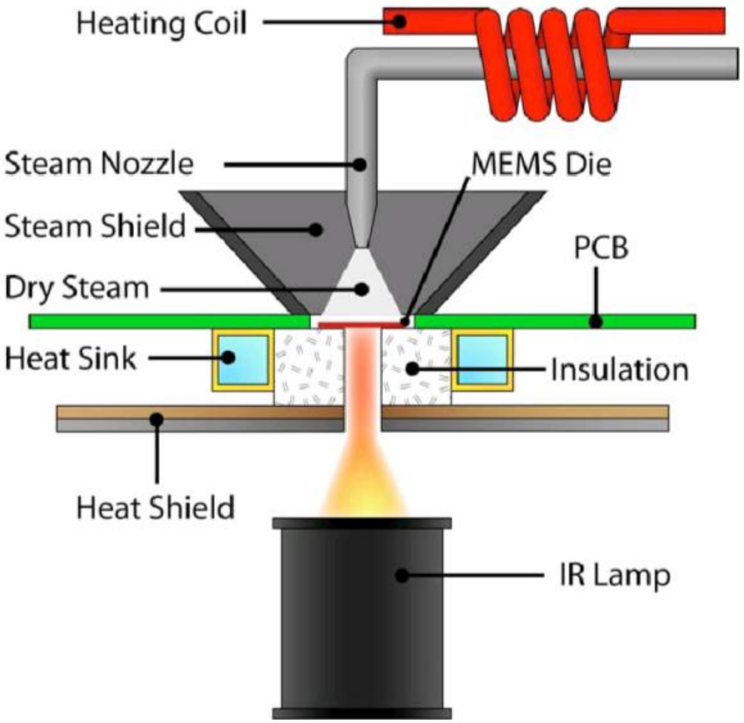
Before G-shock
Sample 1 Device 1

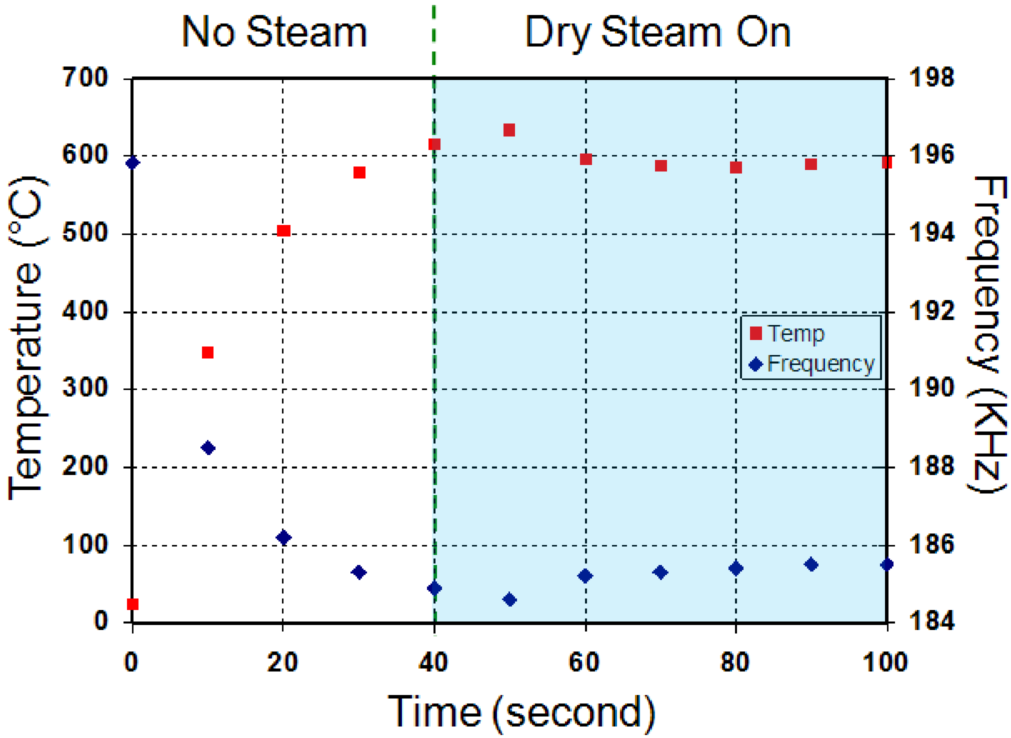


After G-shock
Sample 1 Device 1



SiC Sensor Operation at 600°C





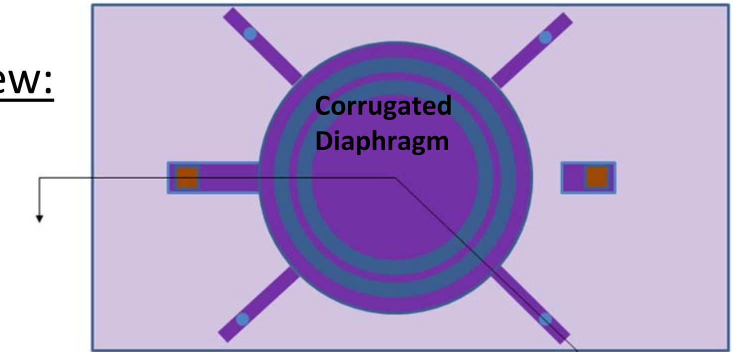
- **The polycrystalline 3C-SiC sensor resonates in air and can operate at 600°C in dry steam**
- **The strain sensor has a sensitivity of 66 Hz/με and resolution of 0.045 με in a 10 kHz bandwidth**
- **This poly-SiC sensor utilizes a fabrication process that can be utilized realize other harsh environment sensors.**

D. R. Myers *et al.*, J. Micro/Nanolith. MEMS MOEMS (2009)

SiC Capacitive Pressure Sensor

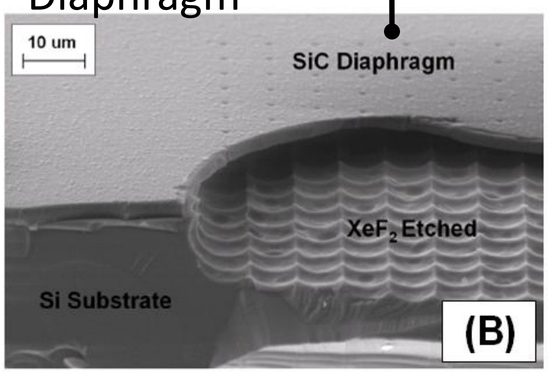
- Designed to operate at 200bar, 374°C, and resist high burst pressure

Top View:

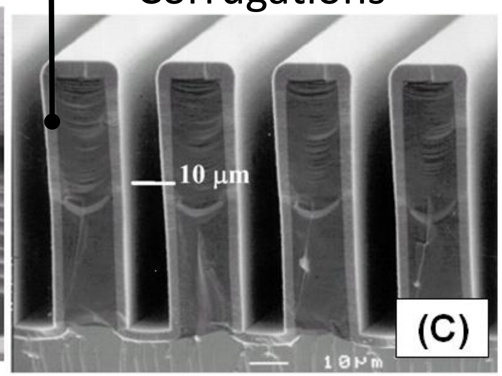


Cross-Section: Top Electrode Bottom Electrode

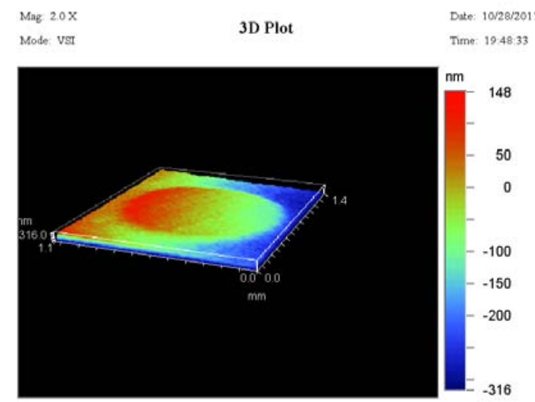
Diaphragm



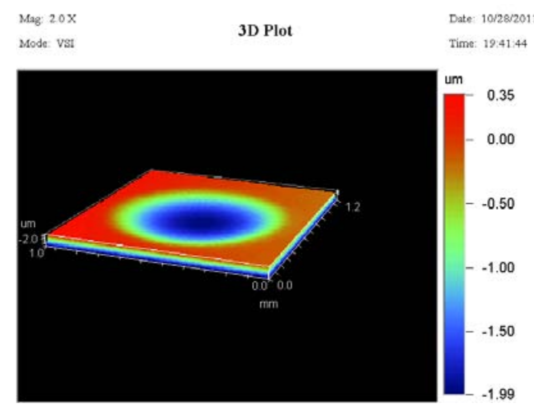
Corrugations



1000 µm diaphragm - Vacuum OFF

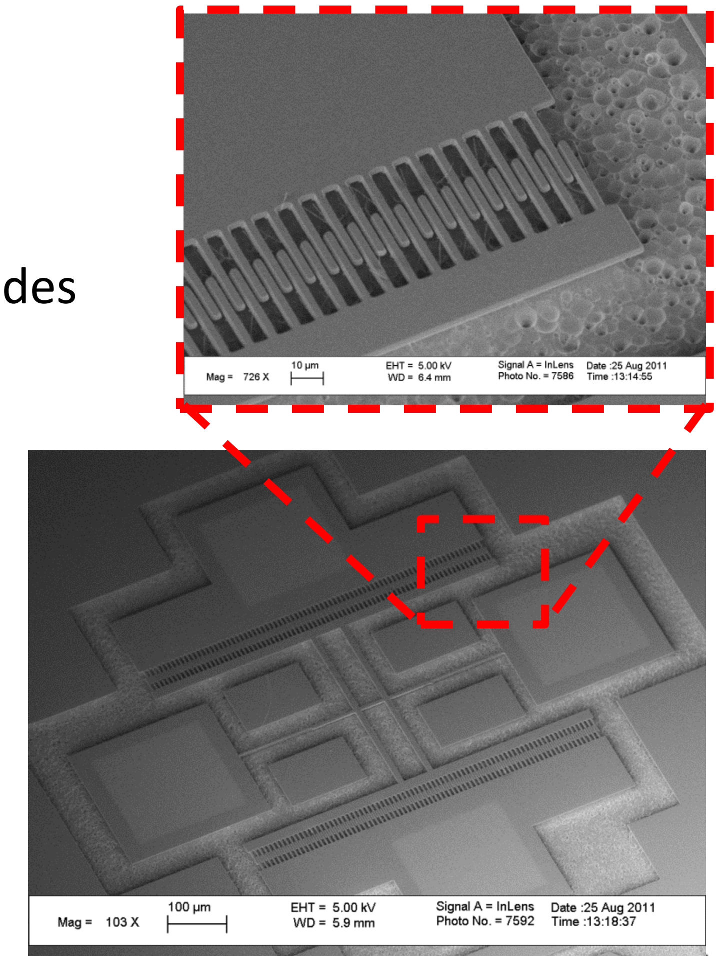


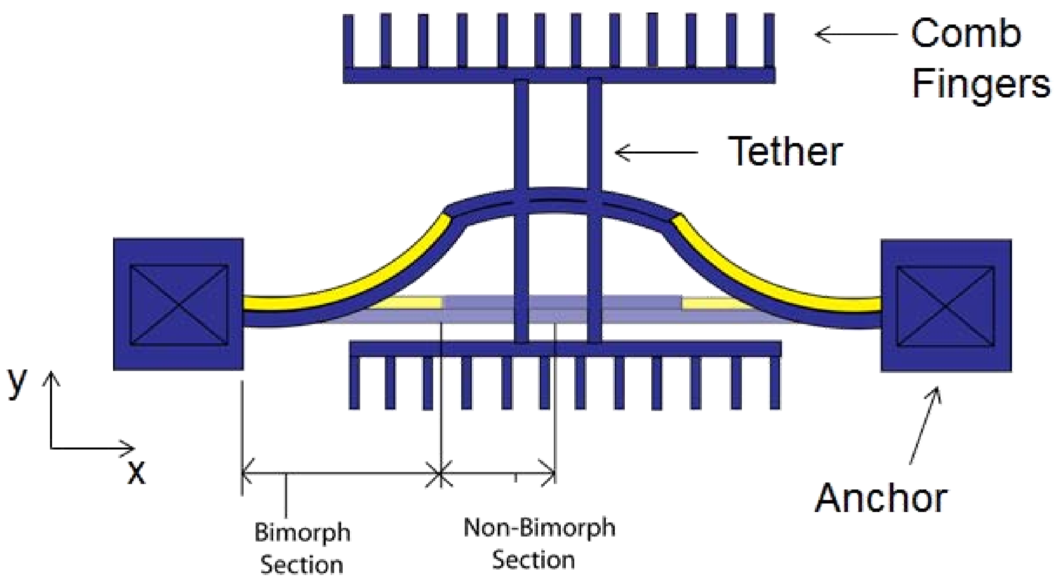
1000 µm diaphragm - Vacuum OFF



SiC Bimorph Temperature Sensor

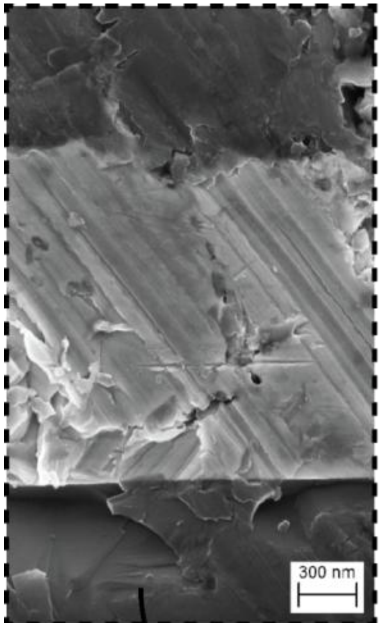
- Electrostatic comb fingers used for mechanical-electrical conversion
  - Linear relationship for capacitance versus displacement
  - Simple fabrication process, no bottom electrodes



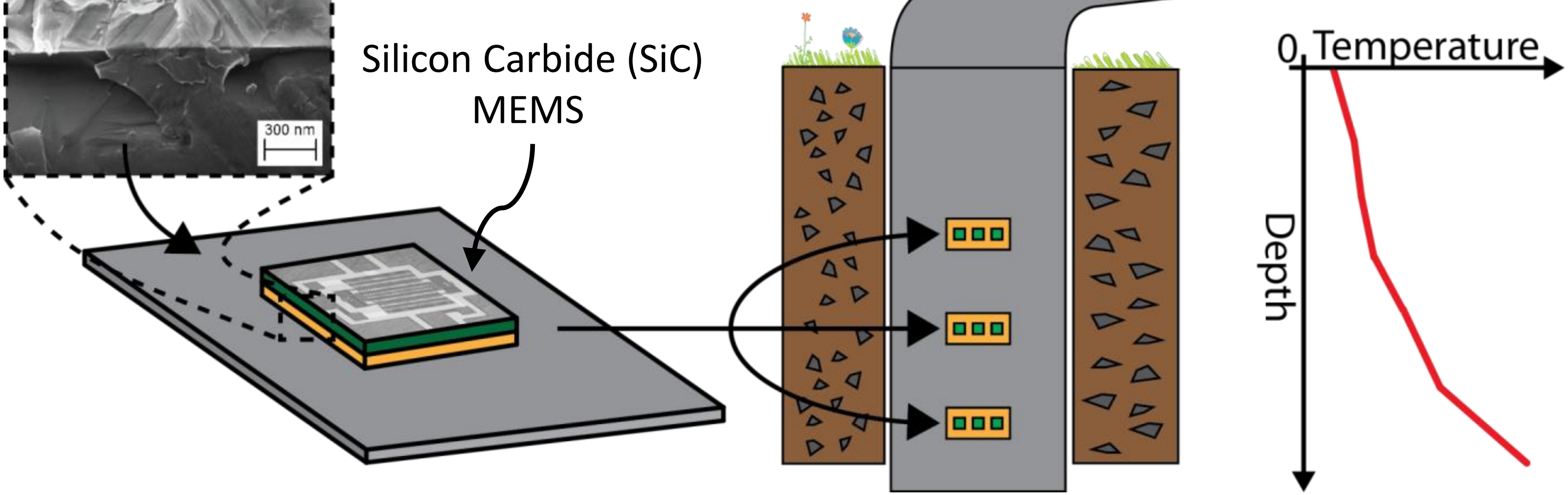


Harsh Environment Sensor Bonding

Silicon Carbide MEMS
bonding to steel
for 500 °C survivability



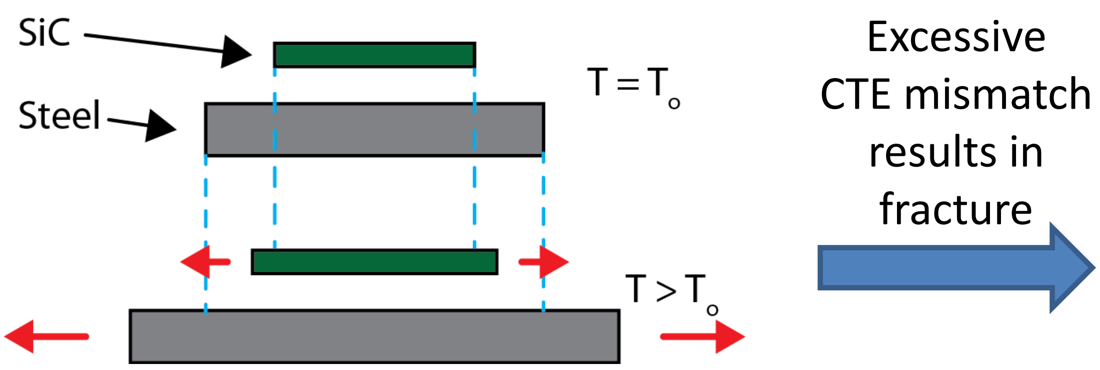
Geysers Geothermal Power Plant



Steel steam-extraction well-casing from hot geothermal rock

Bonding Challenges for High Temperatures

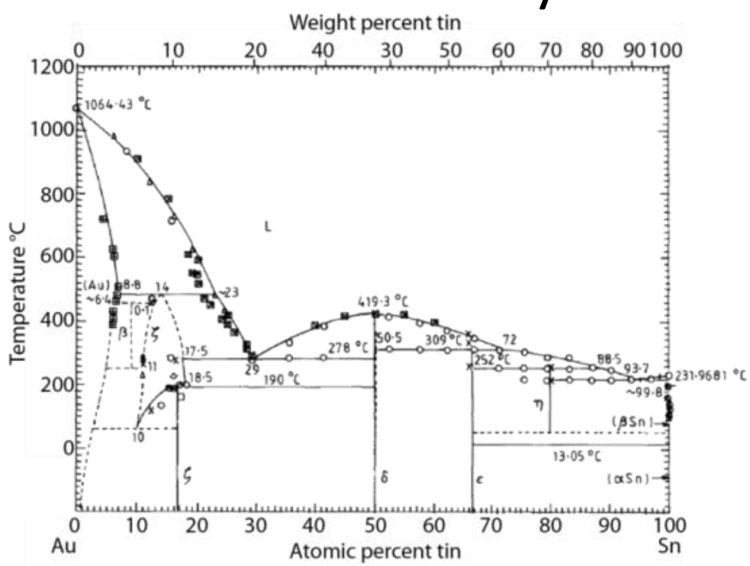
- Coefficient of Thermal Expansion (CTE) mismatch
- Soldering is not suitable for high temperatures (>450°C)
- Brazes typically require bonding well above operating temperature
- Welding processes vaporize SiC
- Long-term survivability at high temperatures

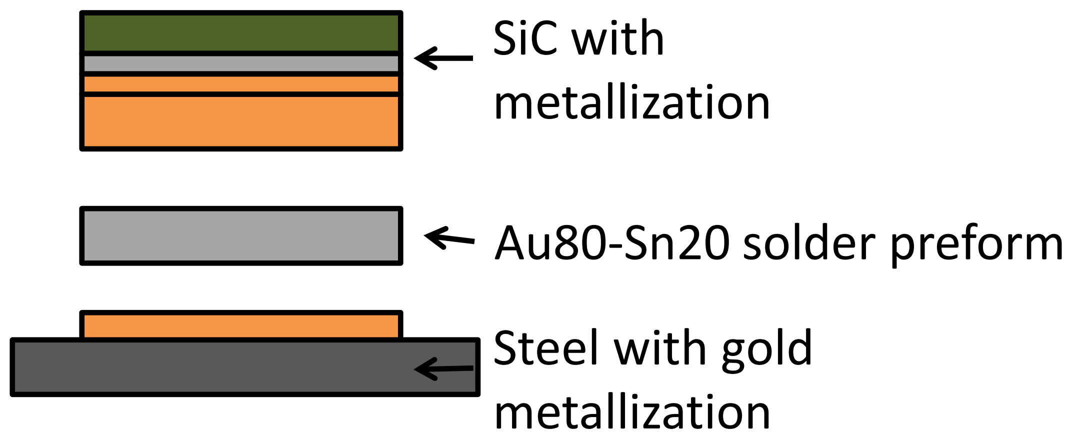


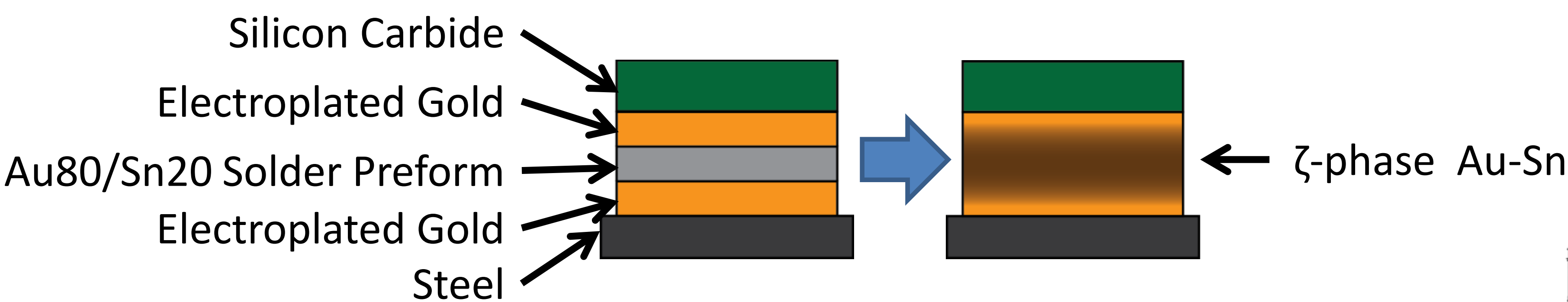
Die brazed at 600°C fractures upon cooling

Solid Liquid Interdiffusion (SLID) Bonding

- Bond at lower temperatures, survive at higher temperatures
- Gold-tin material system for bond

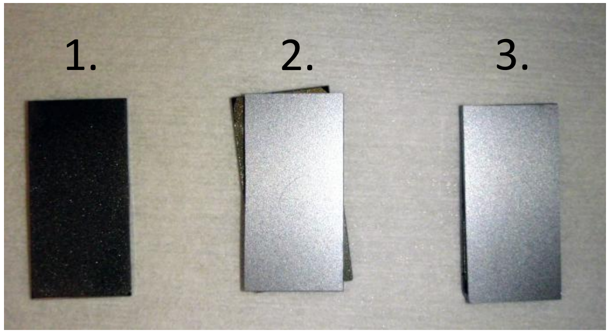


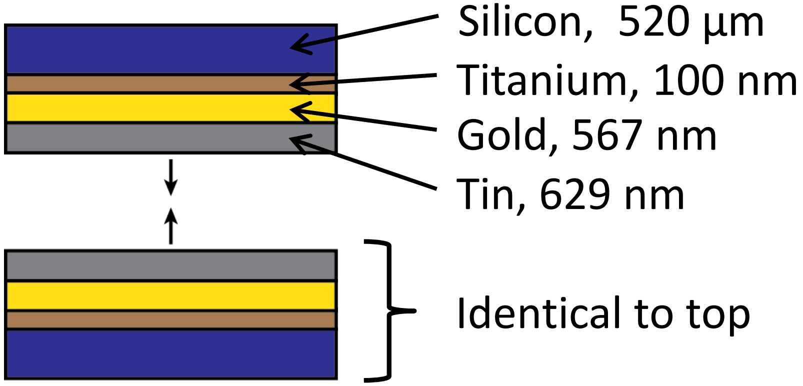


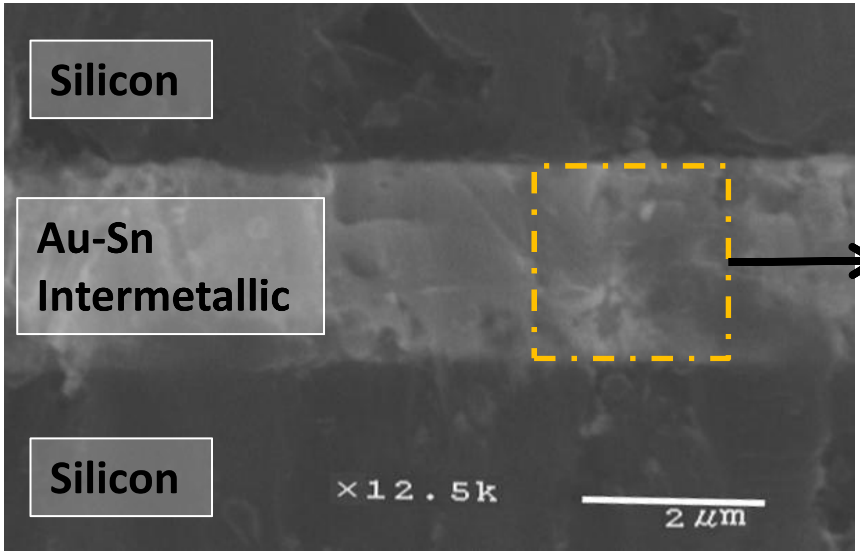


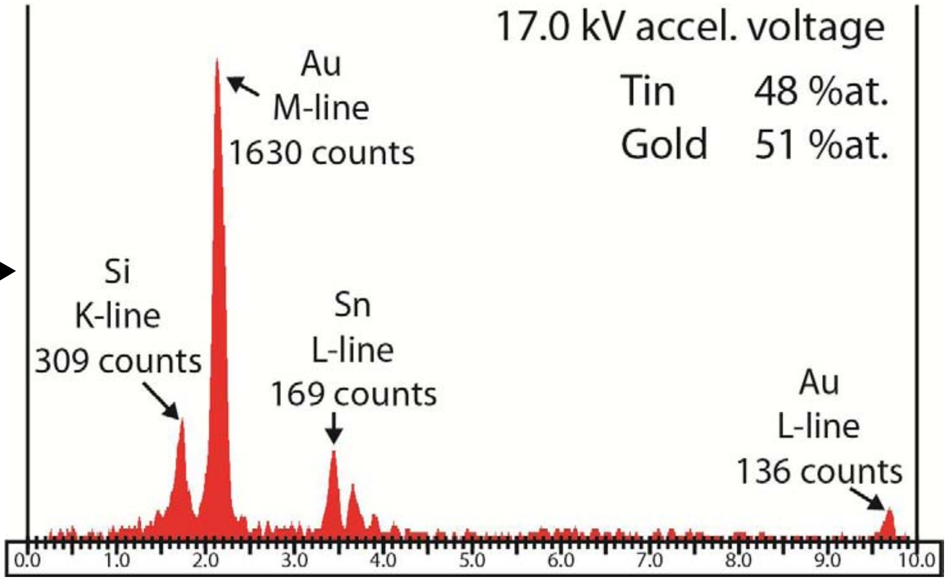
Preliminary Bonding Experiments

- Silicon-to-silicon bonding with thin Au-Sn intermetallic









Conclusions

- We envision fully-integrated wireless sensor platforms for the advanced monitoring and improved efficiency of engineering systems operating in harsh environments
- Silicon Carbide is a suitable material for developing harsh environment sensor platforms
- High-temperature SiC sensors have been developed and demonstrated in hostile environments

Acknowledgements

Many Thanks:

- Professor Knut Aasmundtveit
- Vestfold University College
- SINTEF
- BMAD Lab and BSAC

Thank You Very Much!

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appisano@me.berkeley.edu