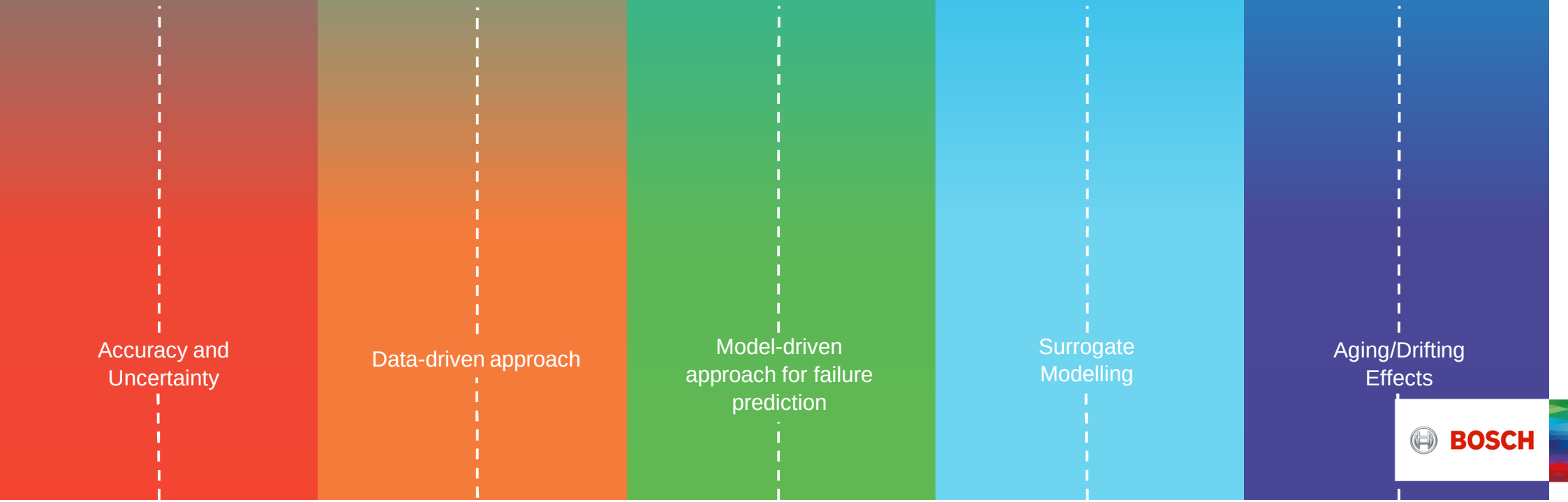
Prognostics and Health Management of safety relevant electronics for future application in autonomous driving

Reinventing reliability in the era of disruption and creativity



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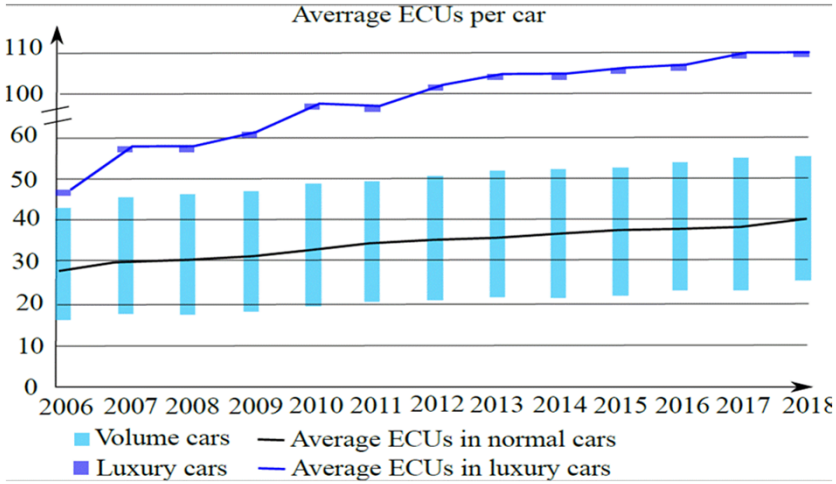
Introduction
Background and Motivation

Fig: Electronic control unit



The Electronic Control Unit (ECU) is used to control the engine and other components functions.

Introduction
Background and Motivation

Challenges	Motivation
Autonomous driving	Functional Safety
Costs	Redundancy reduction
Short-time-to-market	Real load collectives
System Availability	Mobility Service
New Design	Heterogeneous integration
New Functions	Internet of Things
Consumer Electronics	Fast qualification

Prognostics and Health Management can be an answer to all these challenges

Introduction
Background and Motivation

Condition Monitoring
Monitoring and Collecting necessary and useful data from real driving conditions

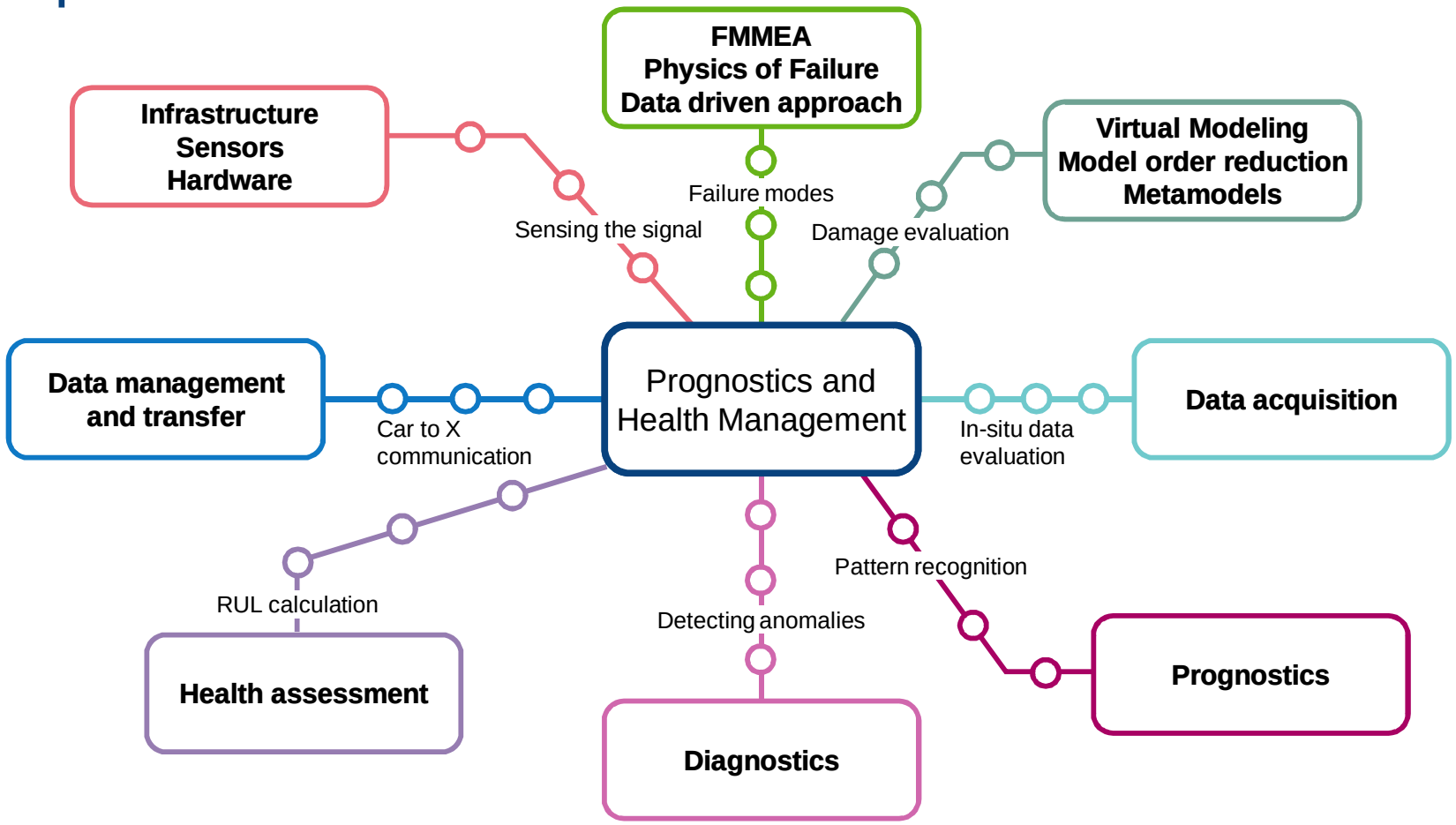
Prognostics and Health Management
Health Assessment and an first level of prognostics

Predictive Maintenance
Fully prognostics usage by enforcing predictive maintenance

Level 1
Level 2
Level 3

Prognostication level to be done in steps

Introduction
Metro map



Concept of PHM
iForce – piezoresistive stress sensor

Piezoresistive silicon based stresss sensor: IForce – in-situ measurements of the stress state inside IC package

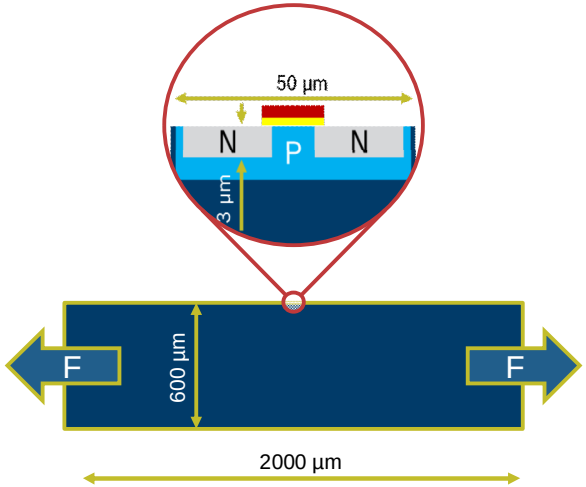
- Localized mechanical stress measurements during active operation and field condition
- Detection of the crack/delamination during active operation and field condition of the ASICs ad power module
- Understanding the state of health: healthy / unhealthy
- Damage evolution using direct damage relevant quantity:
  - Mechanical stress difference;

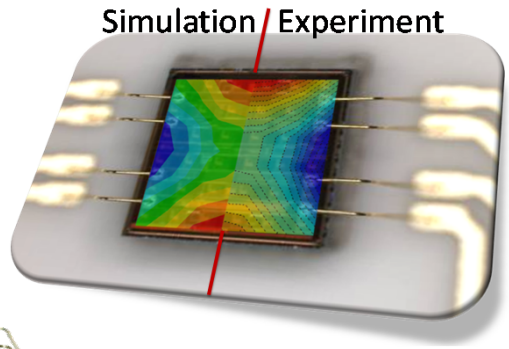
$$\sigma_D = \sigma_x - \sigma_y = \frac{2}{\pi_{44}^{(p)}} \frac{\Delta I}{I}$$

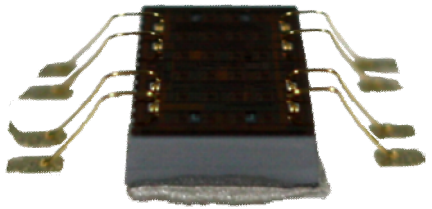
$$\frac{\Delta I}{I} \approx -\frac{\Delta R}{R}$$

  - Shear stress.

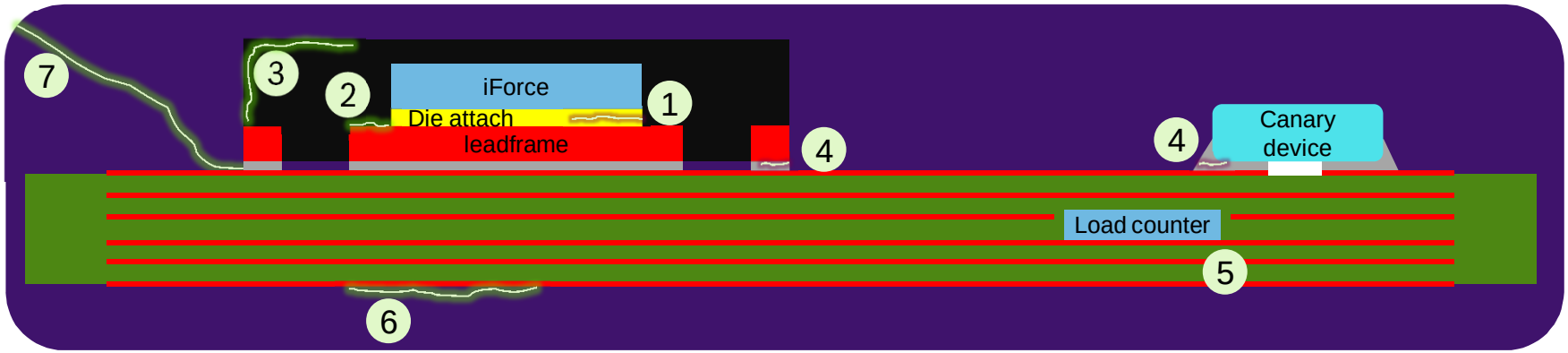
$$\sigma_{xy} = -\frac{1}{\pi_{11}^{(n)} - \pi_{12}^{(n)}} \frac{\Delta I}{I}$$







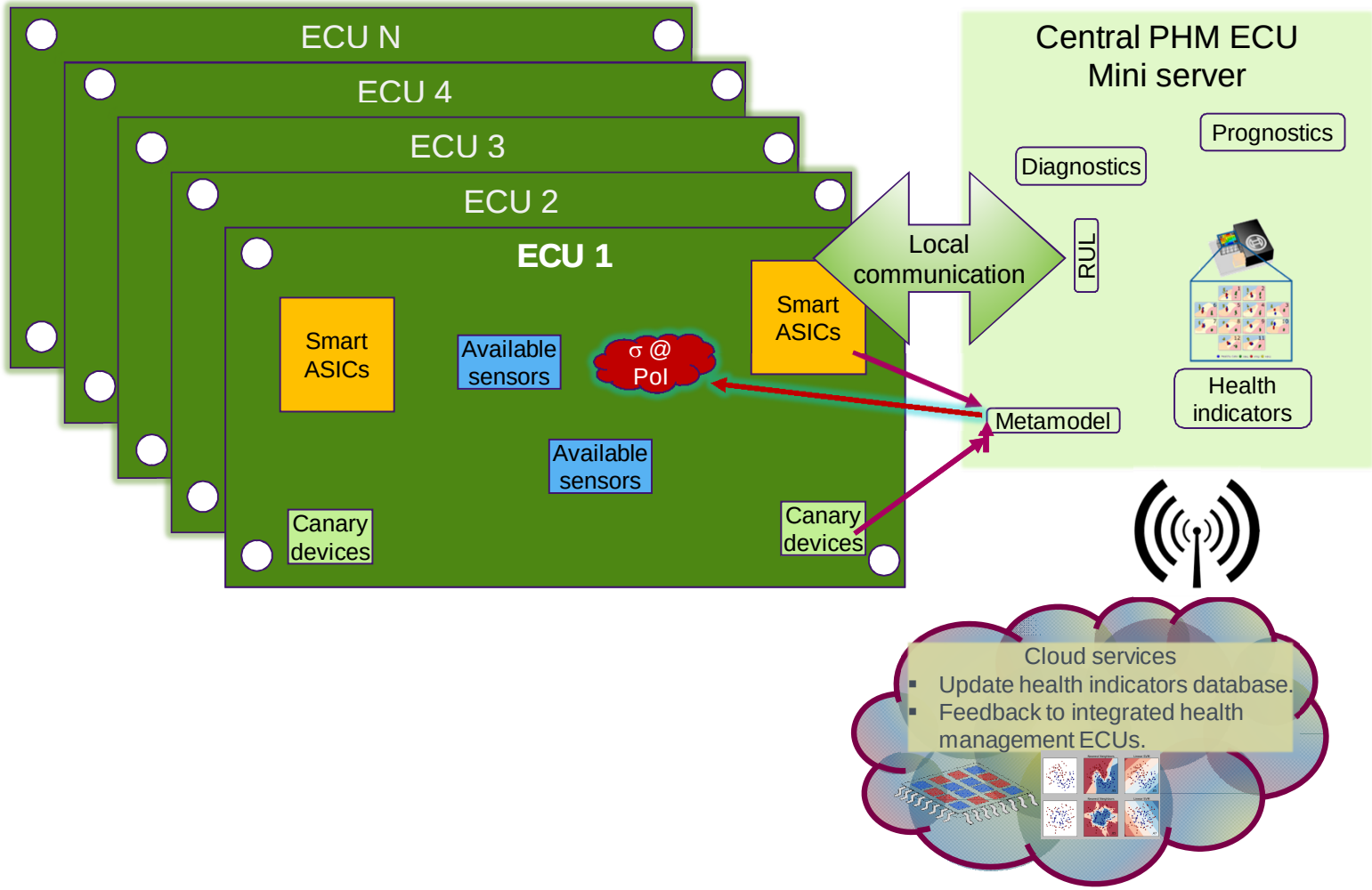
Failure modes
Investigated failure modes → packaging and ECU level



1. Delamination in the die attach → data driven approach with iForce
2. Delamination mold/copper lead frame → data driven approach with iForce
3. Aging of polymers → data driven approach with iForce
4. Solder fatigue → PoF and event detector (canary devices / -features)
5. Aging of other components → data driven approach with iForce
6. Delamination PCB / Mold
7. Crack mold

Integrated health management ECU

Concept



Data-driven Approach

Degradation Prediction of electronic packages using piezoresistive stress sensor

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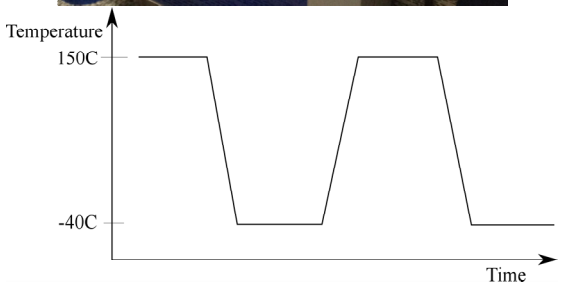
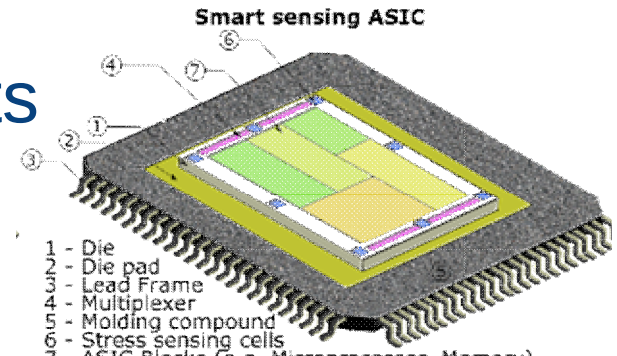
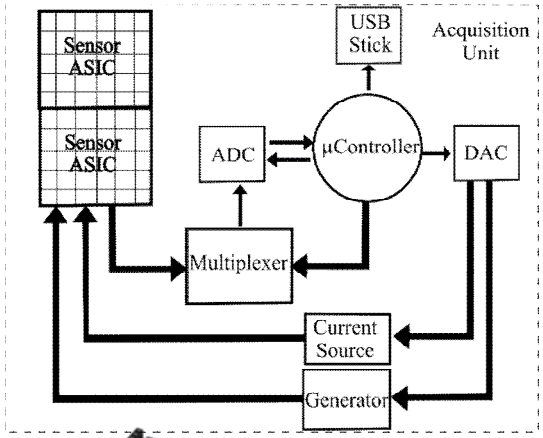
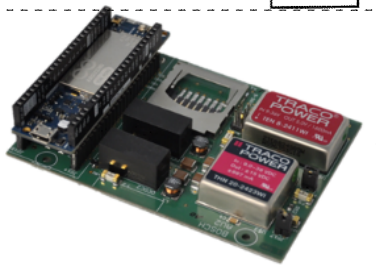
Test Vehicle
Investigated Experiments

Thermal Shock Chamber







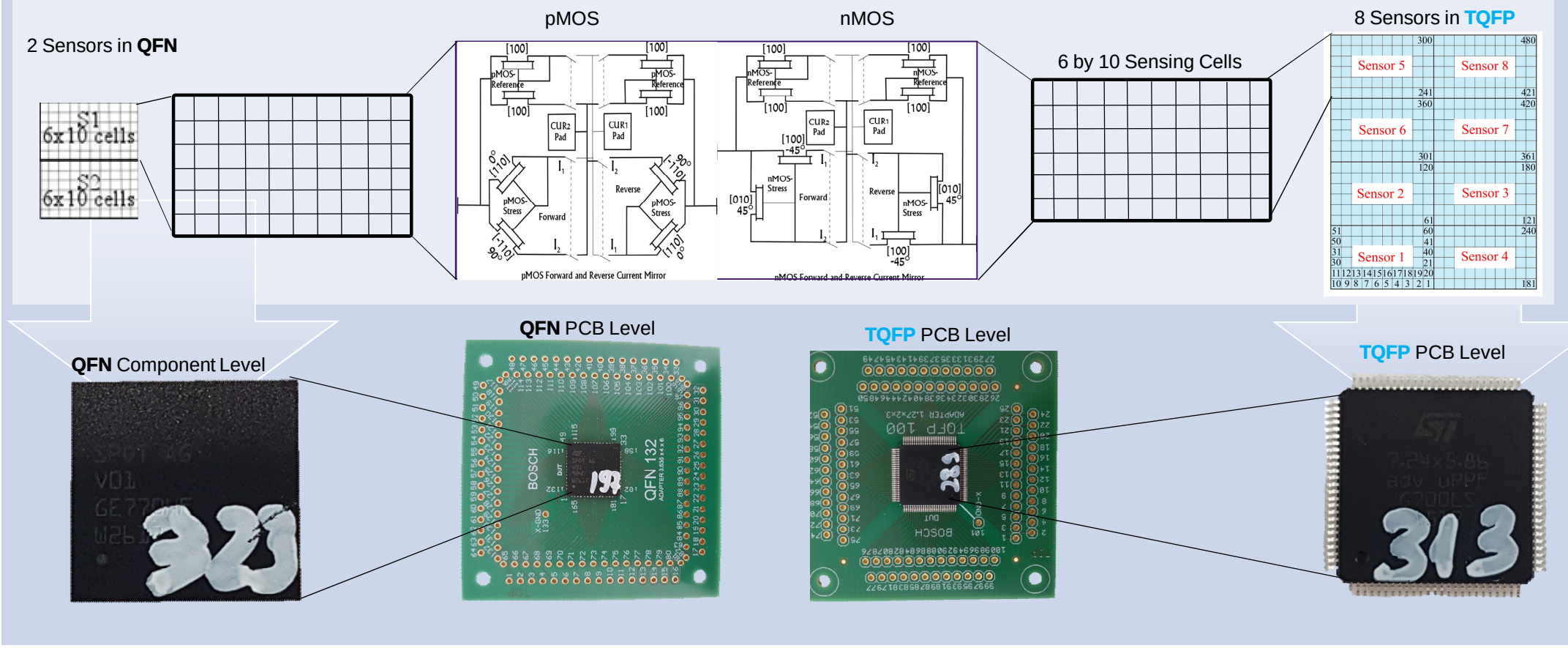


AU transmits data
to Raspberry Pi via WiFi

WiFi

Raspberry Pi saves data
to Web Application via WiFi

Test Vehicle
Components



Thermal Shock Chamber

MC2_1

MC2_2

MC1_1

Wires to Digital I/O pins

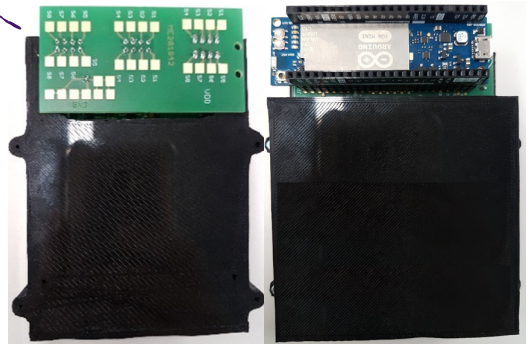
Wires to Digital I/O pins

Wires to Digital I/O pins

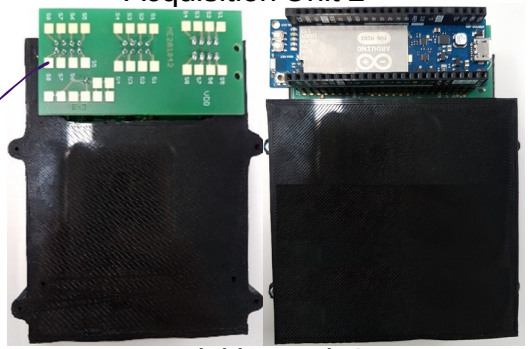
Acquisition Unit 1

Sensors connector

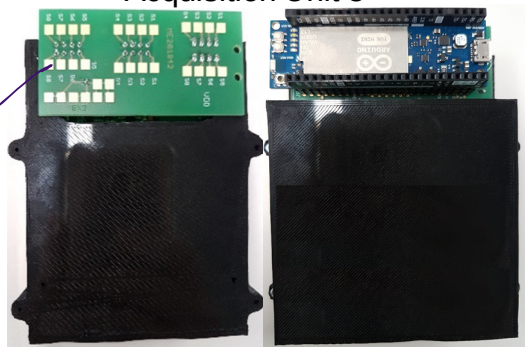
Arduino Board side



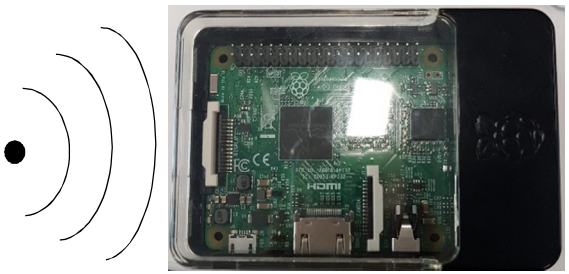
Acquisition Unit 2

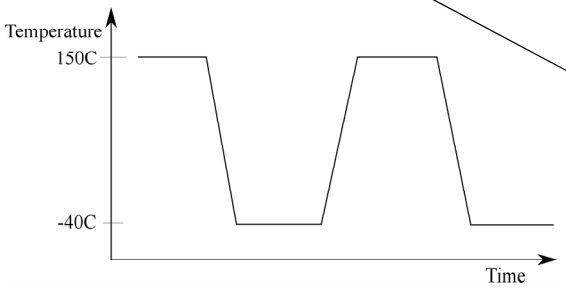


Acquisition Unit 3



WiFi





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Results
Feature Extraction

- The resulted stresses are first subtracted from 150C stresses every each cell position and then their absolute values are summed up;

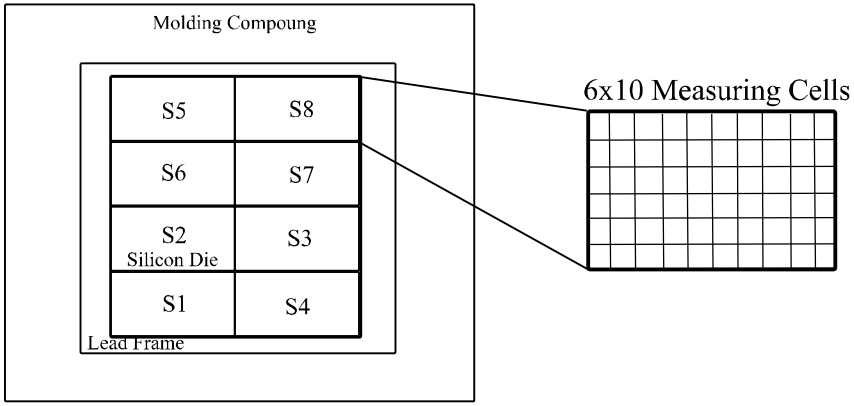
$$f_p^s = \sum_{cell1}^{cell60} |S^{-40C} - S^{150C}| \; ; p = 1,..,8 \; Sensors; \; s = \sigma_D, \sigma_{XY}, \tau_{Max}$$

- S can be any of the following stresses:

$$f_p^{\sigma_D} = \sum_{cell1}^{cell60} |{\sigma_D}^{-40C} - {\sigma_D}^{150C}| \; ; p = 1,..,8 \; Sensors; \; s = \sigma_D, \sigma_{XY}, \tau_{Max}$$

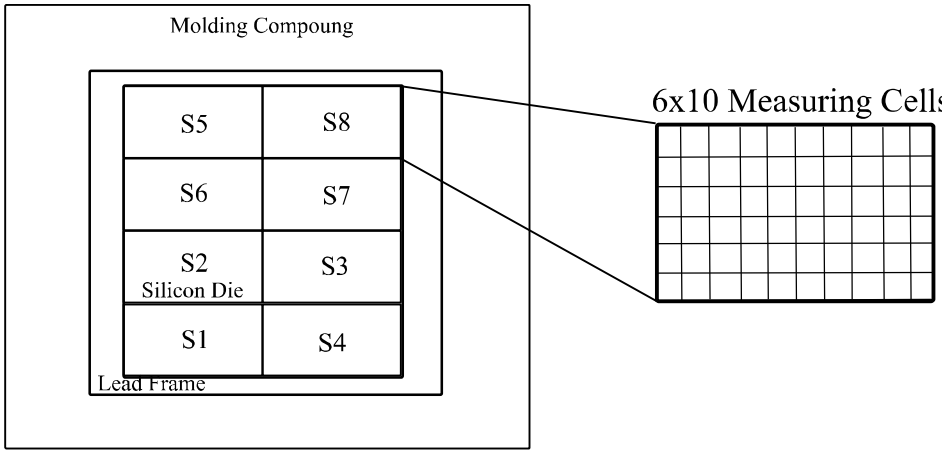
$$f_p^{\sigma_{XY}} = \sum_{cell1}^{cell60} |{\sigma_{XY}}^{-40C} - {\sigma_{XY}}^{150C}| \; ; p = 1,..,8 \; Sensors; \; s = \sigma_D, \sigma_{XY}, \tau_{Max}$$

$$f_p^{\tau_{Max}} = \sum_{cell1}^{cell60} |{\tau_{Max}}^{-40C} - {\tau_{Max}}^{150C}| \; ; p = 1,..,8 \; Sensors; \; s = \sigma_D, \sigma_{XY}, \tau_{Max}$$

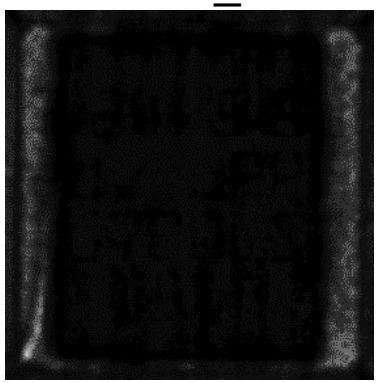


Results
SAM Images

- 2 Delaminated Samples, 1 No delaminated sample

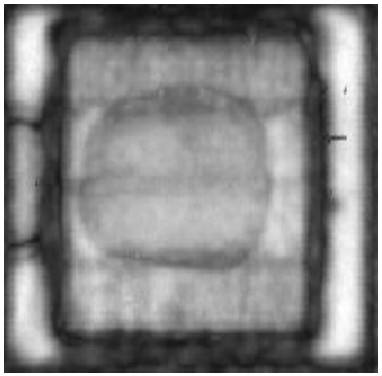


MC1_1



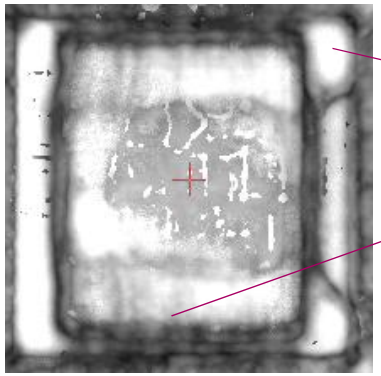
No Delamination

MC2_2

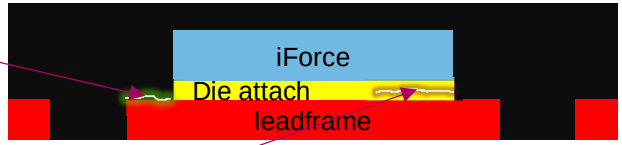


Delamination

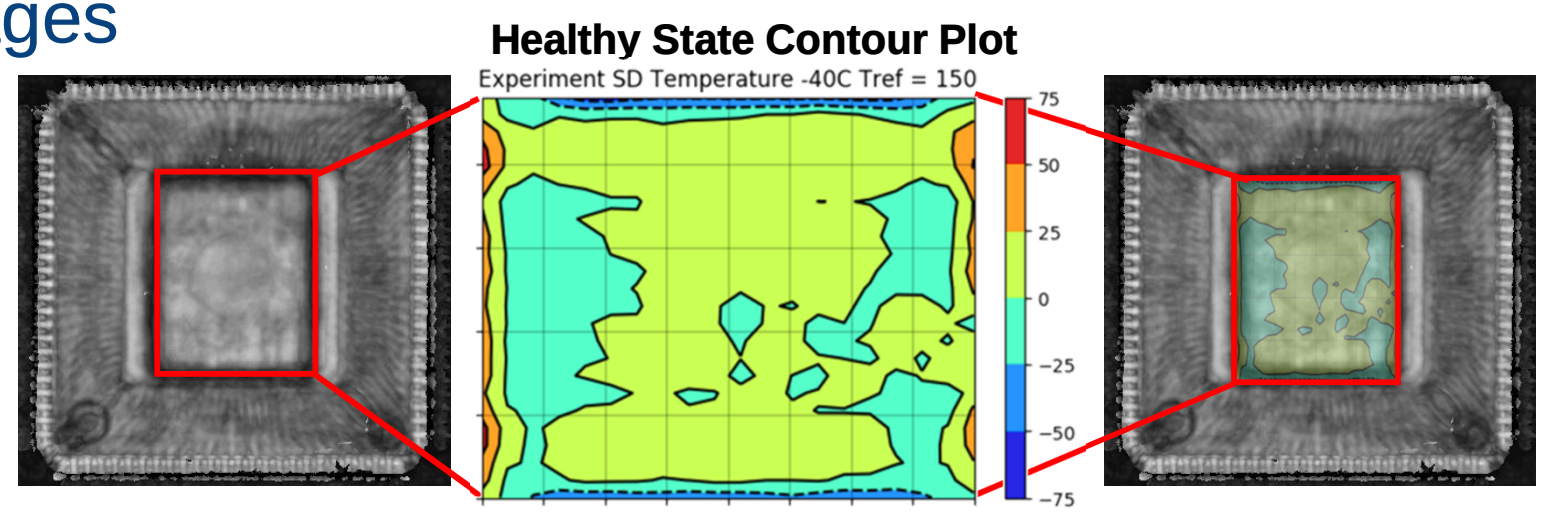
MC2_1

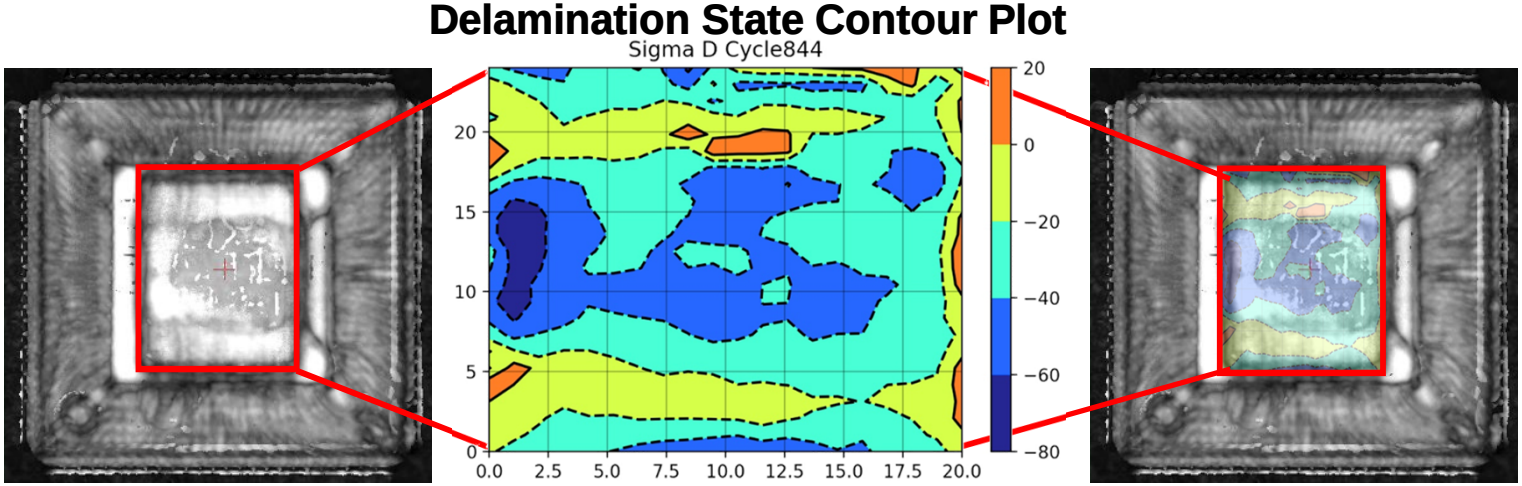


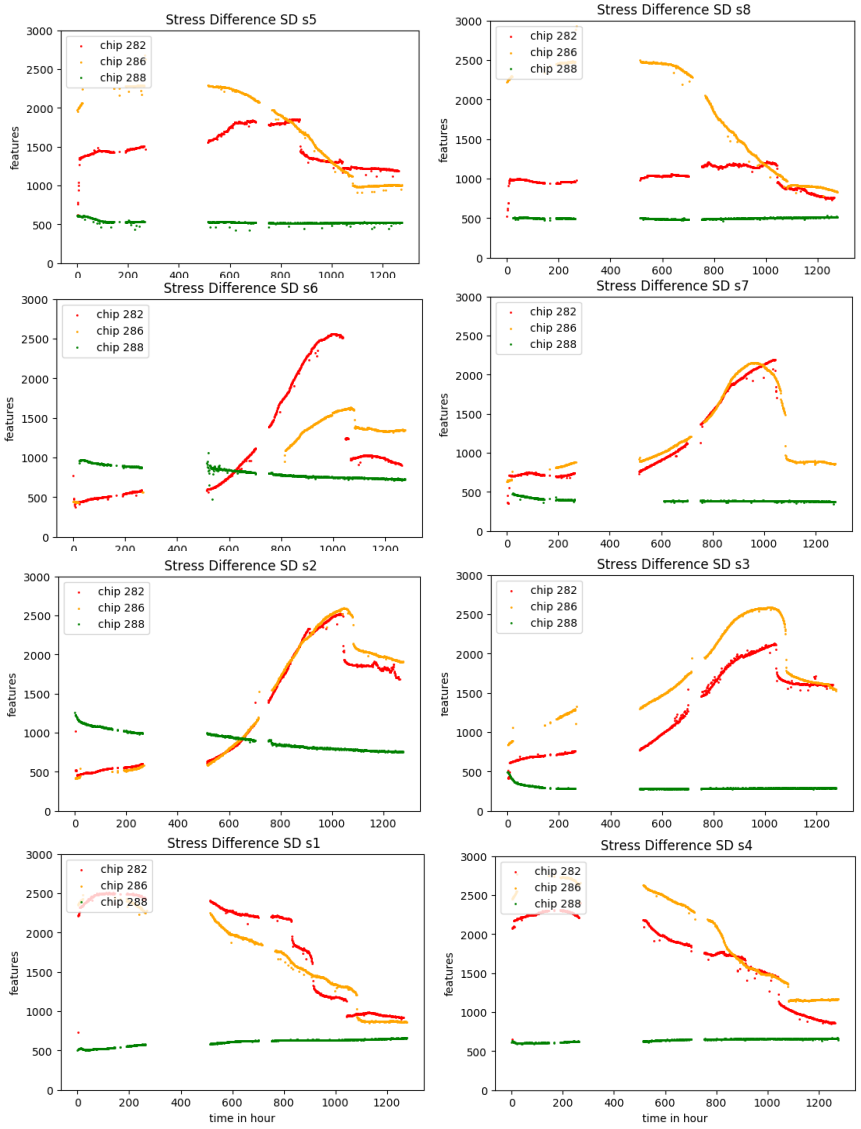
Delamination

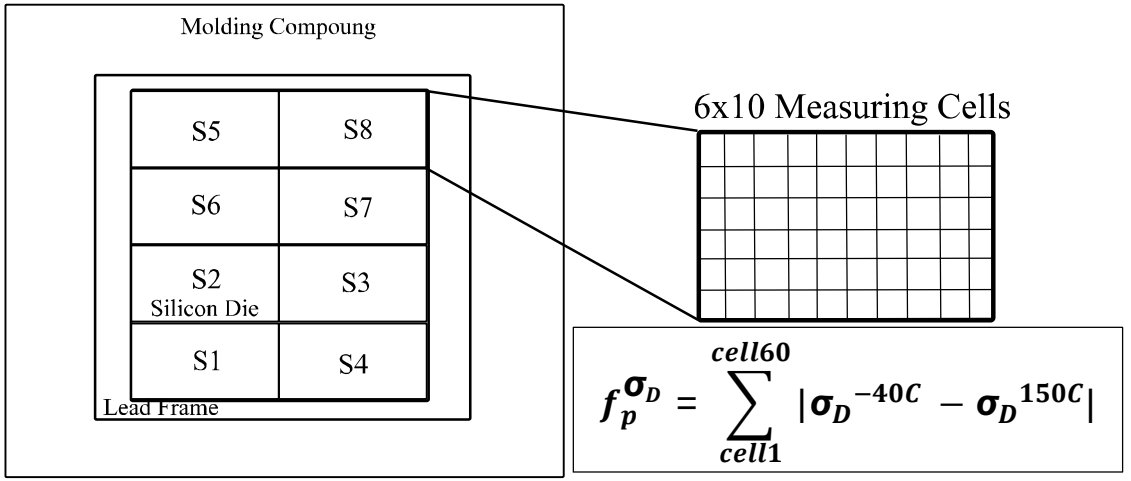


Results
SAM Images



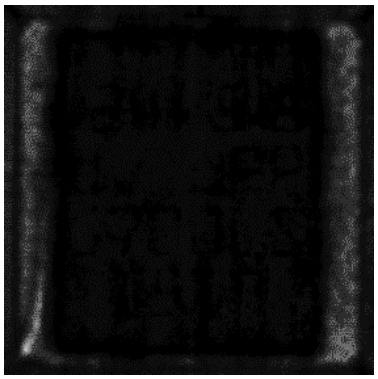




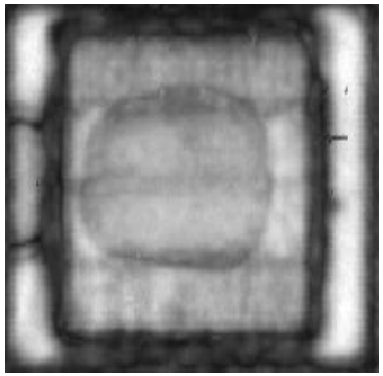


$$f_p^{\sigma_D} = \sum_{cell1}^{cell60} |\sigma_D{}^{-40C} - \sigma_D{}^{150C}|$$

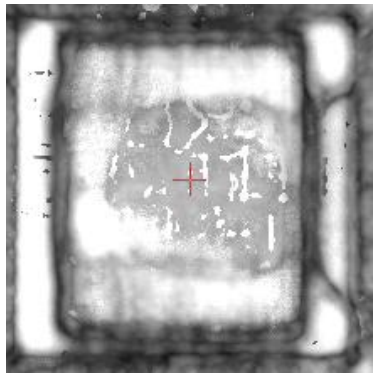
MC1_1



MC2_2



MC2_1



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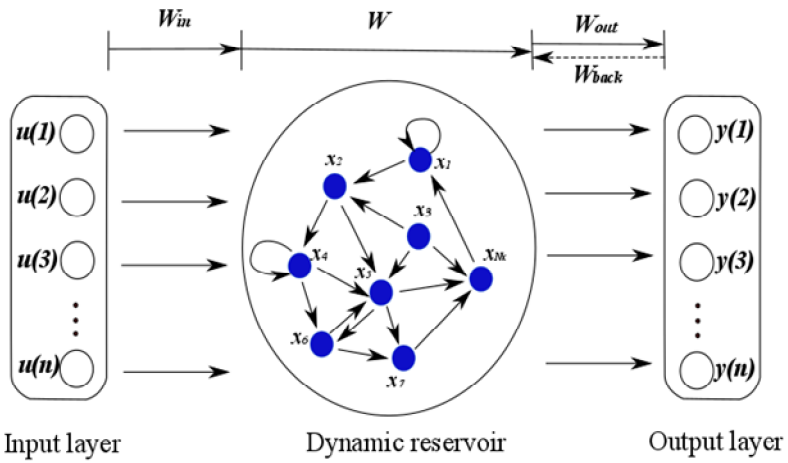
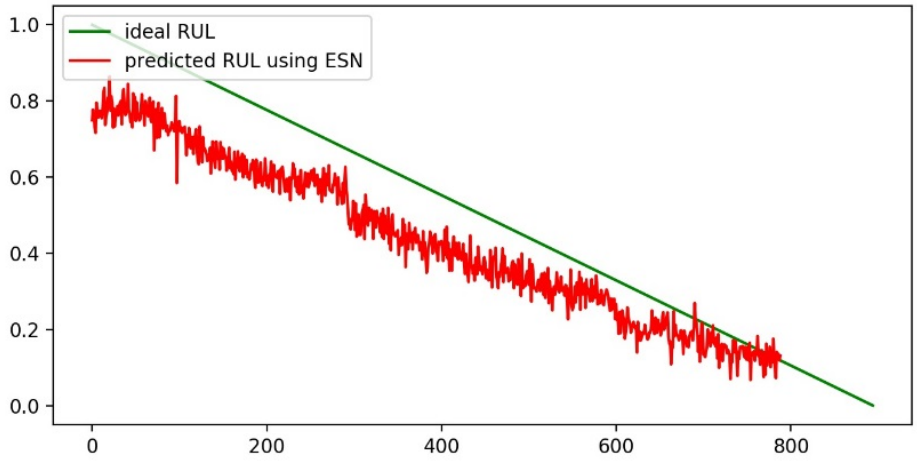
Degradation Prediction
Echo State Network



- reservoir size , spectral radius of reservior
- input shift , input scaling
- output shift , output scaling



Hidden layers->dynamic reservoir

W_{in}, W generated randomly, only W_{out} is trained

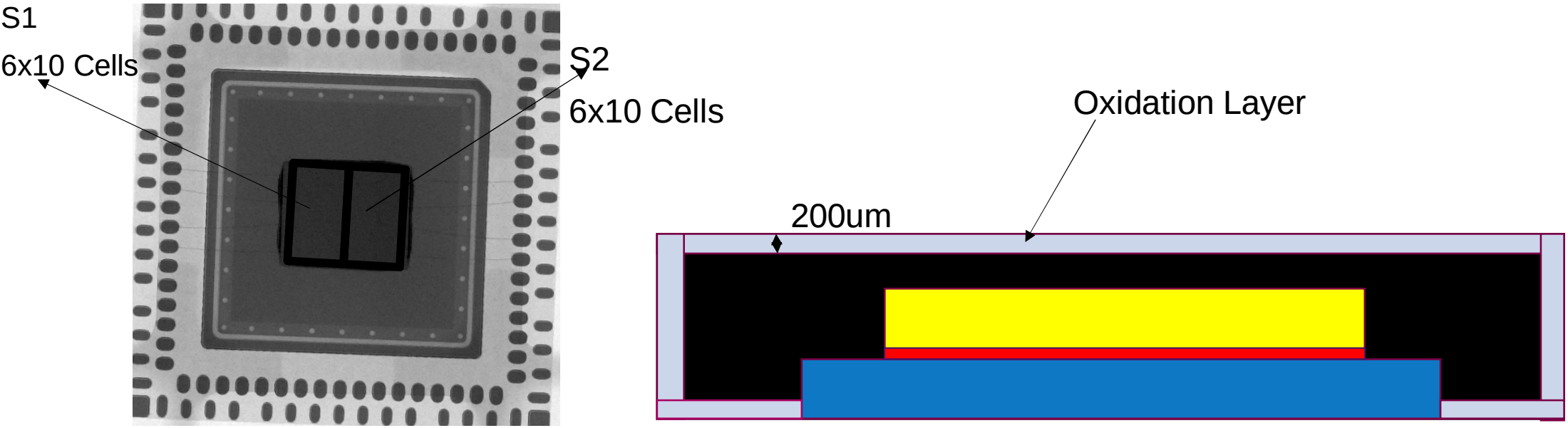
$u(1), u(2), \ldots . u(n), \ldots , u(T)$: stress values during cycling

$y(1), y(2), \ldots . y(n), \ldots , y(T)$: RUL ,1….0

AGING/DRIFTING EFFECTS

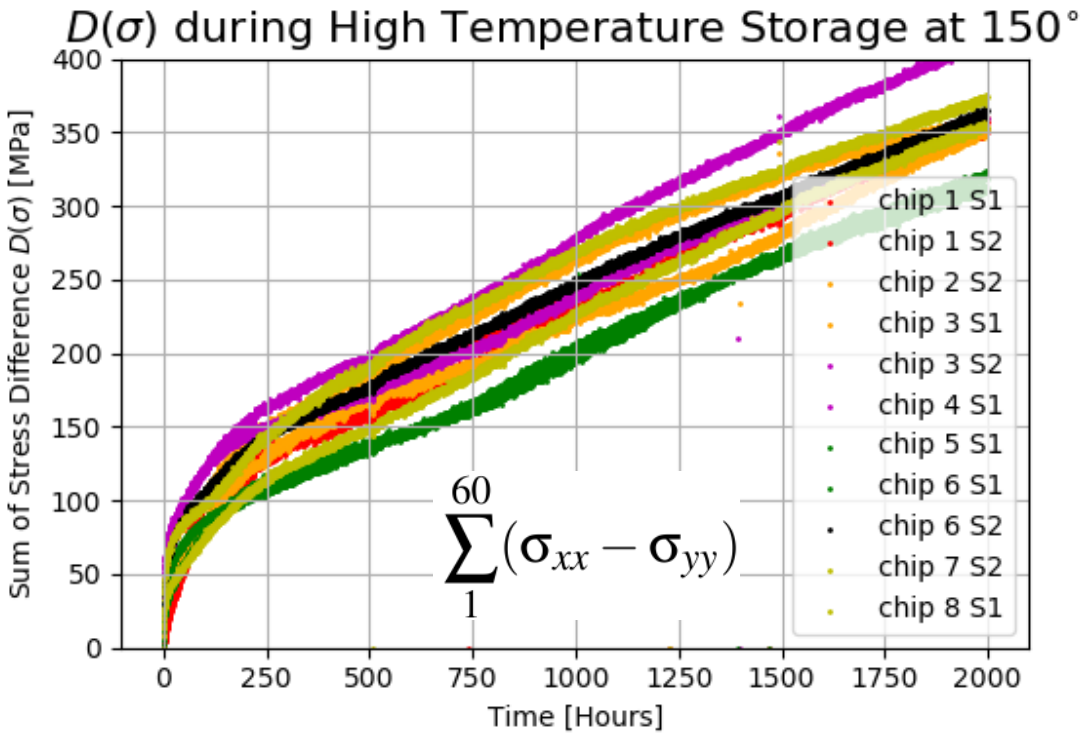
AGING/DRIFTING EFFECTS OF HIGH TEMPERATURE STORAGE ON STRESS MEASUREMENTS

Aging Phenomena
Oxidation Layer in Molding Compound

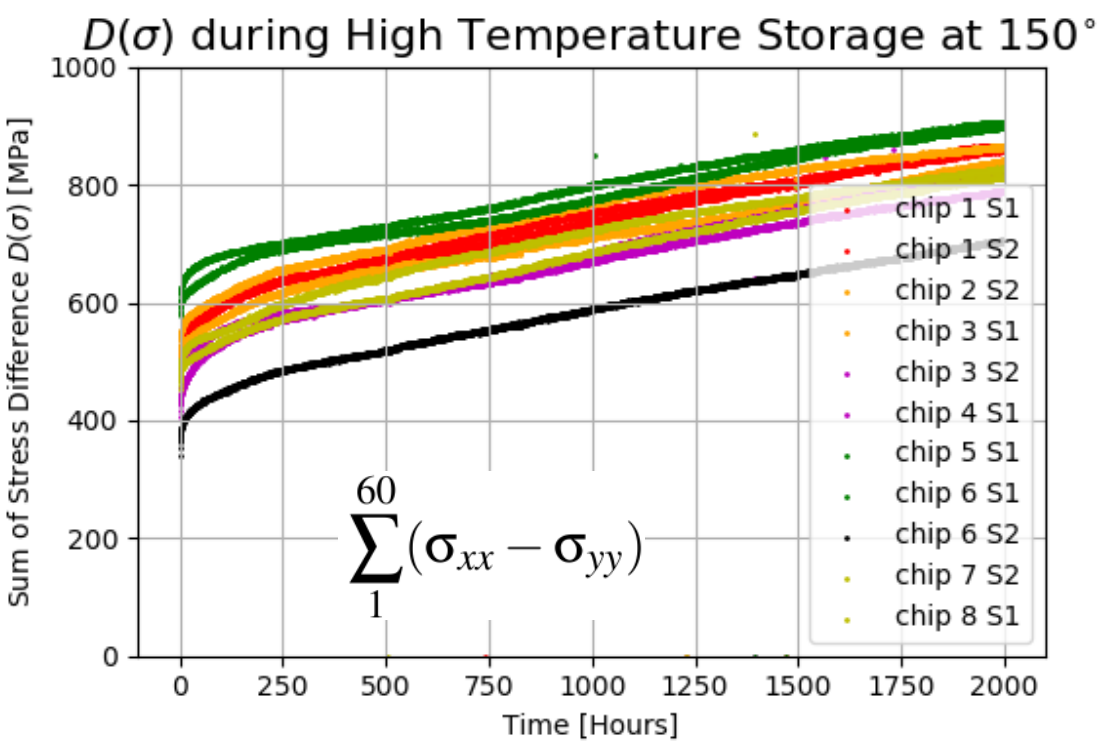


Results
Oxidation Layer in Molding Compound

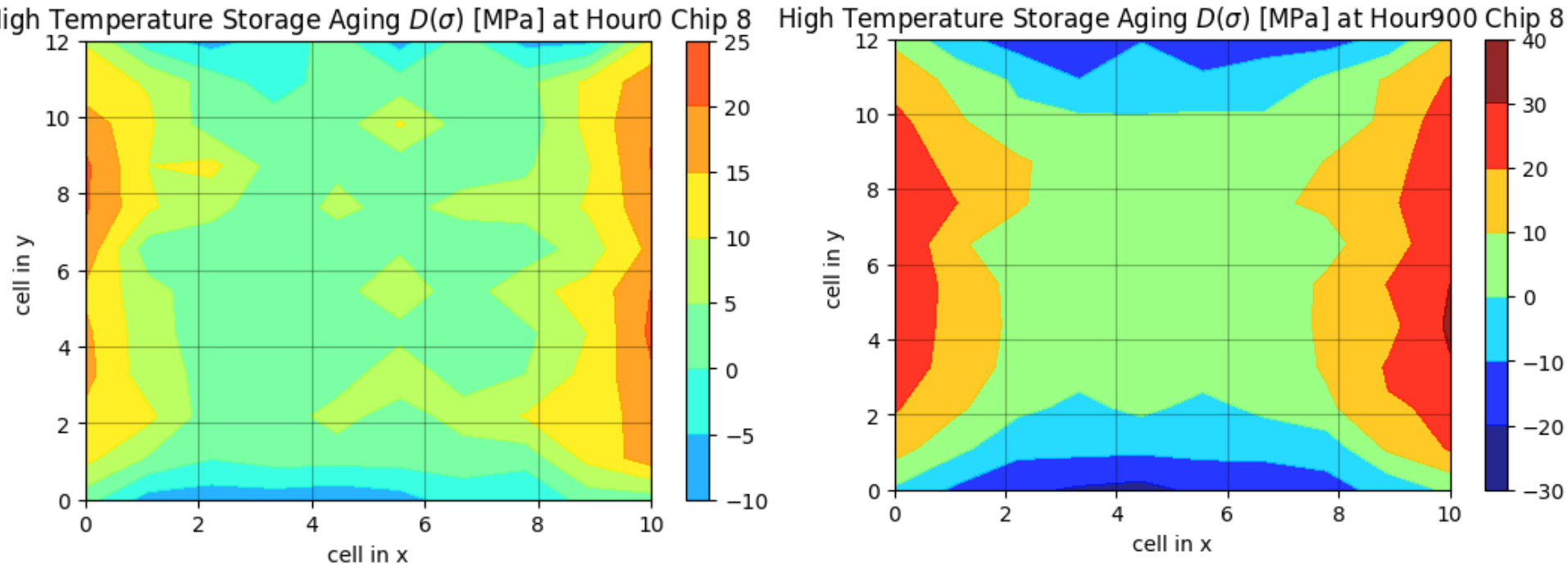
Relative Sum Stresses



Absolute Sum Stresses



Results
Oxidation Layer in Molding Compound



Stress Difference Contour Plot due to the aging effect