IMAPS 12th International Conference and Exhibition on Device Packaging, Fountain Hills, Arizona; March 14-17, 2016

Comparison of hermetic sealing using SAC and SnPb solder for a MEMS pressure sensor

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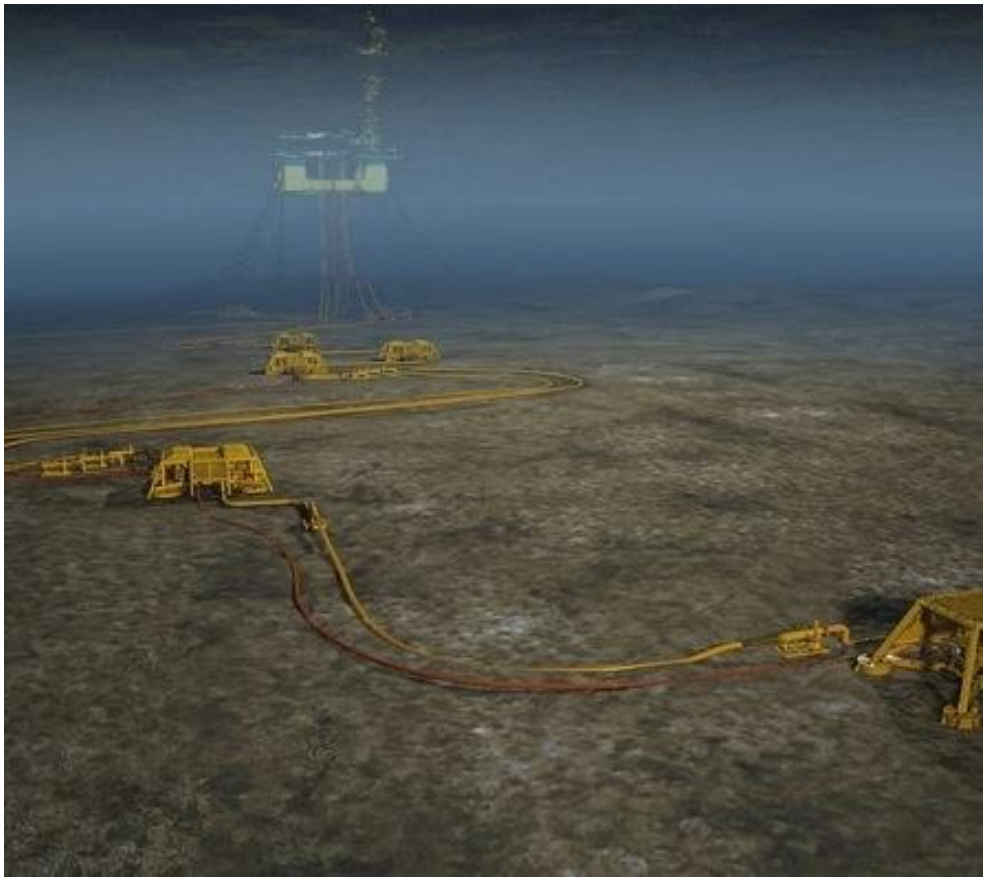
Subsea application

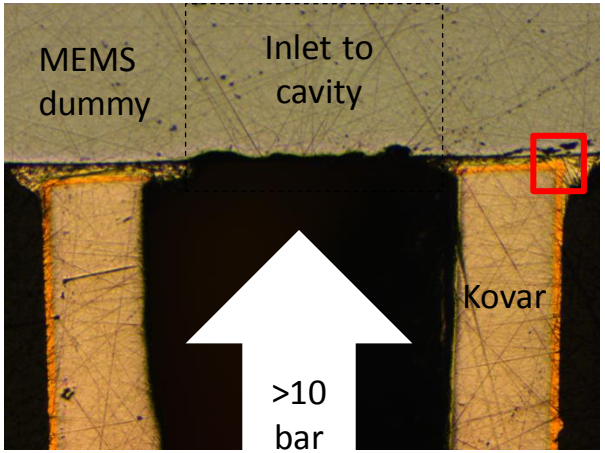


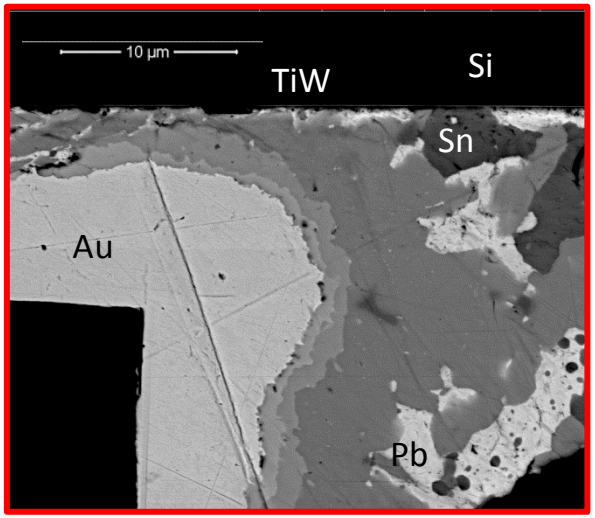
- Stable temperature conditions
- The challenge:
  Replacement or repair in case of failure is expensive or even impossible

→ Life time

Motivation for detailed studies

- Simple, initial assembly tests using Si/TiW/Au, Kovar/Au - and SnPb solder
  - Strong (burst tested to >10 bar)
  - "Hermetic" (He leak tested)





BUT will this seal also be strong and tight enough after 10 years subsea?

Outline

- Concept and Design of Experiment for detailed studies
- Environmental exposure
  - Thermal aging

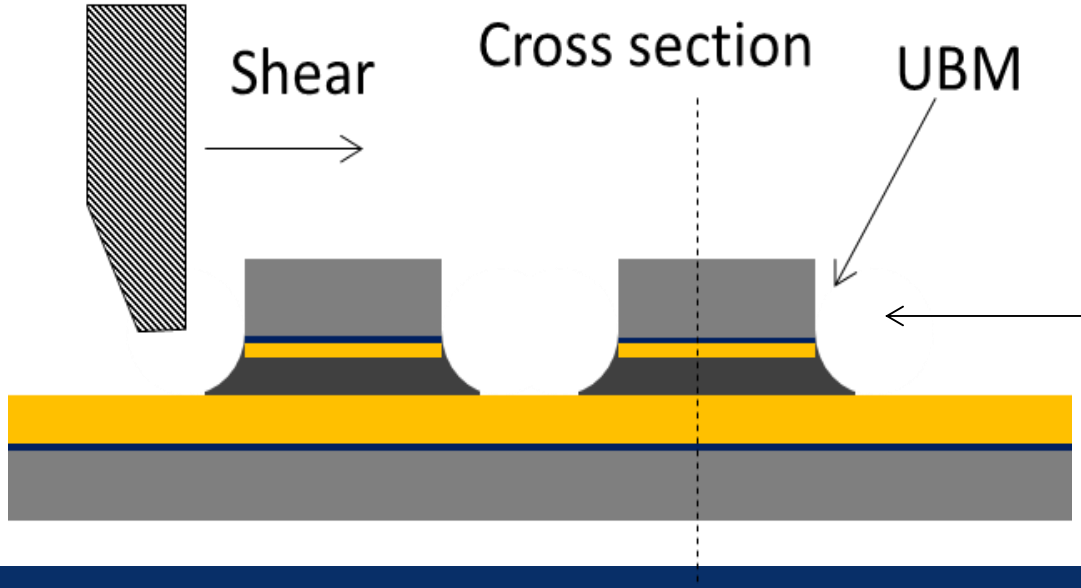
- Cross sections, microstructure evolution
  – what does it tell?
- Shear strength tests
- Fractography, failure mode evolution

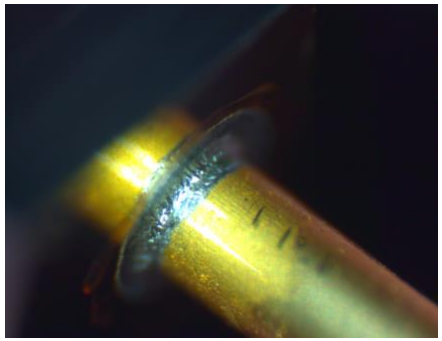
- Comparison and summary

Nordson DAGE 4000PLUS

Concept: Si dies mimicking MEMS and Kovar tube ending

- Pressure assisted solder deposition and controlled chip dimensions
- Characterization as bonded and after thermal aging
  - Cross sections and light microscopy and/or SEM/EDX
  - Bond strength evaluation



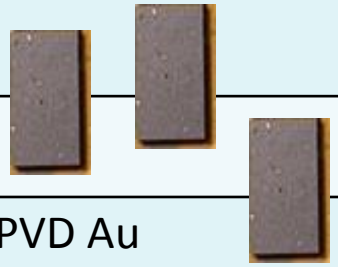


The Design of Experiment

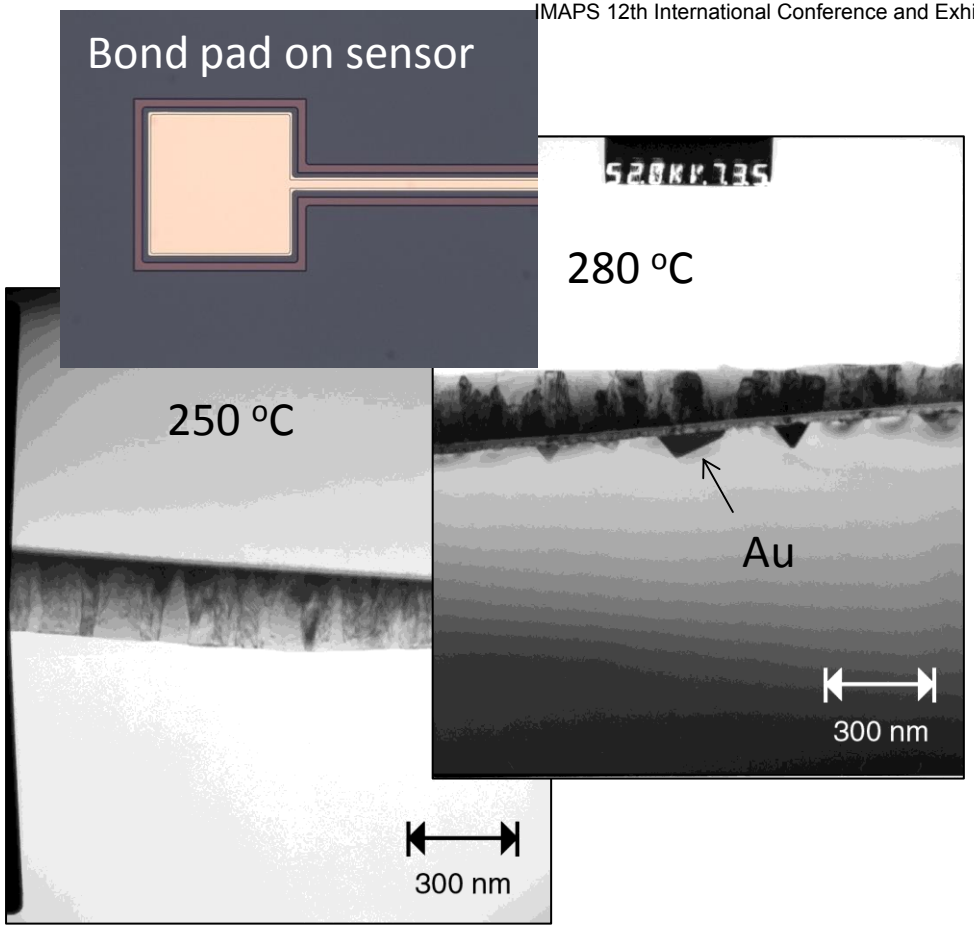
Metallization of bonding surfaces

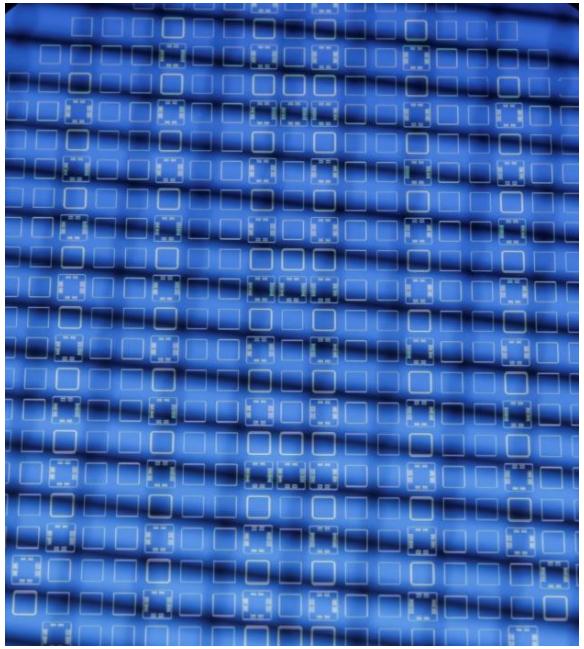
Mimics plated Au or Ni/Au on tube ends

Wafer ID	Material layers deposited on the wafer
Substrate Au	150 nm PVD* NiCr, 250 nm PVD Au, 5 µm EP** Au
Substrate Ni	150 nm PVD NiCr, 250 nm PVD Au, 5 µm EP Ni, 250 nm EP Au
Chip NiCr	150 nm PVD NiCr, 250 nm PVD Au
Chip TiW	60 nm PVD TiW, 500 nm PVD Au
Chip Ox/NiCr	750 nm SiO_2, 150 nm PVD NiCr, 250 nm PVD Au



*) PVD: Physical vapor deposition by sputtering, **) EP: Electroplating

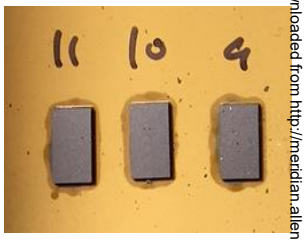




NiCr applied by SINTEF for radiation detectors since ~1960, but not a barrier for traditional soldering temperatures, *M.M.V. Taklo et al., J. Micromech. Microeng. 14 (2004) 884–890*

TiW applied by SINTEF for Au wafer level bonding, *H. R. Tofteberg et al., J. Micromech. Microeng. 24 (2014) 084002 (8pp)*

Design of experiment, assembly* combinations



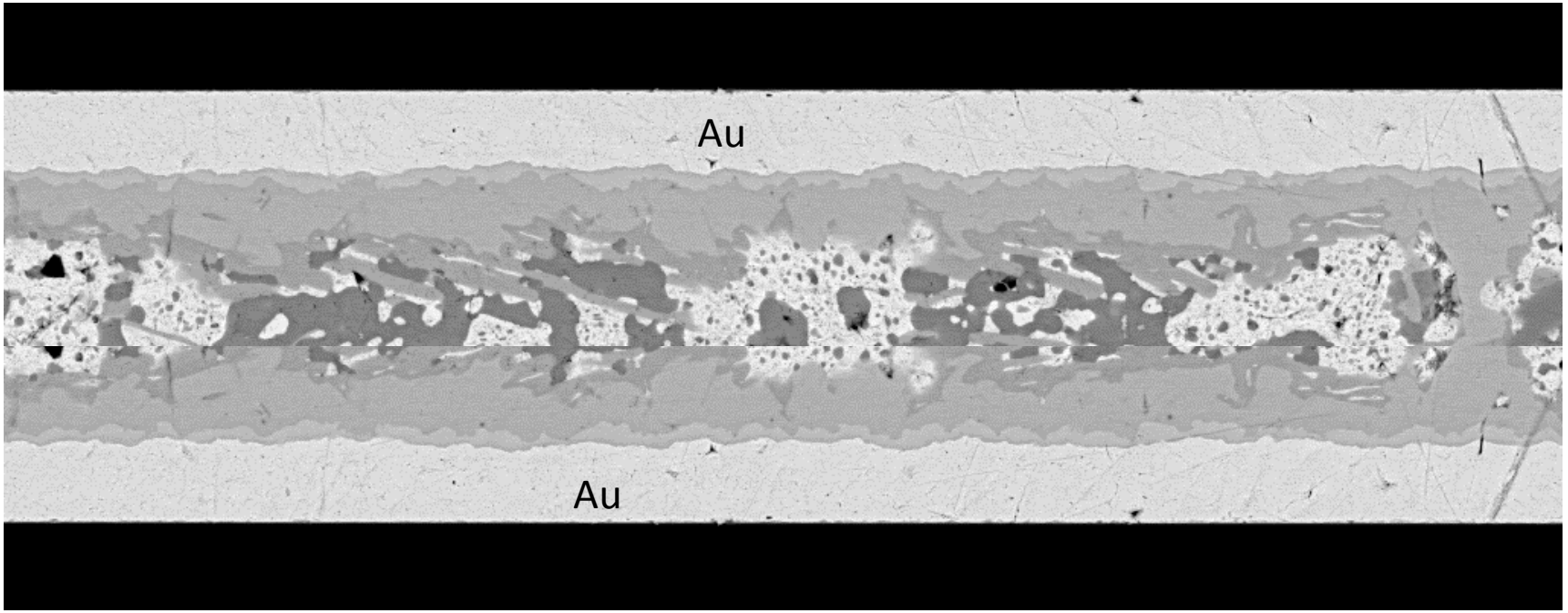
- SnAgCu (SAC) and SnPb Paste: Martin Super-Finepitch-6

Combo	Substrate	Chip	Solder
1	Au	TiW/Au	SAC
2	Au	TiW/Au	SnPb
3	Au	NiCr/Au	SAC
4	Au	NiCr/Au	SnPb
5	Au	Ox/NiCr/Au	SAC
6	Au	Ox/NiCr/Au	SnPb
7	Ni/Au	TiW/Au	SAC
8	Ni/Au	TiW/Au	SnPb
9	Ni/Au	NiCr/Au	SAC
10	Ni/Au	NiCr/Au	SnPb
11	Ni/Au	Ox/NiCr/Au	SAC
12	Ni/Au	Ox/NiCr/Au	SnPb

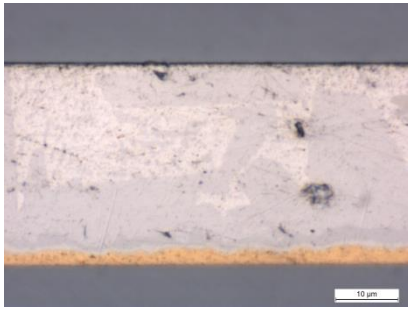
*) Soldered on a hot plate at 237 ^{o}C for 5 seconds

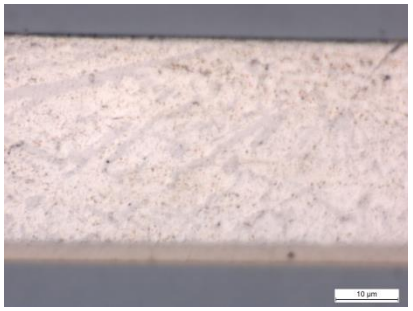
Two strategies

1. Limit the amount of Au to a minimum OR
2. Ensure sufficient Au, achieve compliant layers on top and bottom



Thermal aging tests





- The samples were aged for 288.5 h
  - @ 150 °C for samples bonded with SAC
  - @ 130 °C for samples bonded with SnPb

- Can correspond to
  - ~14 years at RT for SAC
  - ~7 years at RT for SnPb

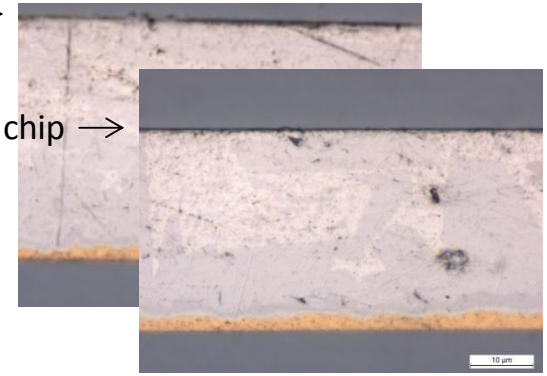
  Assumptions: a simple Arrhenius type of correlation (thermally activated) and an activation energy of 0.5 eV (rather conservative)

- A tougher test for the SAC, but unknown activation energies
  - Failures related to consumption of UBM (diffusion of Au/Ni into Sn)

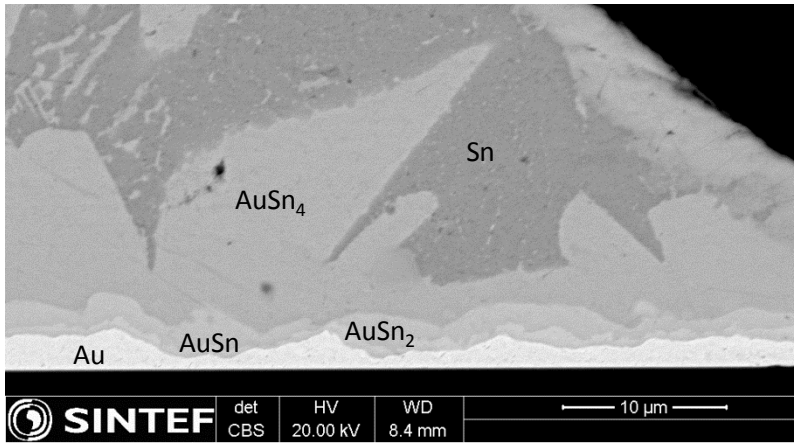
Microstructure solder, Au on tube

NiCr on chip →

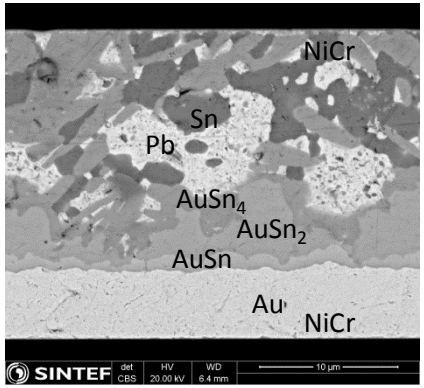
TiW on chip →



SAC as bonded

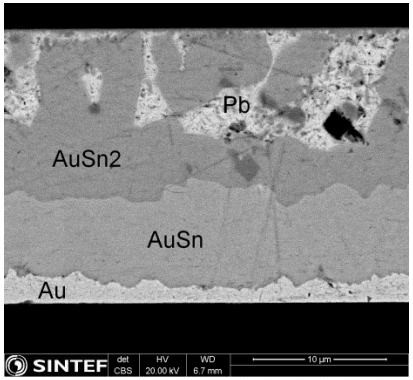


NiCr on chip →



SnPb as bonded/aged

Au thickness reduced, Sn and $AuSn_4$ consumed, layered structure →



Microstructure solder, Ni on tube

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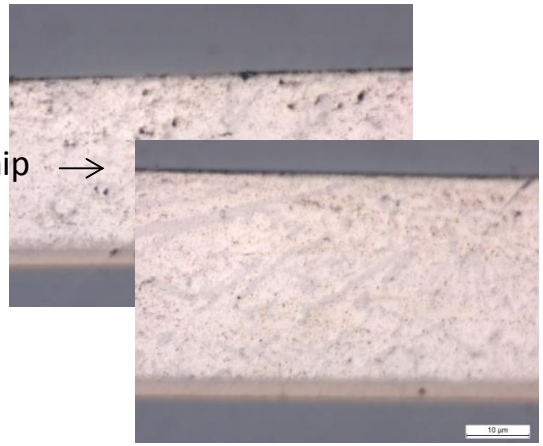
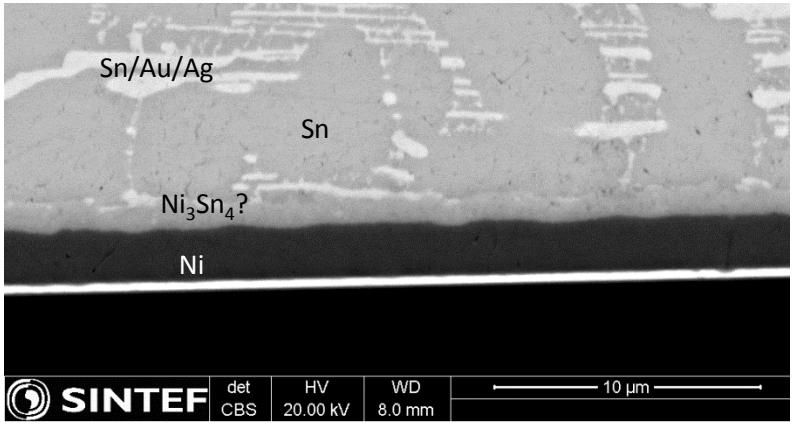
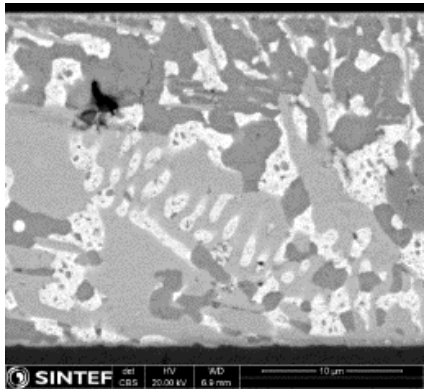


SAC as bonded



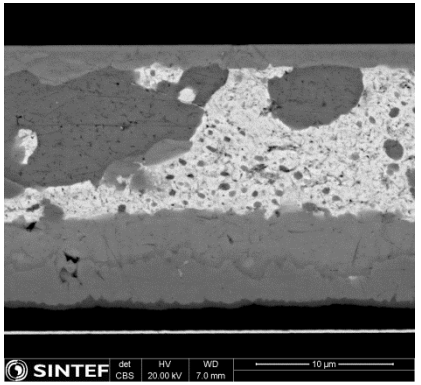
NiCr on chip →

SnPb as bonded/aged



Ni thickness reduced, layered structure

→

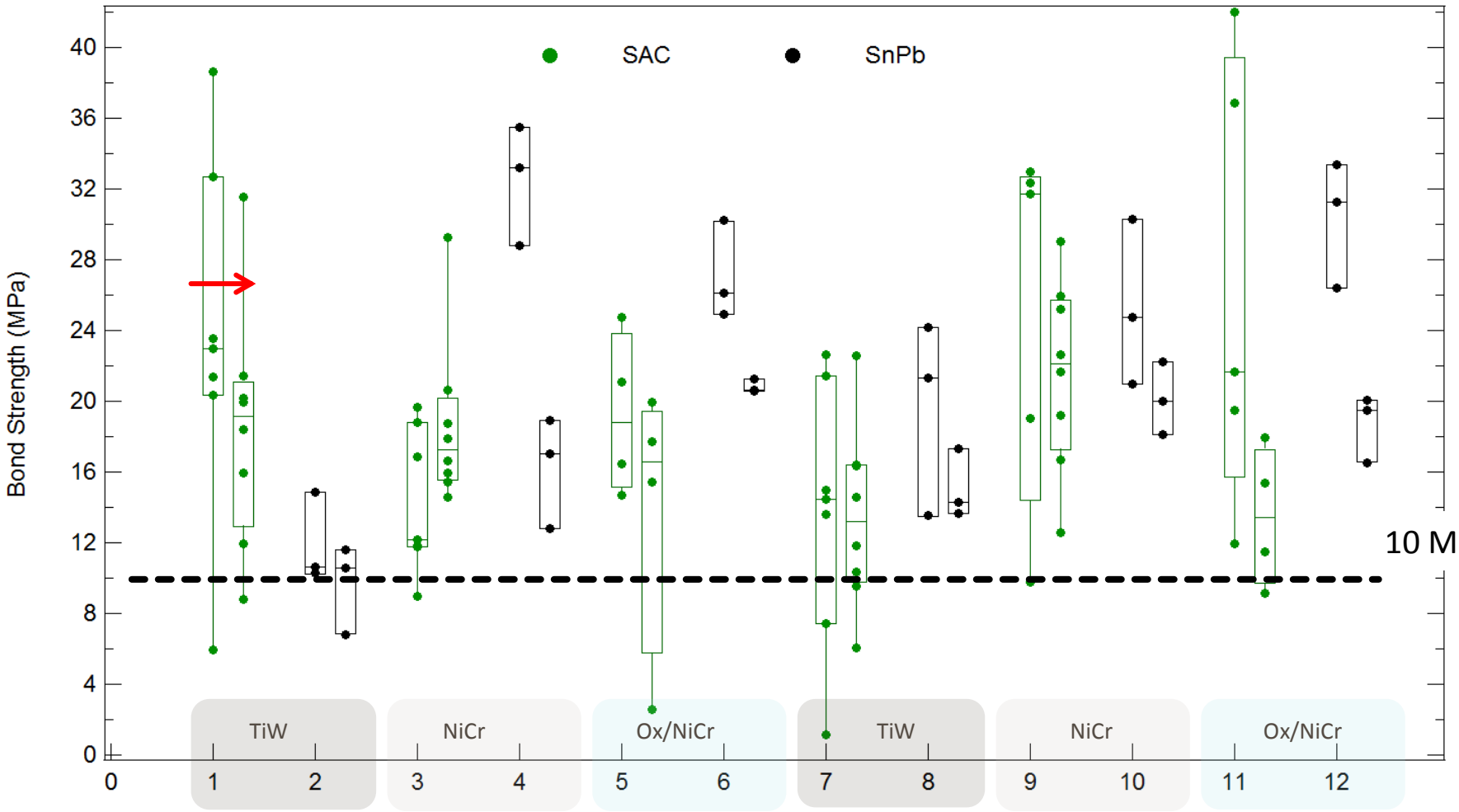


Summary of cross section observations

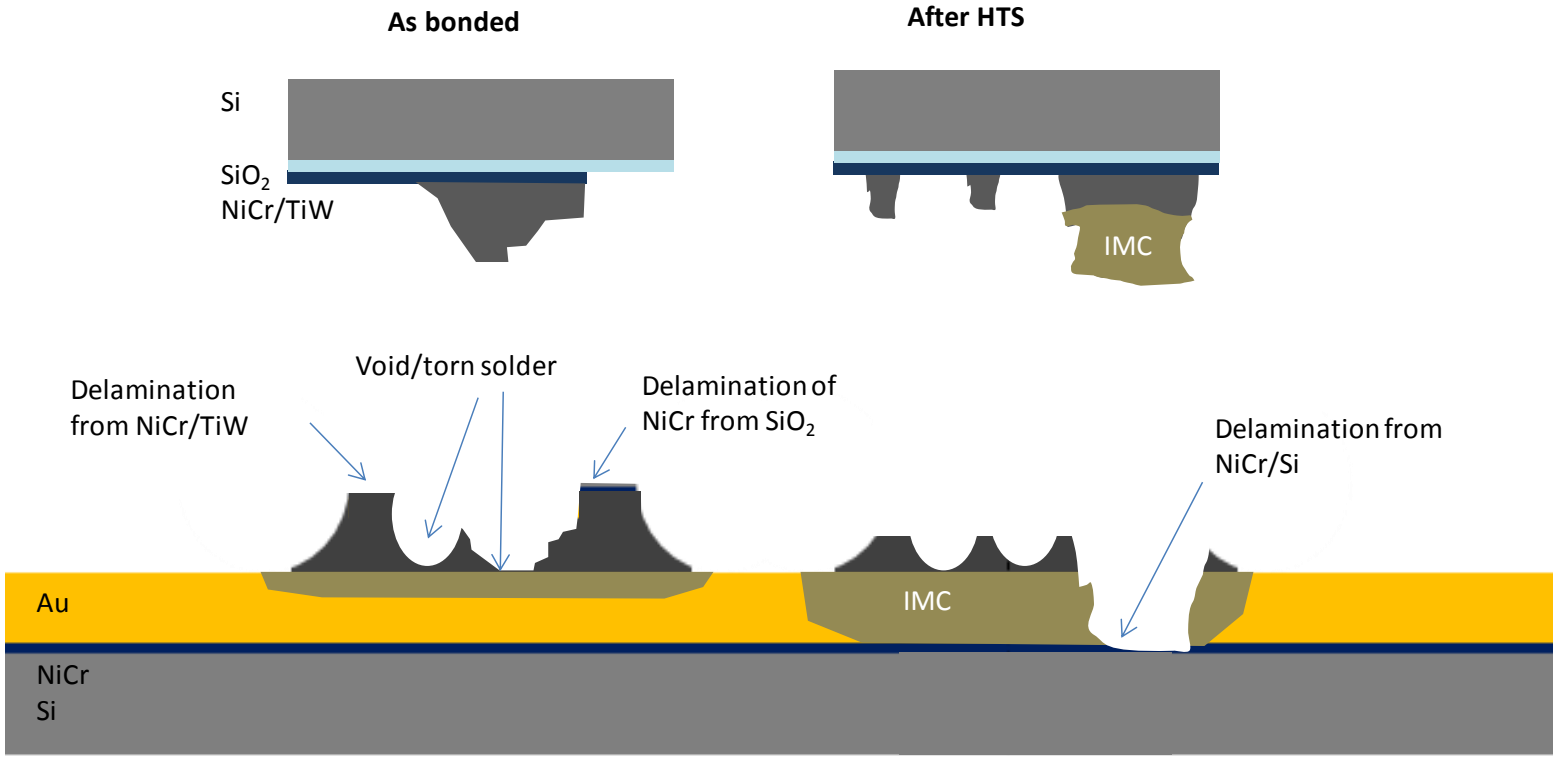
- Delamination/voids/cracks not observed
  → Apparently an acceptable seal?
- Intermetallic compound formation does not involve Pb
  → Some ductility conserved for these systems
- Gradual consumption of Au and Ni layers
  - Grain growth and layered structured (less sharp)
  - Change in overall hardness and therefore in stress concentrations during application

→ Shear tests as bonded and after thermal aging, fracture surfaces

Bond strength results



Possible fracture situations



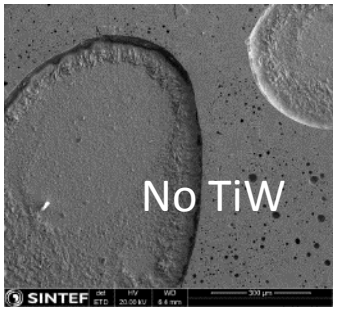
Assumption

A cohesive failure mode is a strong indicator of a hermetic seal

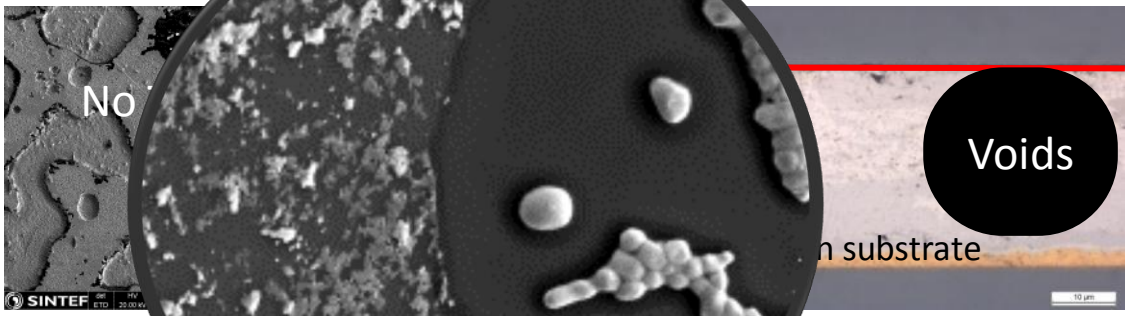
TiW/Au on chip side **as bonded**

- Au on substrate: Only adhesive fracture at chip side

SAC



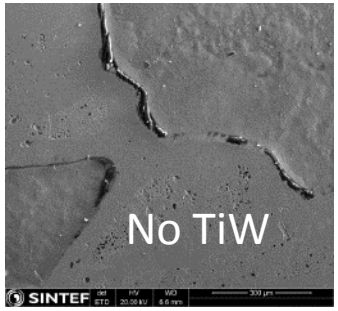
SnPb



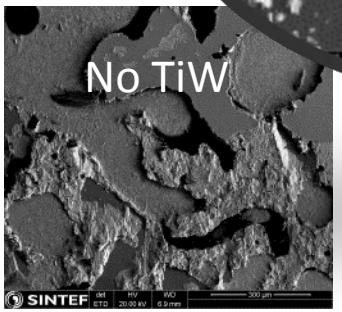
Fracture

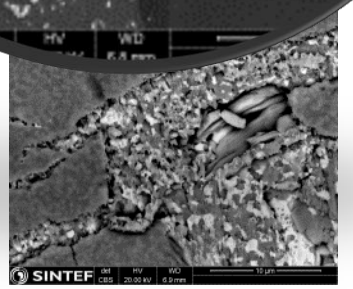
- Ni on substrate: Only adhesive fracture

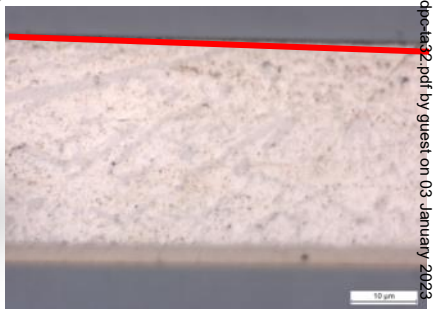
SAC



SnPb



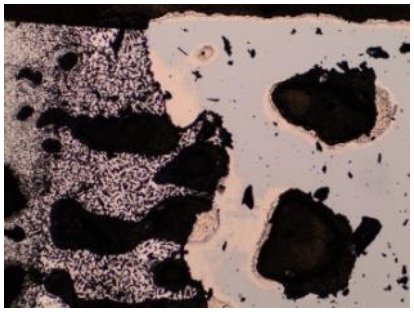


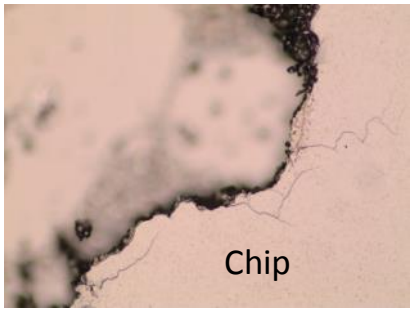


TiW/Au on chip side **aged**

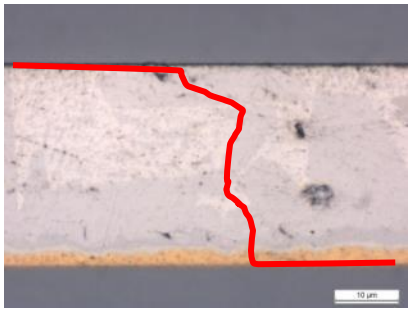
- Au on substrate: Mix of adhesive fracture at chip/substrate side

Shown for SAC, but similar for SnPb



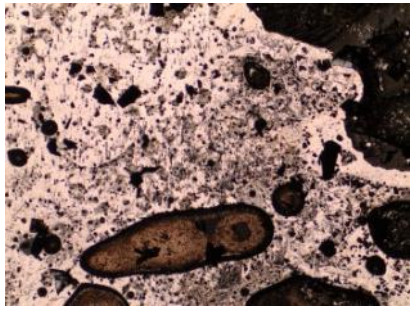


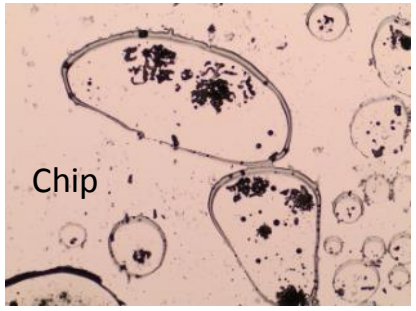
Fracture

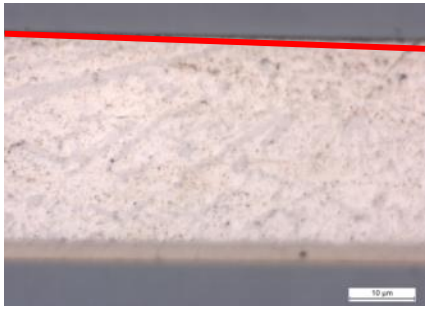


- Ni on substrate: Only adhesive fracture at chip side

Shown for SAC, but similar for SnPb



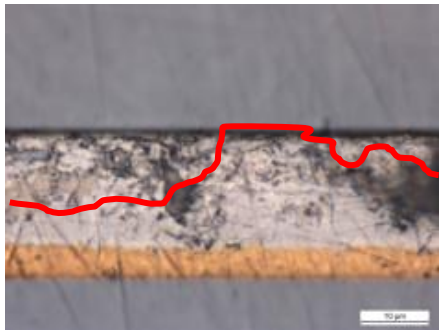




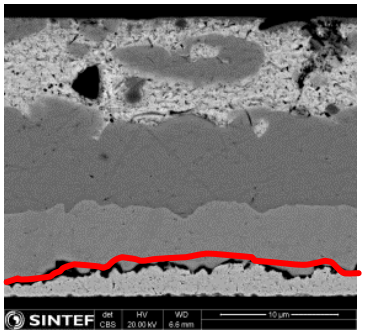
Ox/NiCr on chip side **as bonded/aged**

- Au on substrate: Change from mostly cohesive to adhesive from substrate

Shown for SnPb, more adhesive from oxide for SAC



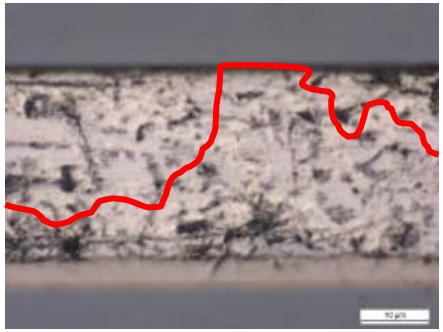
Aged

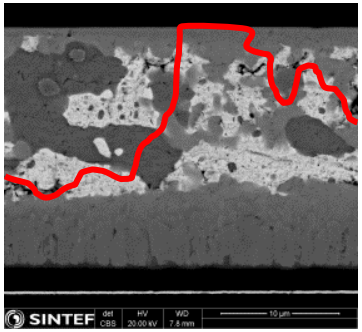


Fracture

- Ni on substrate: Mostly cohesive

Shown for SnPb, mainly adhesive from oxide for SAC

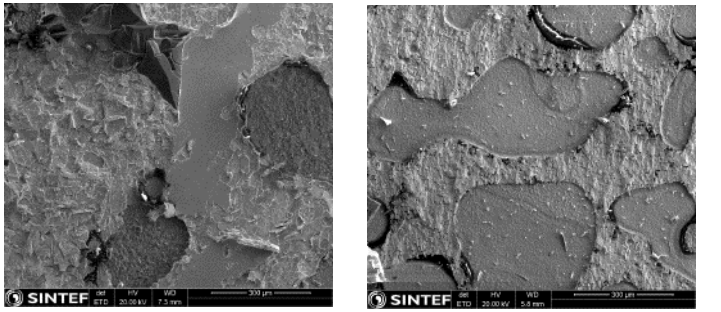




NiCr on chip side **as bonded/aged**

- Au on substrate: Change from mostly/all cohesive to delamination from Au

SAC SnPb SAC SnPb



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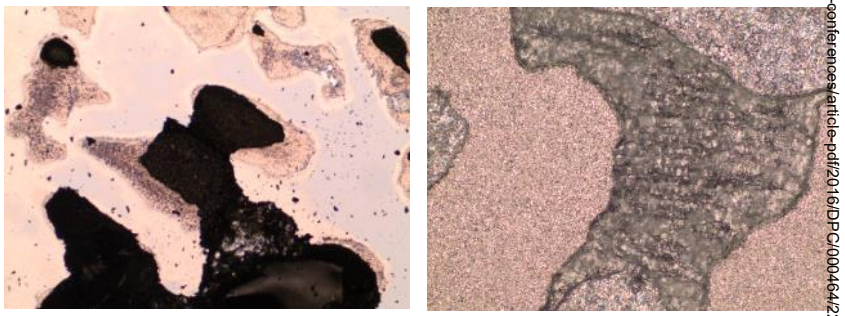
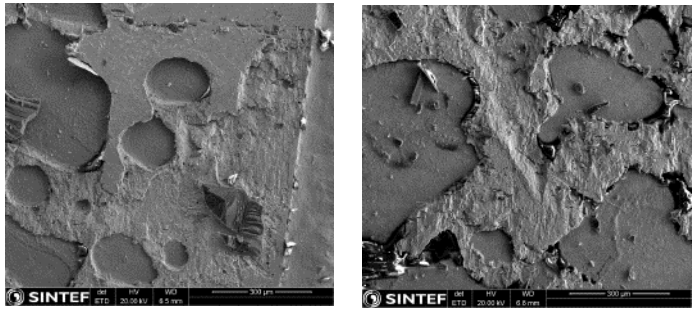
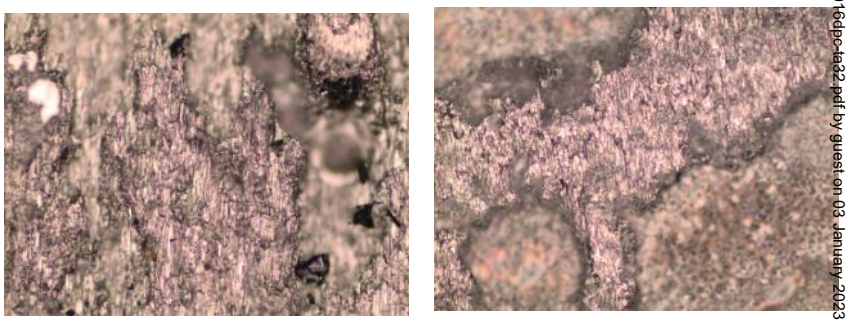


- Ni on substrate: All cohesive



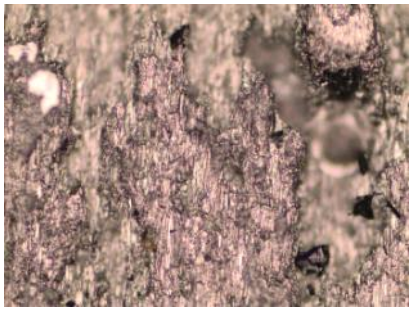


Summary

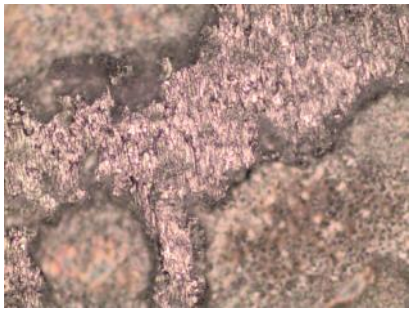
- Average bond strength of >10 MPa achieved for
  - All combinations of materials
  - Before and after thermal aging
- Cohesive fracture also after aging
  - NiCr/Au on chip
  - Ni (Au) on substrate
  - SAC or SnPb solder
- Not recommended
  - TiW on chip, Au on substrate
- Cohesive fracture surface

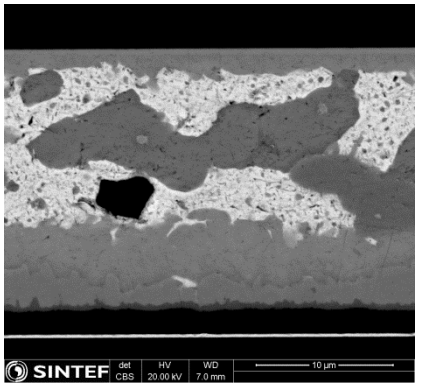
  → Hermetic (assumption and length scale dependency)

SAC on Ni aged



SnPb on Ni aged





Acknowledgments

We would like to thank the Research Council of Norway for support under grant 215620/E30 and Dag T. Wang at GE Presens for solid technical and scientific guidance.

SINTEF

Technology for a better society