Willkommen
Welcome
Bienvenue

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Materials Science and Technology

Development of reactive joining technologies for electronic packaging and assembly

Workshop “Miniaturized Photonic Packaging”, 16.05.2017, CSEM, Alpnach

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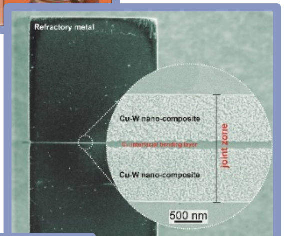
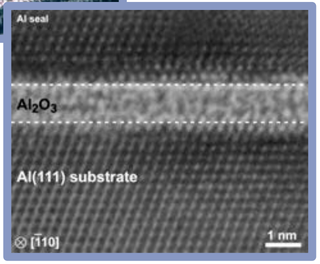
Laboratory Joining Technologies & Corrosion at Empa

Our portfolio

- Advanced Joining Technologies
  (soldering, brazing, TLP, diffusion bonding, micro- & nano-joining)
- Corrosion Management
  (investigations of corrosion failures, mechanisms and prevention strategies)
- Surface & Interface Engineering
  (of metals, alloys, oxide films and their coating systems)



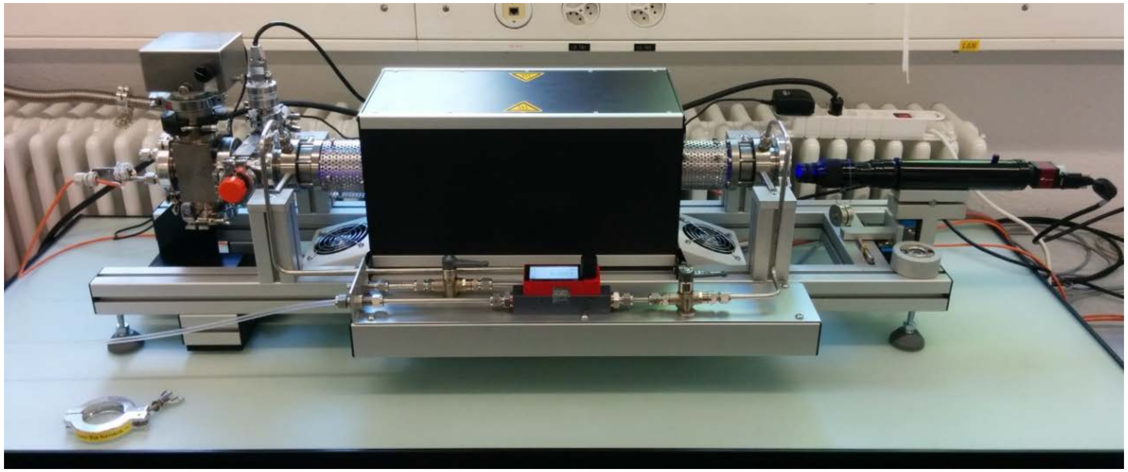


Our expertise within the Swiss Photonic Packaging Laboratory

- Custom-designed solutions in the field of joining: brazing, soldering, diffusion bonding, transient liquid phase bonding, development of nanostructured filler alloys, coatings and foils,…

Laboratory Joining Technologies & Corrosion at Empa

New wetting furnace, financial support from SWISS PHOTONICS



Purpose

- investigation of wettability (contact angle, spreading) under controlled conditions (*t*, *T*, atmosphere)
- generally: visual inspection of samples at high temperature under controlled atmosphere

Specifications

- quartz tube furnace
  - max. heating rate: ca. 20 K/min
  - max. *T*: ca. 1000 °C
- atmospheres
  - controlled flow rates: inert, reducing, oxidising
  - vacuum (HV range)

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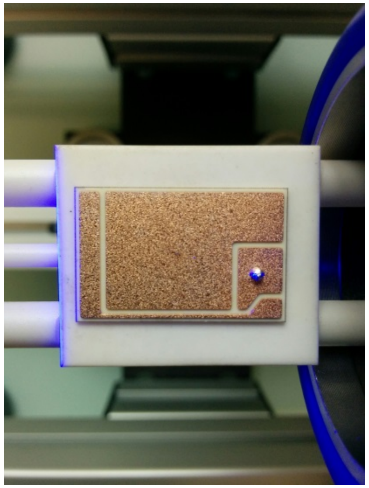
New wetting furnace, financial support from SWISS PHOTONICS

- Example: Sn pearl on DCB substrate



HR = 5 K/min

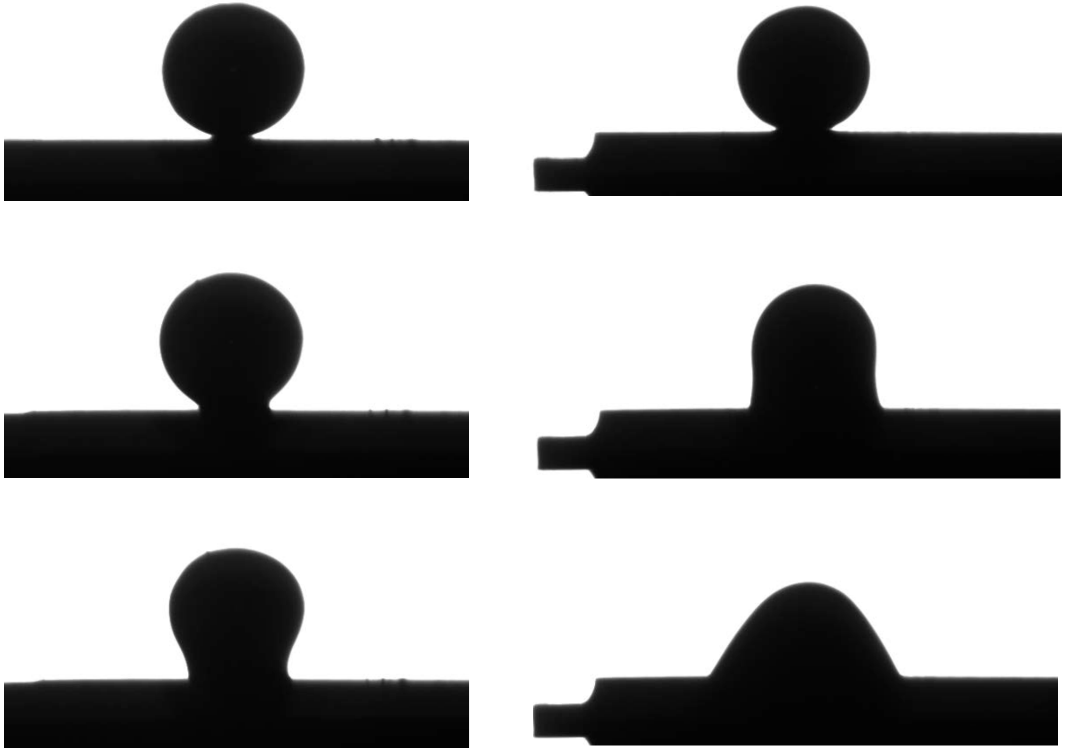
as received

cleaned

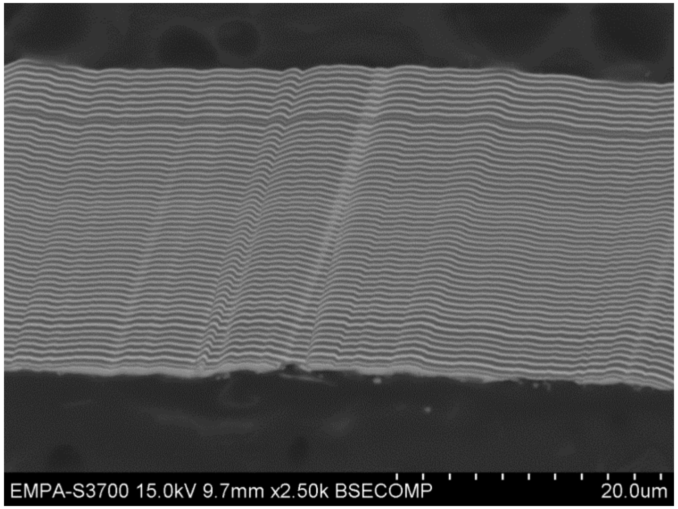
T = 18 °C,
t = 0 min

T = 265 °C,
t = 49 min

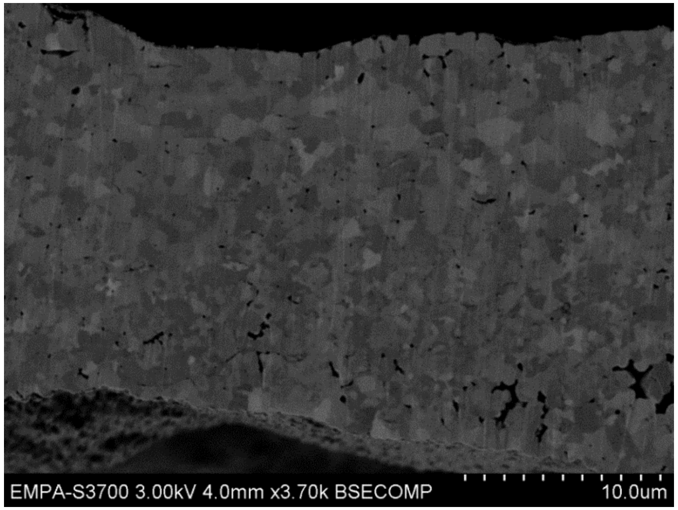
T = 295 °C,
t = 55 min



Reactive nano-multilayers



before reaction:
nano-multilayers

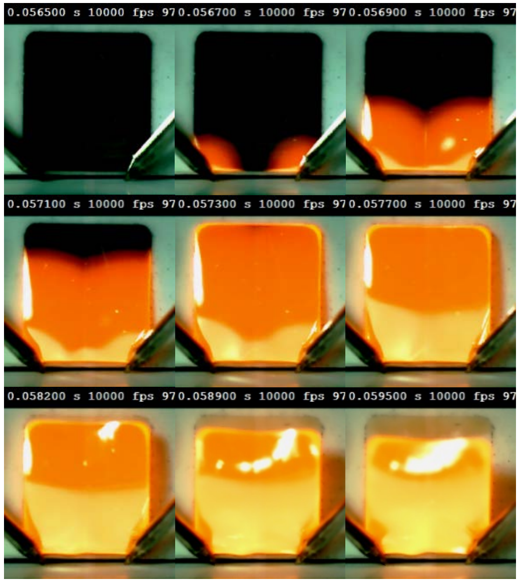


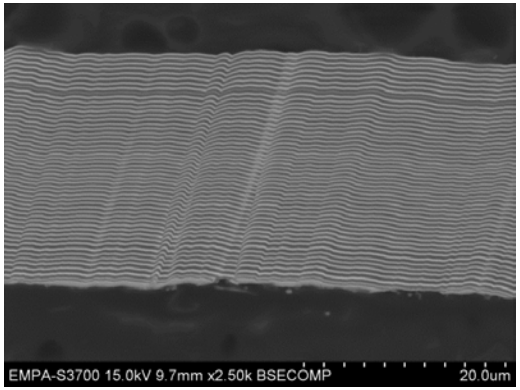
after reaction:
intermetallic
phase

cross-sections of a nano-multilayer foil before and after reaction

high-speed recording of a reacting Nanofoil®, total time: 2.5 milliseconds

Reactive nano-multilayers





Key facts

- alternating layers of metals (e.g. Ni+Al)
- internal heat production by metal-metal reaction, no gas phase involved
- high reaction temperatures (>1000 °C)
- high reaction speeds (1-50 m/s)
- defined heat generation by variation of system and total thickness (10 - 250 µm)

type	heat release	example
low	30 - 59 kJ/mol-atom	Al/Ti
medium	60 - 89 kJ/mol-atom	Ni/Al
high	> 90 kJ/mol	Al/Pd

➡ idea: usage as internal heat source for soldering/brazing

Reactive nano-multilayers

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Development

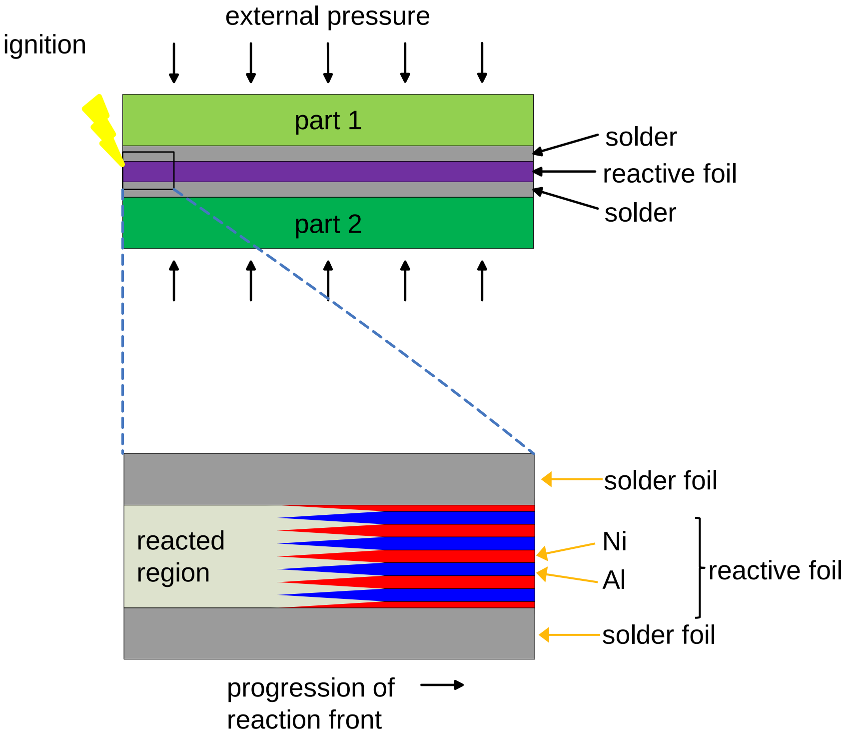
- **1960s** (esp. USSR): exothermal reactions for production of intermetallics
- **1979**, Prentice: “Heat Sources for Thermal Batteries: Exothermic Intermetallic Reactions” (US patent); **one scenario: alternating metallic layers**
- **1986**, Floro: “Propagation of explosive crystallization in thin Rh–Si multilayer films” (J. Vac. Sci. Technol. A); **preparation of nano-multilayer films**
- **1995**, Makowiecki: “Low Temperature Reactive Bonding” (patent); **films**
- **2001**, Weihs: “Method of making reactive multilayer foil and resulting product” (patent, US only); **freestanding foils**
  2001, Weihs: founding of “Reactive NanoTechnologies” (now Indium Corp.); **start of commercial production of Nanofoils®**
- since then: increased usage for joining

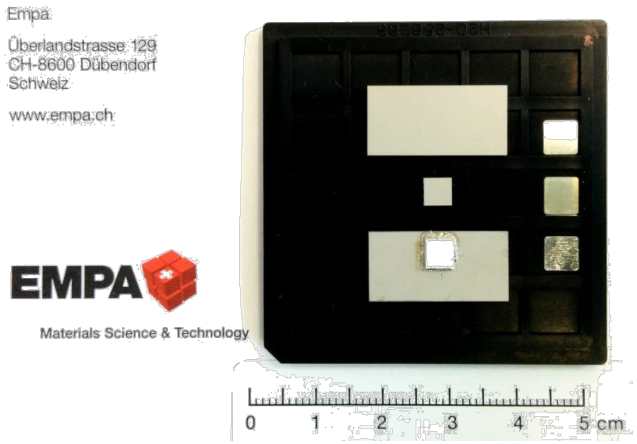
2011, Longtin/Empa: ”Benign Joining of Ultrafine Grained Aerospace Aluminum Alloys Using Nanotechnology” (Adv. Mater.)

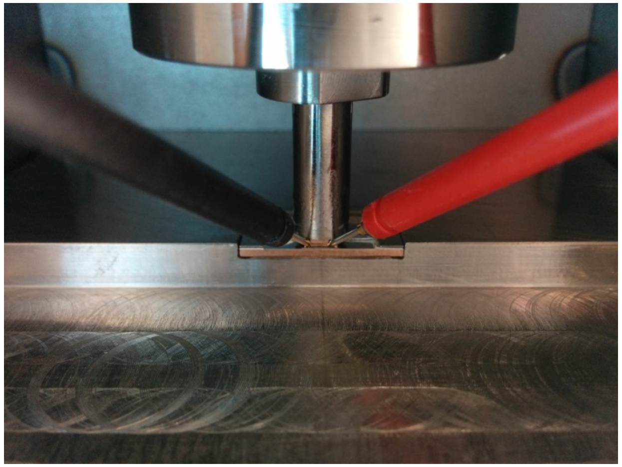
please contact author for further information

Joining with reactive nano-multilayers

Principle







alternative approach: direct deposition of reactive nano-multilayers (e.g. on wafer)

Joining with reactive nano-multilayers

Advantages

Processing

- localised heat source: components remain “cold”
- no furnace
- no protective atmosphere
- no flux (if clean components)
- easy handling of joining components (→pick and place)
- short processing time

Joint performance

- microstructure refinement
- good thermal properties (heat conductivity)
- stability against high temperatures & humidity

temperature-sensitive components

stress-sensitive components

controlled atmosphere, hermetic encapsulations*

prototyping

alternative to step-soldering

rework

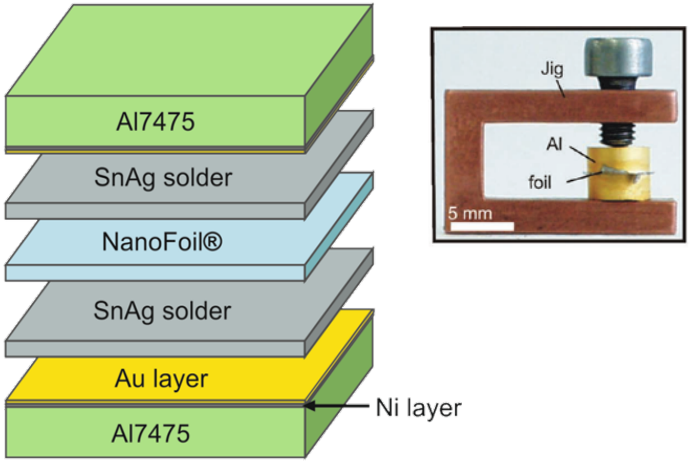
high-strength joints*

bonding of heat-sinks

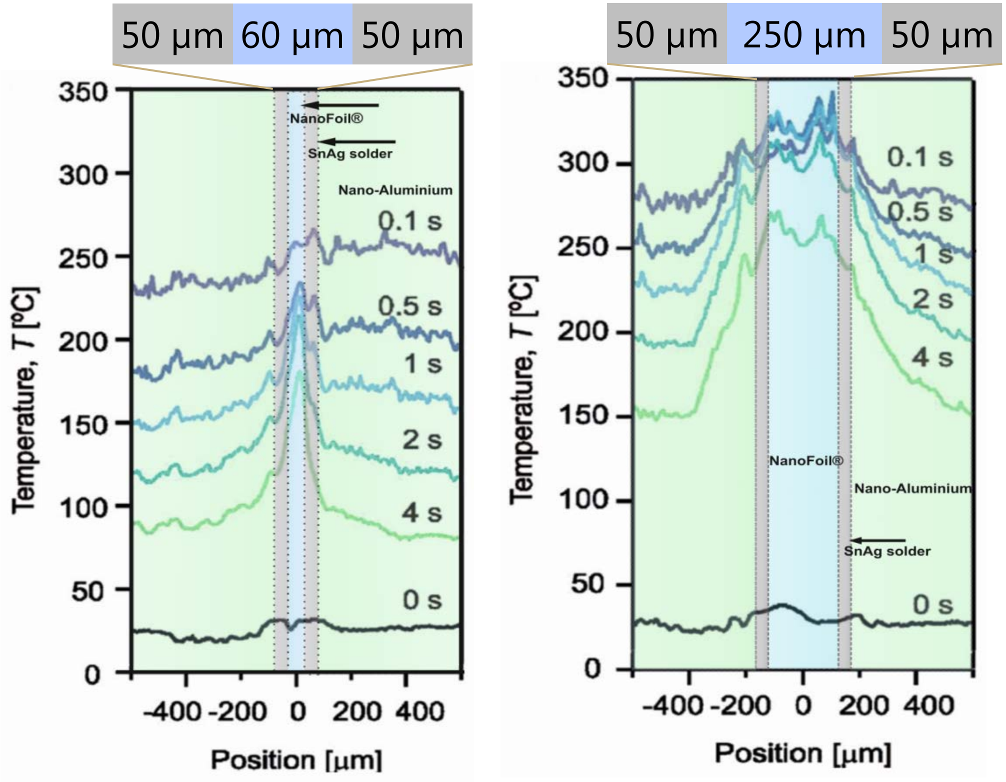
* esp. for directly deposited RNMLs

Joining with reactive nano-multilayers

Example: joining of a nano-crystalline Al alloy (Empa, 2011)



joining set-up



temperature development in joining zone

➡ **successful joining of heat-sensitive materials**

Benign Joining of Ultrafine Grained Aerospace Aluminum Alloys using Nanotechnology
Longtin et al., Adv. Mater 23, 2011

Joining with reactive nano-multilayers

Typical problems & challenges

1. “Classical” soldering problems

- Example: Joining of stainless steel, shear strength
  - Wang 2005: **36 MPa** (Ni-Au metallisation, AgSn solder; J. Appl. Phys. 97)
  - Sen 2016: **9 MPa** (Ni metallisation, Sn + InCuSil solder, Euro Hybrid Proceedings 2016)

➡ **handling, cleaning, general bonding issues…**

2. Process-intrinsic problem: heat management

- no possibility for external control of process time and temperature
  - too hot: damage of components (cf. joining of nano-Al)
  - too cold: no melting of solder
  - additionally: thermo-mechanical shockwave

➡ **challenge: influence of substrates and components**

Joining with reactive nano-multilayers

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Interreg V – Project: "Schonendes reaktives Fügen von Mikrosystemen"

interreg
Alpenrhein | Bodensee | Hochrhein

EUROPÄISCHE UNION
Europäischer Fonds für regionale Entwicklung

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Kanton
Zürich

Project partner:

Hahn Schickard

- Hahn-Schickard, Baden-Württemberg, Germany
- R&D in micro-assembly and packaging, sensor development,…

Project goals:

- development of *truly* benign joining processes
- characterisation of thermo-mechanical stress during joining
- design rules for reactive joining

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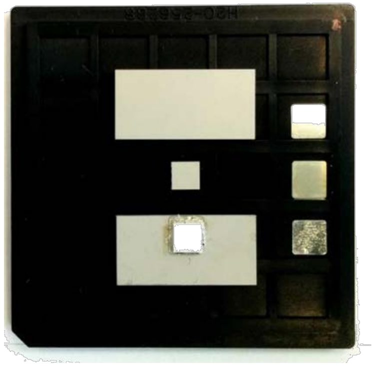
Montage von Mikrosystemen mit reaktivem Nanofügen in einer Fertigungsprozesskette (ReMTeC)
Abschlussbericht, IGF-Vorhaben-Nr. 17368 N, Axel Schumacher, Hahn-Schickard

Focus: influence of substrates/components

Design of test series

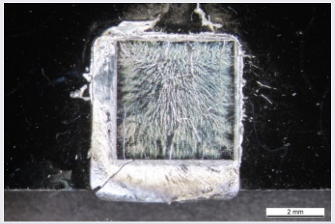
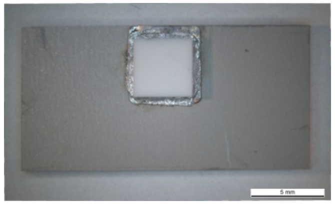
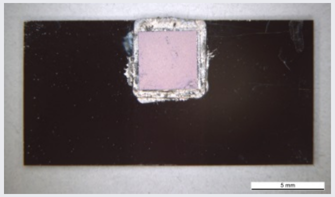
- joining components
  - materials: borosilicate glass, Si, Al_2O_3, Cu
  - bond area: 4 mm x 4 mm



- joining setup
  - reactive system: Ni-Al, commercial nanofoils®
    (60 µm + 2 x 1 µm InCuSil)
  - metallisation: Ni
  - solder: Sn foils (2 x 10 µm)
- test methods
  - non-destructive (scanning acoustic microscopy, computer tomography)
  - destructive (shear strength, cross-sections)

Focus: influence of substrates/components

Overview results

substrate	heat conductivity ($W \cdot m^{-1} \cdot K^{-1}$)	solderability
borosilicate glass	1.2	joint formed, but extensive cracking 
Al_2O_3	30	good 
Si	129 (avrg.)	good 
Cu	401	no joint formed 

Focus: influence of substrates/components

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Example borosilicate glass: non-destructive testing

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optical microscopy, differential interference contrast

scanning acoustic microscopy, pore echo

- ➡ cracks, mechanical stress
- ➡ voiding in solder layer
- ➡ voiding, cracks in reactive foil

Focus: influence of substrates/components

Example borosilicate glass: process optimisation

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optical microscopy, differential interference contrast

please contact author for further information

scanning acoustic microscopy, pore echo

please contact author for further information

computer tomography

Solution: 2 x 75 µm Sn instead of 2 x 10 µm + pressure reduction

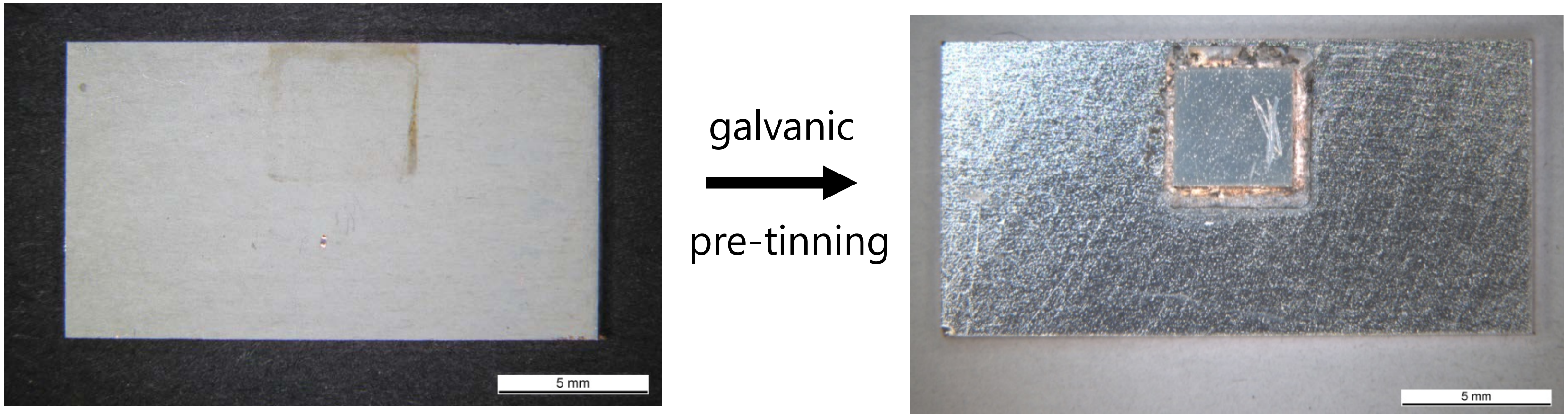
➡ no cracks in glass (but still pores)

Focus: influence of substrates/components

Other materials: Al_2O_3, Si and Cu

- Al_2O_3 and Si: some porosity, but excellent strength
  - Al_2O_3 : shear strength around 45 MPa
  - Si: fracture of substrates around 20 MPa

- Cu
  - thicker reactive foil (250 µm) = more heat generation: **unsuccessful**
  - galvanic pre-soldering of substrates: **successful**



Summary

Joining with RNMLs: promising new technique

- simple, fast and flexible: no furnace, no protective atmosphere, flux-free…
- benign joining possible
- hermeticity possible
- high-quality joints possible

Crucial

- **good soldering practice**
- **tailored joining setup for heat management:**
  - **reactive foil vs.**
  - **solder vs.**
  - **substrate/components**

Thank you for your attention!

Looking forward to your questions ...and potential cooperation projects!

Acknowledgements

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