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Materials Science and Technology

Nano-Joining Technologies

Dr. Pierangelo Gröning

Trends in Mikro Nano
Swiss Micro- & Nanotechnology Network
Basel, 30. November 2017

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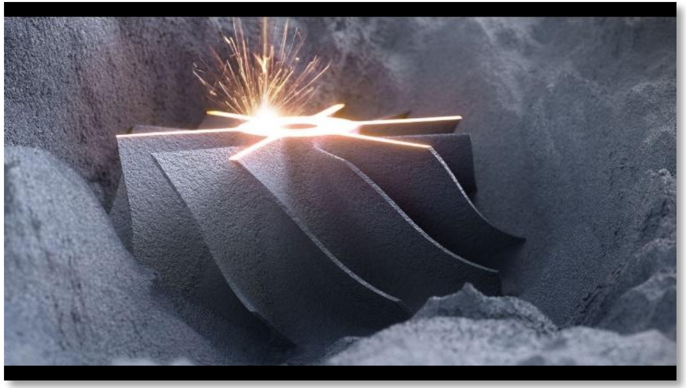
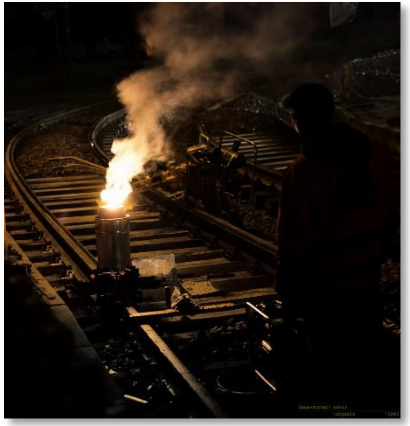
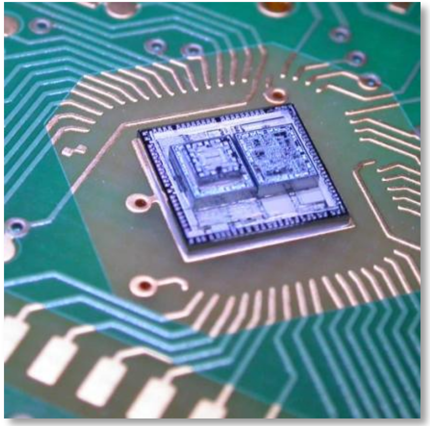
Joining Technologies

Barely a Device without Joining Processes







Brazing & Soldering Applications @ Empa

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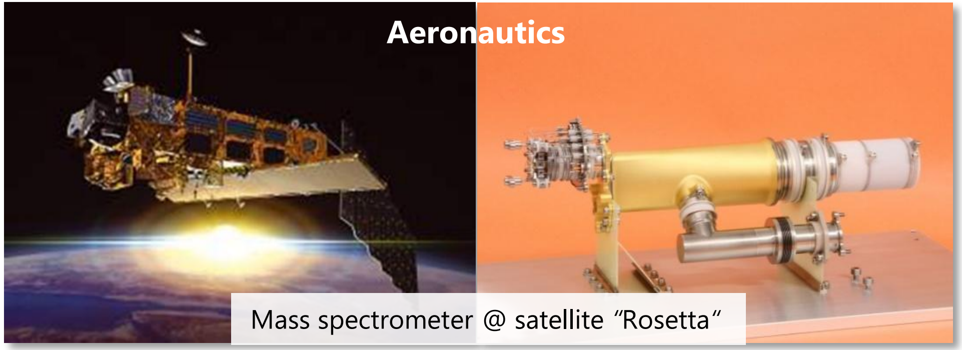
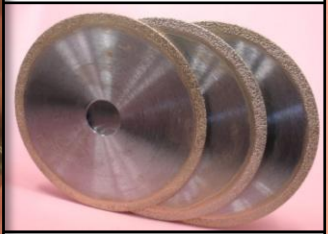
Aeronautics

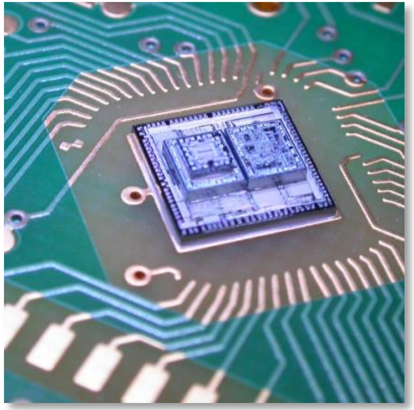


Mass spectrometer @ satellite "Rosetta"

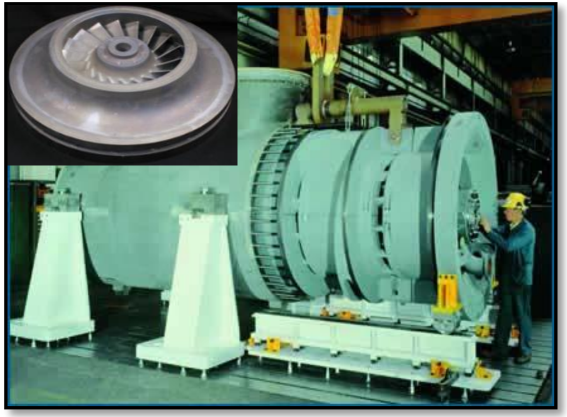
Cutting Tools



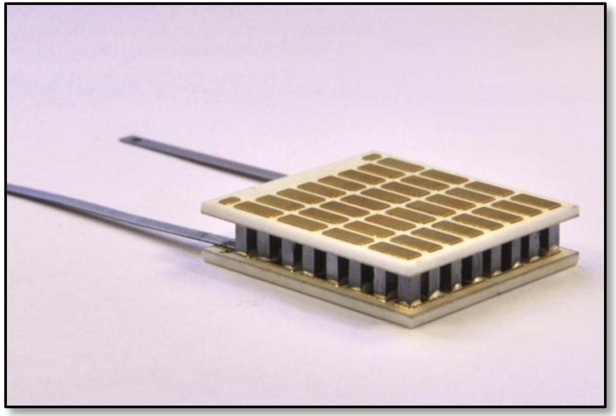
Microelectronics & Sensors



Turbines



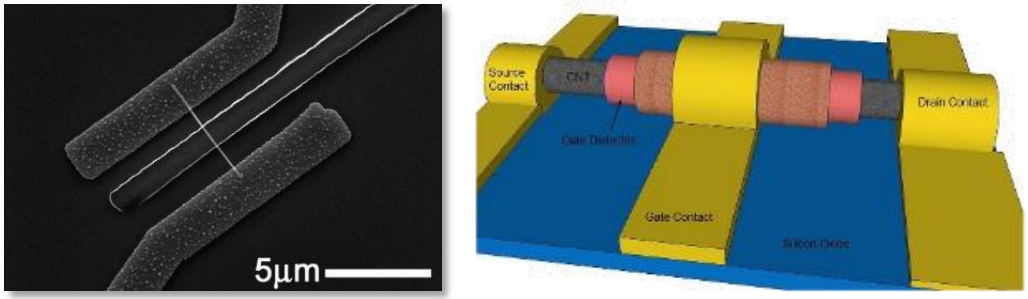
Thermoelectric



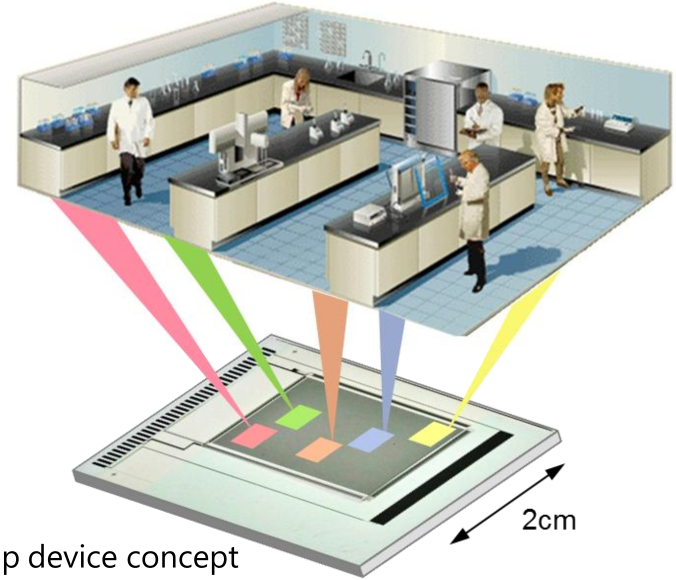
Miniaturization & Diversification

Advanced bonding & packaging technologies require

- ✓ Low-*T*, *pressure-less*, solvent-free joining process with high alignment accuracy
- ✓ Hybrid nanotechnology (i.e. bonding of wide variety of dissimilar materials)
- ✓ Heterogenous integration (i.e. combine different functionalities in single system)



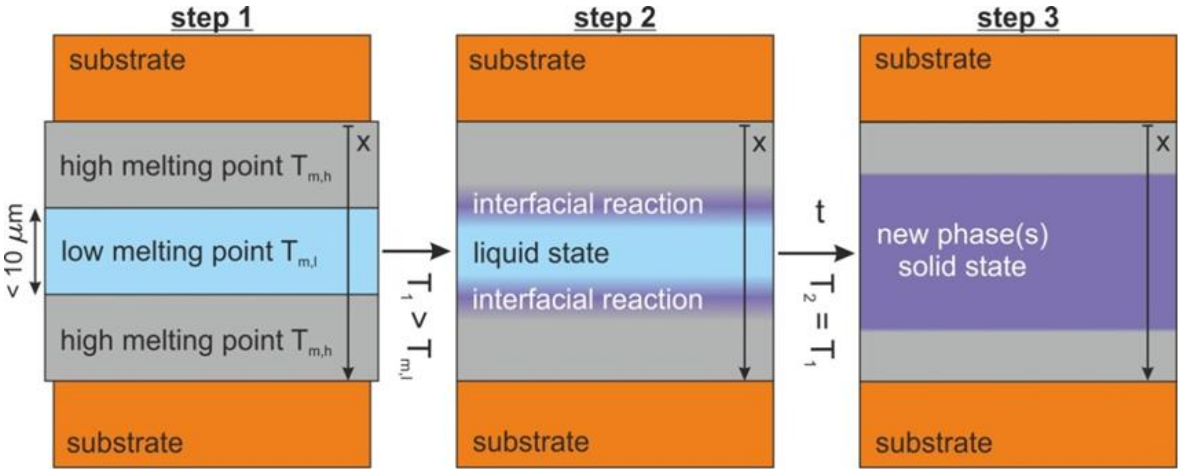
Nanowire FETs
Source: ITRS 2.0 (2015)



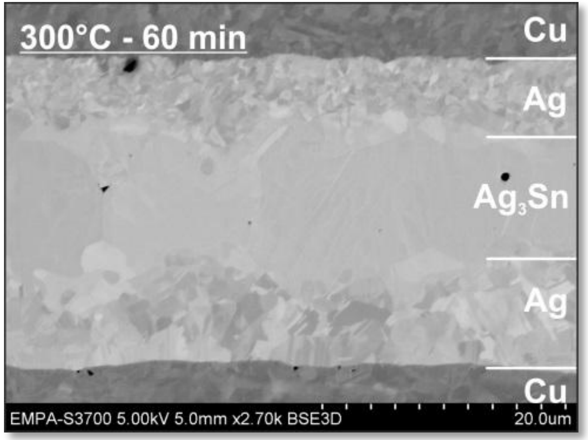
Microfluidic lab-on-a-chip device concept
<u>Source:</u> *http://www.sle.sharp.co.uk*

Transient Liquid Phase (TLP) Bonding

Principal



Basic Principles of the TLP process



Low-melting metal

- Sn ($T_{m,l}$ = 232 °C)
- In ($T_{m,l}$ = 157 °C)

+

High-melting metal

- Cu, Ag, Au
- Ni ($T_{m,h}$ =1455°C)

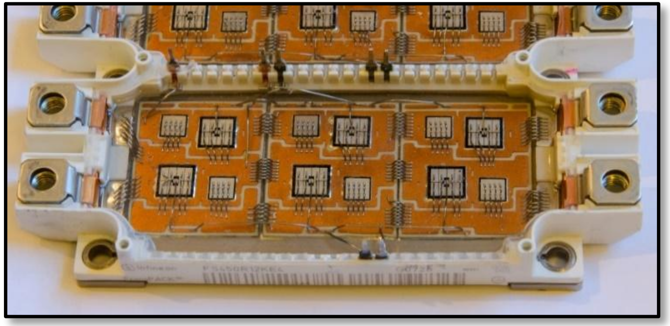
TLP (Sn; Ag, Ni): 235 °C ≤ $T_{process}$ ≤ 300 °C

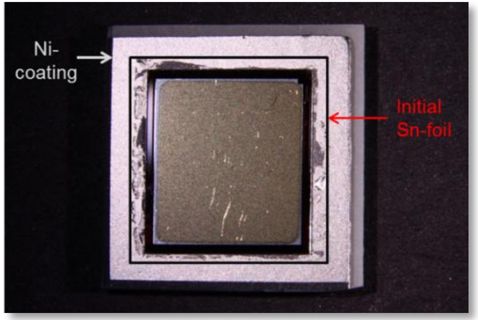
- Ag-Sn: formation of $Ag_3Sn(\varepsilon)$: T_m = **480°C**
- Ni-Sn: formation of Ni_3Sn_4: T_m = **794.5 °C**

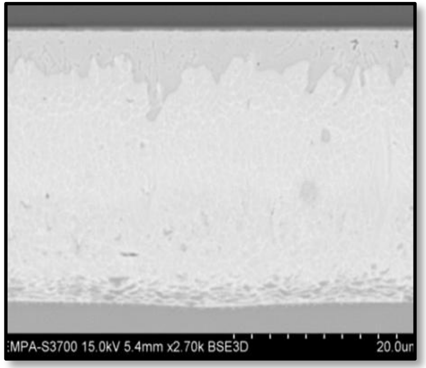
Transient Liquid Phase (TLP) Bonding

Applications

Ag-Ni-Sn TLP bonding for power electronics

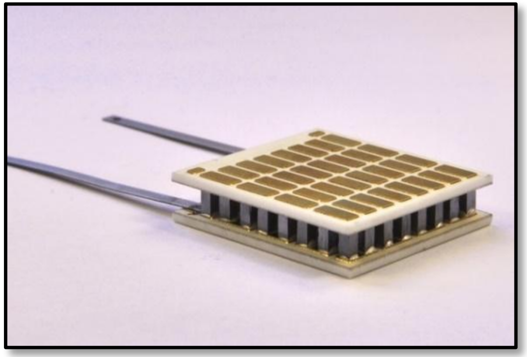


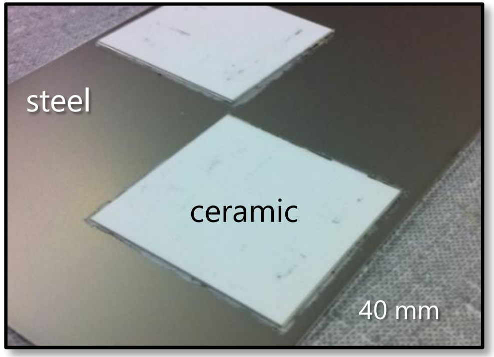


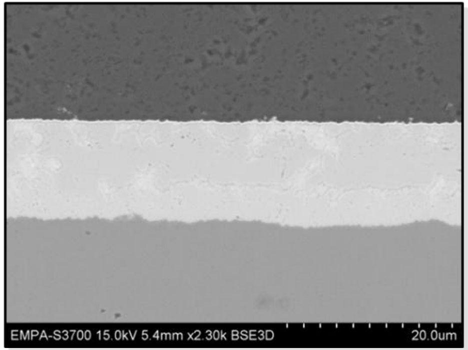


→ Si chip
→ Ni_3Sn_4
→ Ag_3Sn
→ Ag

Ni-Sn TLP bonding for thermoelectric module for exhaust applications







→ Al_2O_3
→ Ni_3Sn_4
→ Ni

Melting Point Depression

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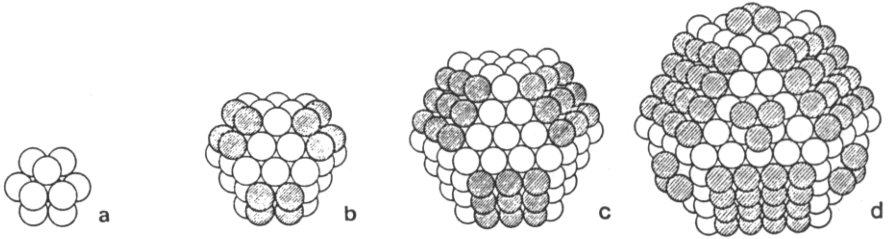


$$\Delta T = (T_S - T) = \frac{2\sigma \cdot T_S}{\rho \cdot L \cdot r} \propto \frac{1}{r}$$

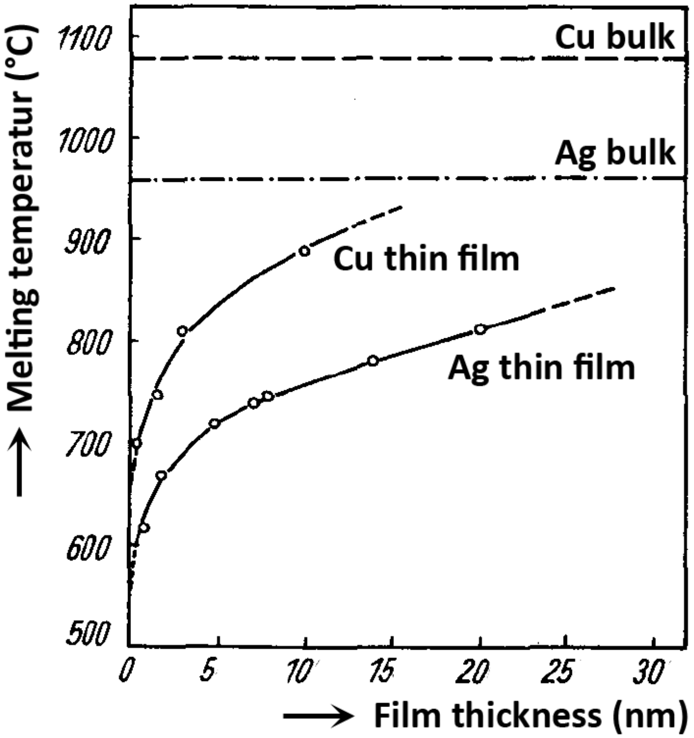
T_s: bulk melting temperature

σ : solid-liquid interface energy

L : bulk heat of fusion

ρ : density of particles

r: particle radius



Film-thickness-dependent melting; Phys. Stat. Sol. 15 (1966) 181

Nano-joining Approach @ Empa

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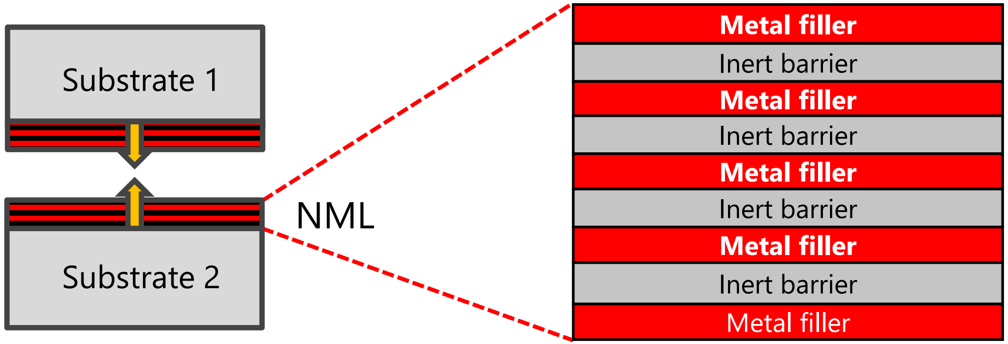
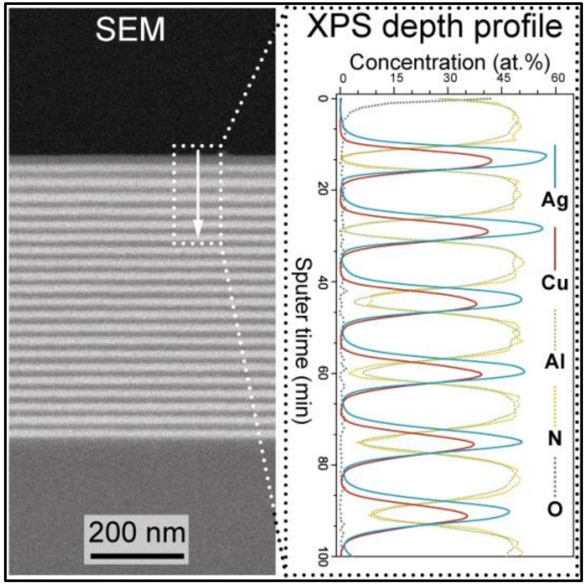
Microstructural design of Nanomultilayered Fillers to direct mass transport for localized bonding by exploiting the following nano-scale effects:

- ✓ Fast short circuit diffusion of atoms along internal interfaces
- ✓ Melting point depression of metals and alloys when confined to the nanoscale



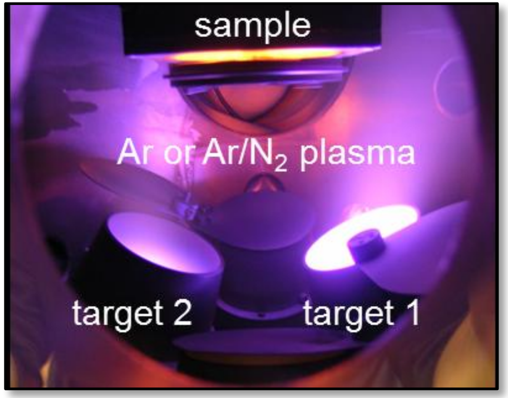


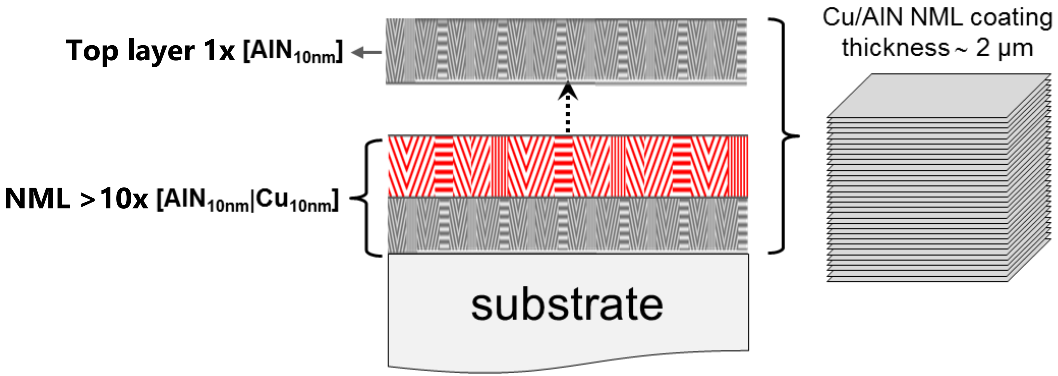
CuAg/AlN NML filler

- *J Mater Chem C 4 (2016), 4927*
- *Phys Chem Chem Phys 17 (2015) 28228*
- *Acta Materialia 107 (2016) 345*
- *Scr Mater 130 (2017) 210*
- *J. Mater. Sci. Eng. B 6 (2016) 226*
- *J Mater Eng Perform 25 (2016) 3275*

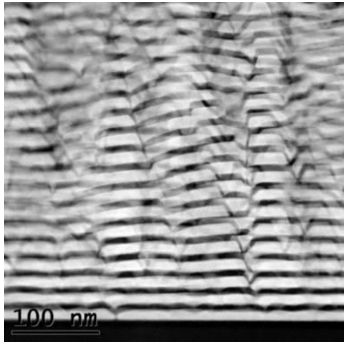
Nano-joining Approach @ Empa

NML Fabrication by DC Magnetron Sputtering



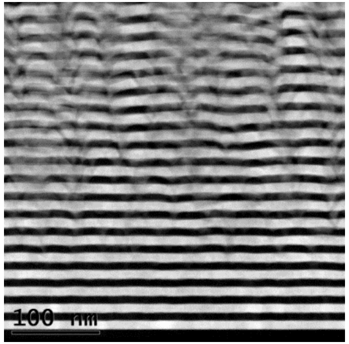


Ag_{10nm}/AlN_{10nm} (dark)



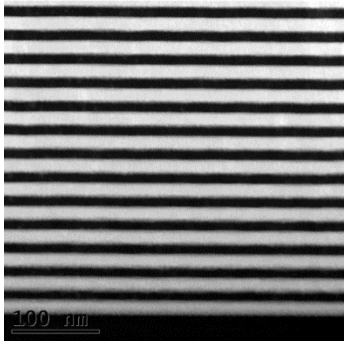
pronounced island growth

Cu_{10nm}/AlN_{10nm} (20x)



interface roughness

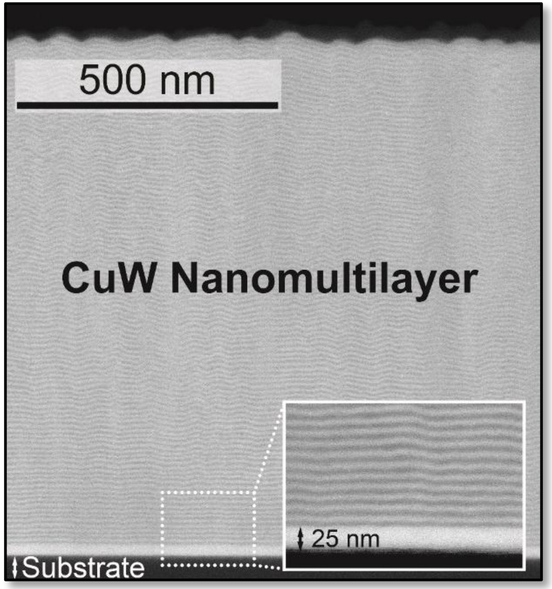
Ag-Cu_{10nm}/AlN_{10nm}



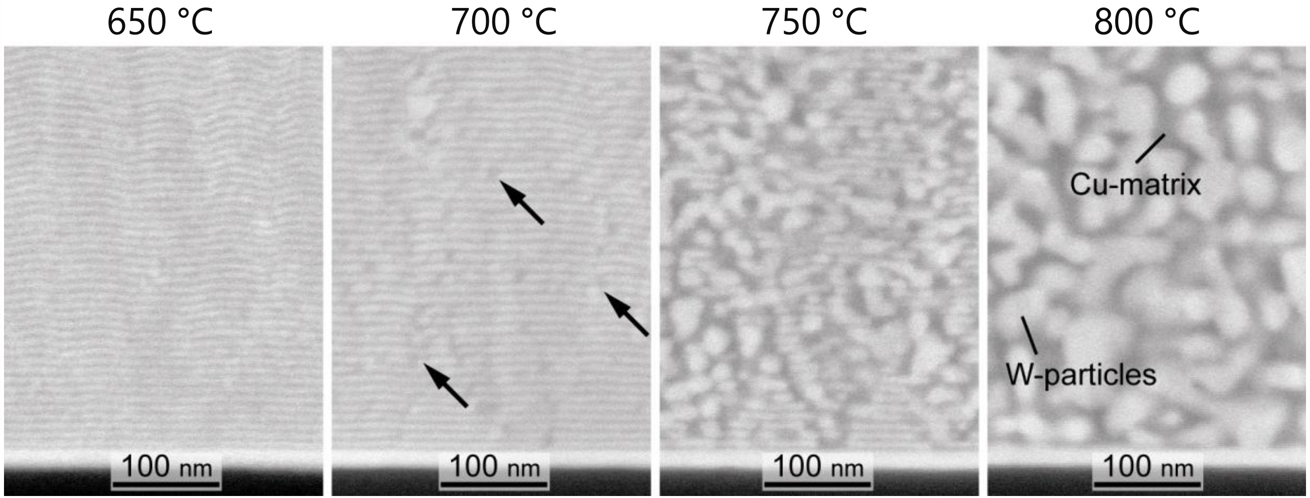
highly uniform layers

Nano-joining Approach @ Empa

Cu/W Nano Multilayer System



$T_{m,W}$ = 3422°C

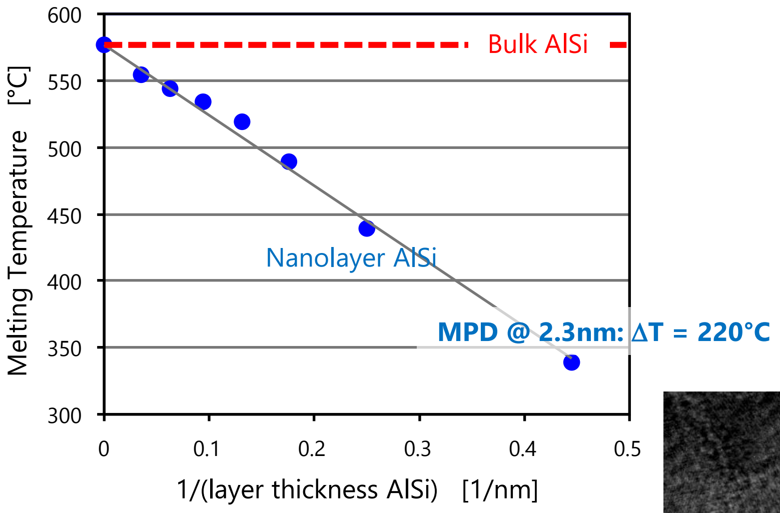


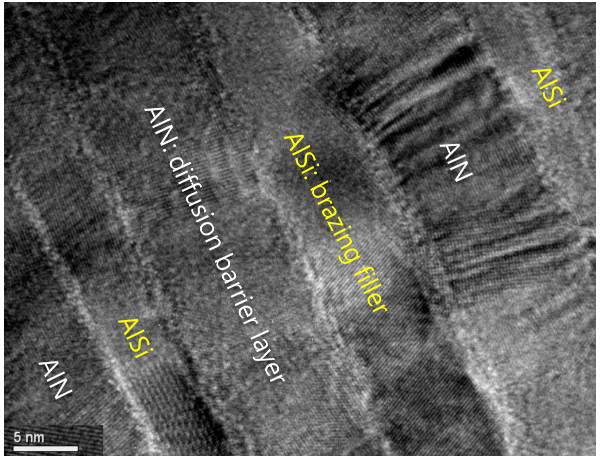
Ref: Acta Materialia 107 (2016) 345

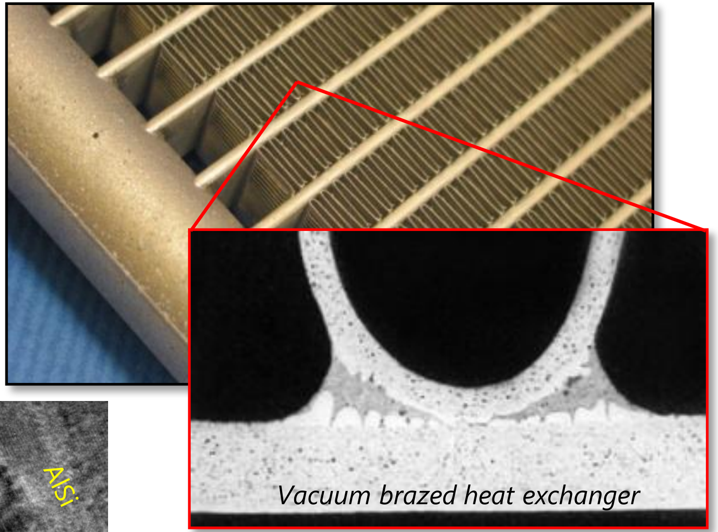
Annealing at *T* > 700 °C leads to gradual degradation of NML into a functional nanocomposite, consisting of globular W particles embedded in Cu matrix.

Nano-Joining

Low-temperature Brazing of Al Alloys (Patent DE102008050433.5)







Ultra-thin Al-$Si_{10at.\%}$ films sandwiched between inert AlN diffusion barriers exhibit size-dependent melting point depression (MPD)

References:

- *J Mater Chem C **4** (2016), 4927*
- *Phys Chem Chem Phys **17** (2015) 28228*
- *Acta Materialia **107** (2016) 345*
- *Scr Mater **130** (2017) 210*
- *J. Mater. Sci. Eng. B **6** (2016) 226*
- *J Mater Eng Perform **25** (2016) 3275*

Reactive Joining Systems

Under Study @ Empa

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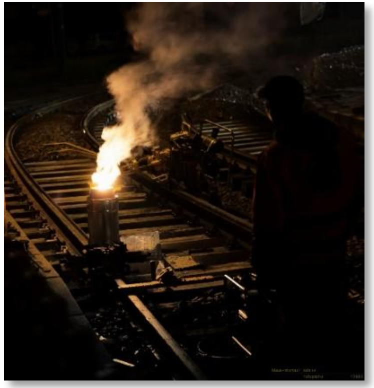
Binary alloy systems

Constituents	Density (g/cm^3)	Heat of reaction (kJ/mole atom)
Al + Pt*	11.63	-100.39
Al + Pd*	7.07	-91.30
3Si + 5Ti	3.72	-72.47
3Si + 5Zr	5.14	-72.10
5Nb + 3Si	6.23	-63.75
Al+Ni*	5.17	-59.17
Al + Co*	5.17	-55.20
2Al + Zr	4.24	-54.09
Al + 2B	2.61	-50.31
2Al + Ti	3.33	-44.61
Al + 3Ni	6.82	-38.25
Al + Ti*	3.63	-37.60
2Al + Zr	4.24	-33.73



Metal-oxide thermite systems

Constituents	Density (g/cm^3)	Heat of reaction (kJ/mole atom)
2Al + 3CuO	5.11	-149.14
Ti + 2CuO	5.83	-126.57
2Al + Fe_2O_3	4.18	-120.79
3Ti + 2Fe_2O_3	5.01	-91.24
Ti + Fe_3O_4	4.97	-82.31
2Al + Cr_2O_3	4.19	-76.60

Ni-Al Nanofoils© is the only commercially product up to date!

Reactive Joining using Ni-Al Nanofoils©

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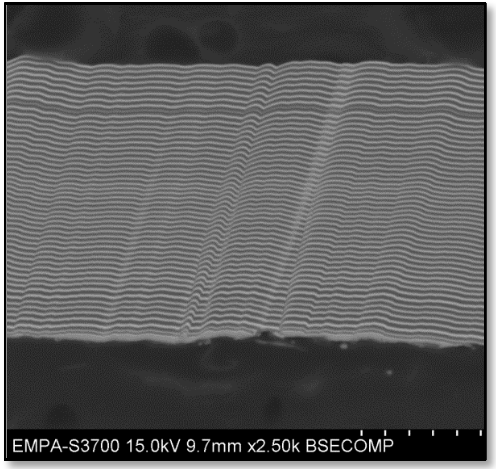
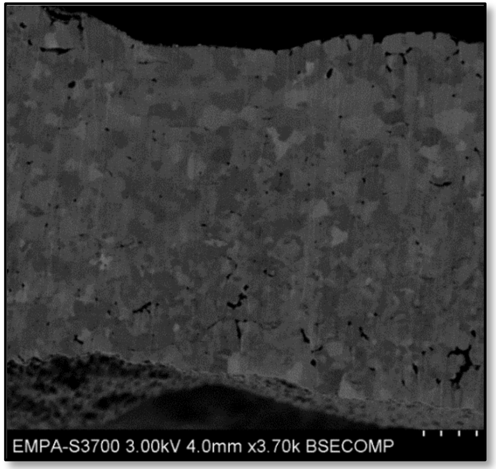
As-deposited Nanofoil©



Electric spark ignition

Reacted Nanofoil©



total time: 2.5 milliseconds

Process characteristics

- Local ignition at room temperature with electrical spark, laser pulse or hot filament.
- Self-propagating reaction: **Ni + Al → NiAl** (no gaseous product; heat of reaction ≈ -52 kJ/mol)
- Self-propagating reaction front with temperature > 1000 °C and speed up to 50 m/s!
- Defined heat release by tailoring the overall composition and bilayer thickness

Reactive Nano-Joining

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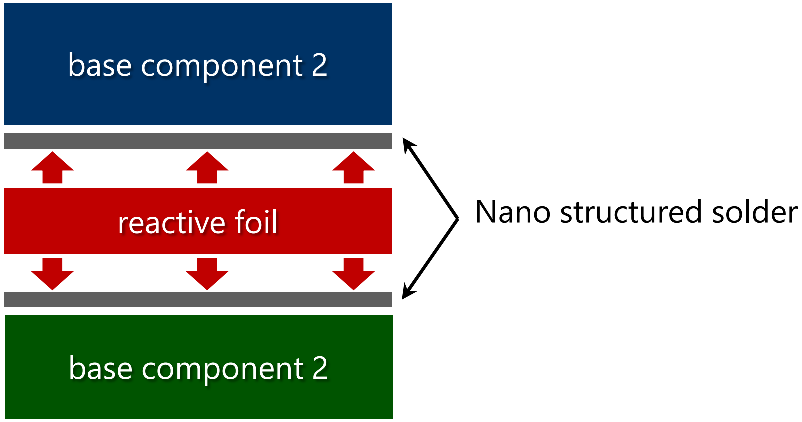
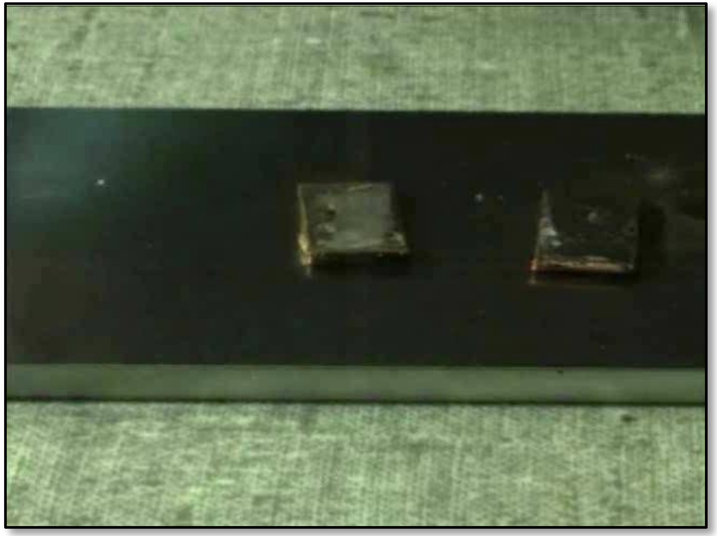
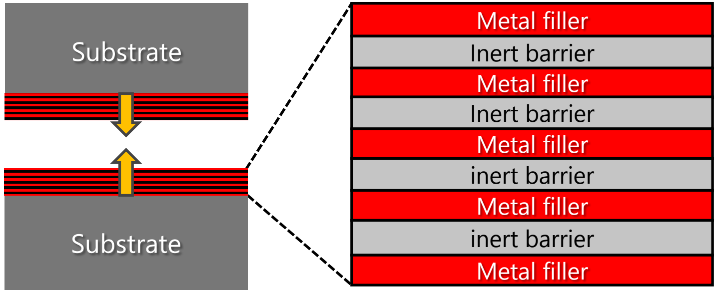
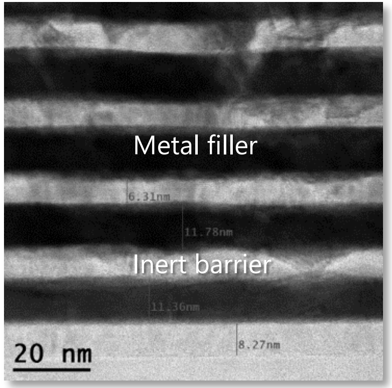
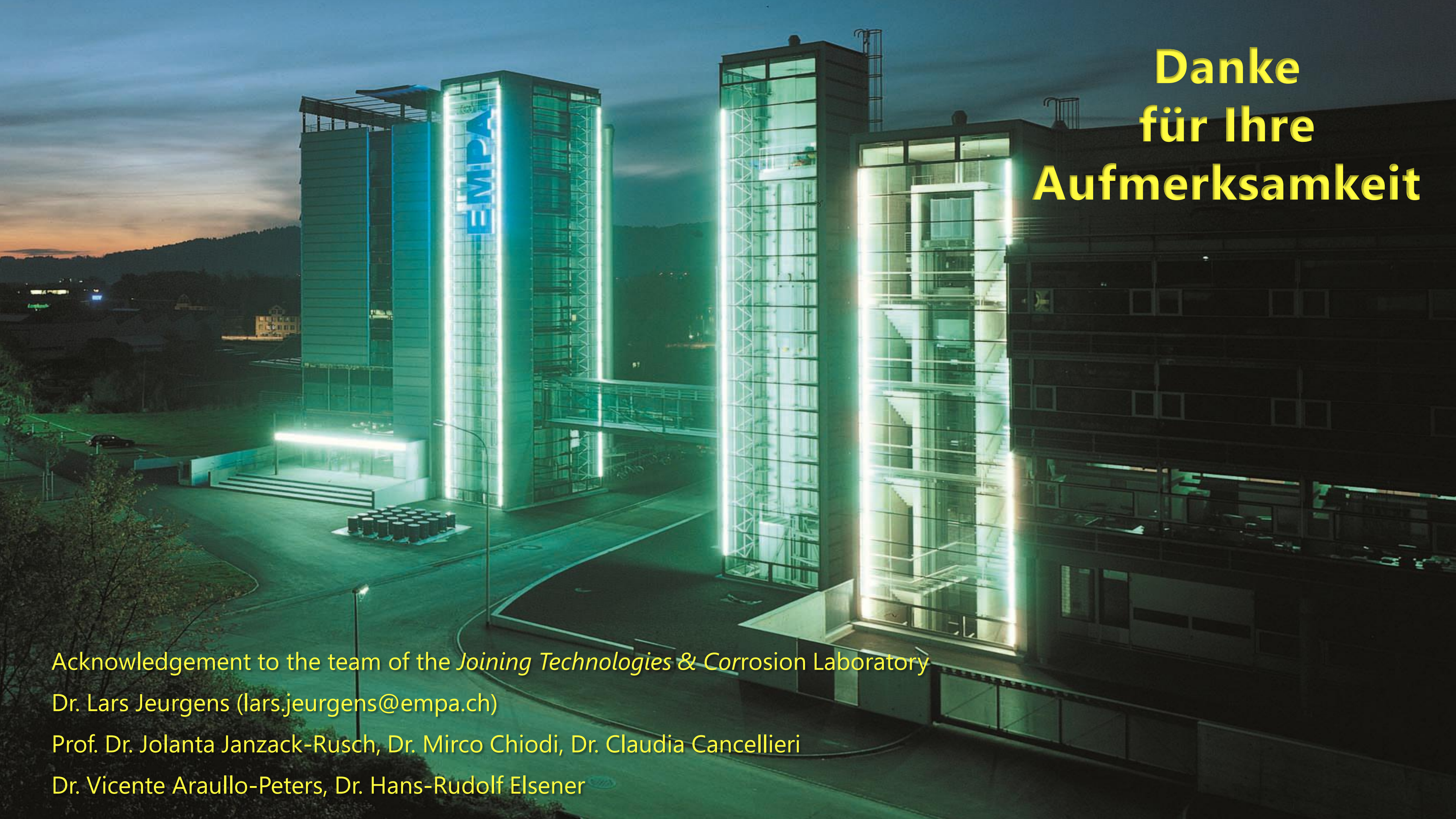




Nano-multilayered fillers (Ni + Al → Ni_3Al)







Danke für Ihre Aufmerksamkeit

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