PADERBORN UNIVERSITY
The University for the Information Society

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Multi-dimensional Ultrasonic Copper Bonding - New Challenges for Tool Design

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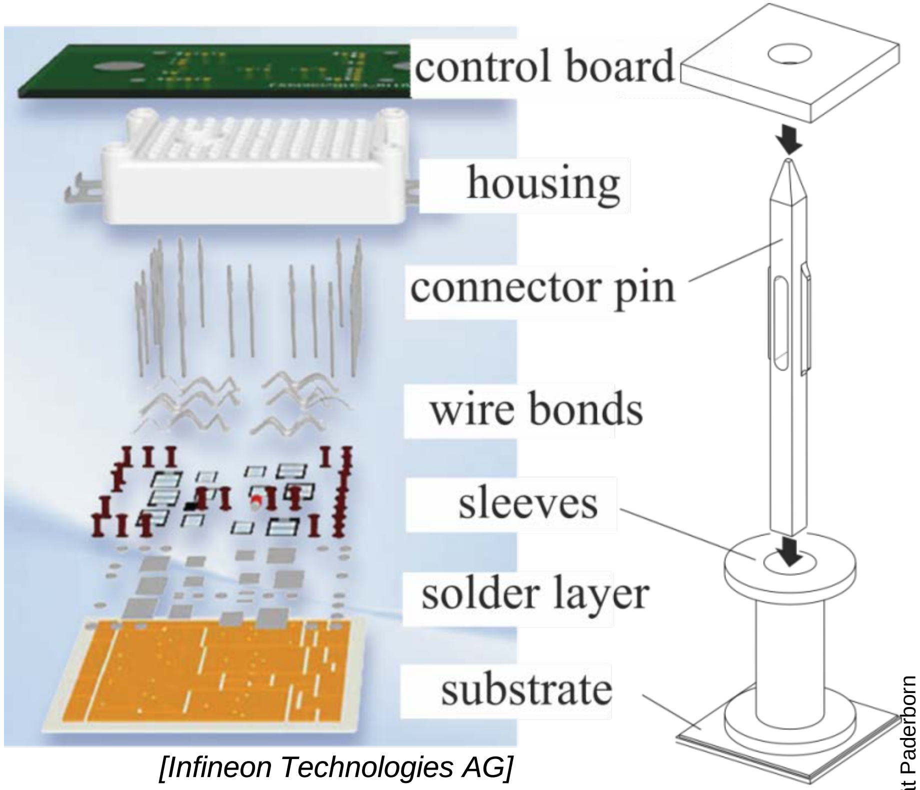
Agenda

- Motivation
- Ultrasonic bonding of connector pin
- Finite element modeling of multi-dimensional ultrasonic bonding
- Experimental investigation and results
- Conclusion

Motivation

- Copper connector pins are used to connect control boards with power modules
- state-of-the-art technology is to solder sleeves to the DBC
- Press-fit Pins are pressed into sleeves
- Soldering not qualified for new generation chip technology (junction temperature)
- Solution: High-temperature-stable connection via high power ultrasonic bonding of pins



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➔ Proper bond tool and suitable connector pin geometry have to be designed

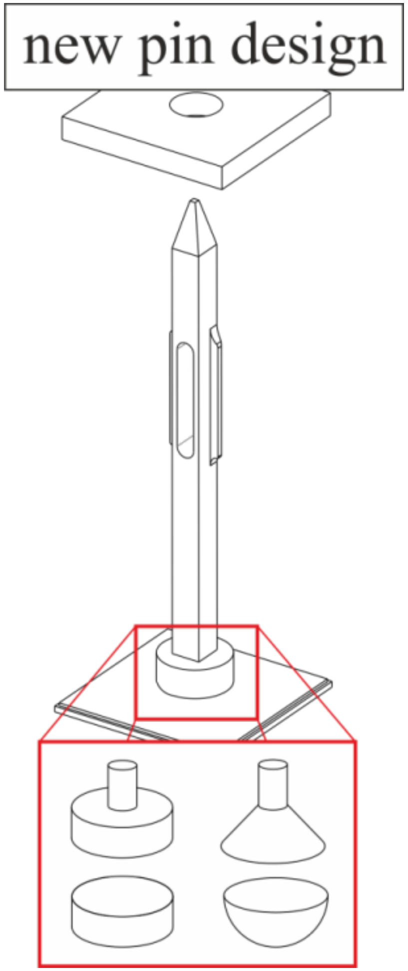
Ultrasonic bonding of connector pin

Bonding tool requirements:

- Fix the complete connector pin while bond head moves to bond location
- Clamping pin during planar ultrasonic motion
- Avoid damages at connector pin.
- Avoid tilting of the pin
- Avoid tool/substrate contact during bonding to prevent substrate damage
- Fulfil dynamic demands of the vibration system, e.g. resonance frequency and required vibration amplitude

New Pin Design:

- Upper section: Established Press-Fit geometry
- Lower part: Nail-shaped
  - Ensure centering of pin
  - Sufficient contact/bond area to substrate



Finite element modeling of multi-dimensional bonding

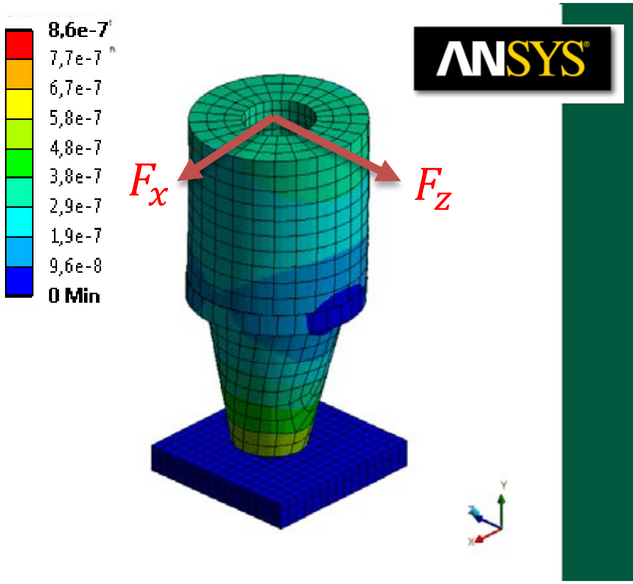
Vibration design

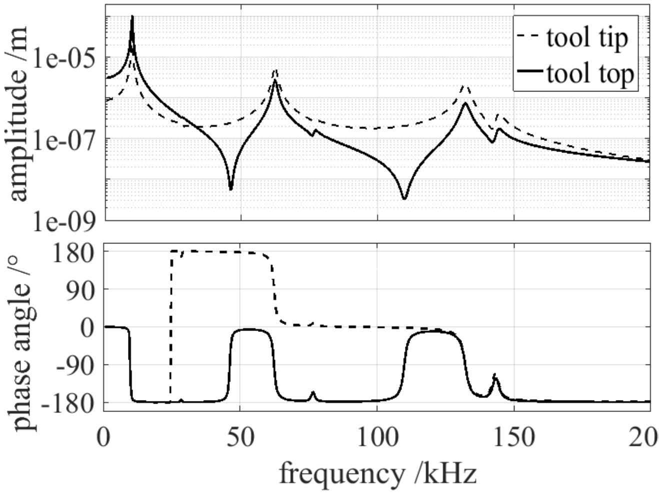
Dynamic demands:

- 2-dimensional vibration (planar)
- Eigenfrequency at approx. 60 kHz (operation freq. of transducer) to achieve high oscillation amplitudes
- Maximum oscillation amplitude at tool tip
- Transferring vibration from transducer to the copper pin
- Uniform deflection in all directions in the working plane (circular motion)

FE-Modelling:

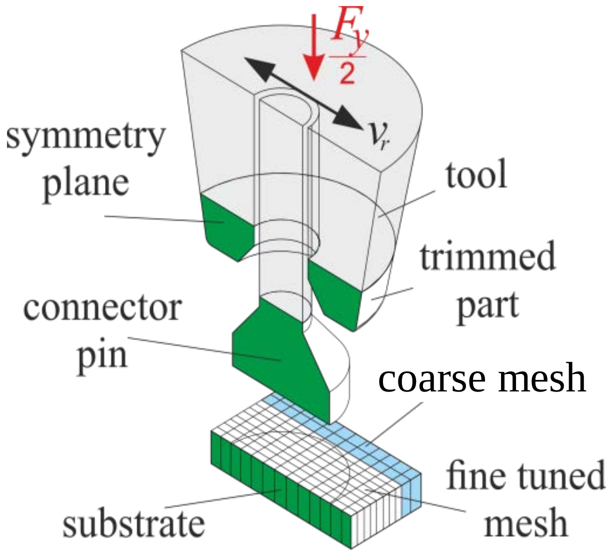
- Constant vertical force (bond normal force)
- Tangential forces F_x and F_z oscillate harmoniously with a relative phase of 90°





Finite element modeling of multi-dimensional bonding

Mechanical analysis of contact section

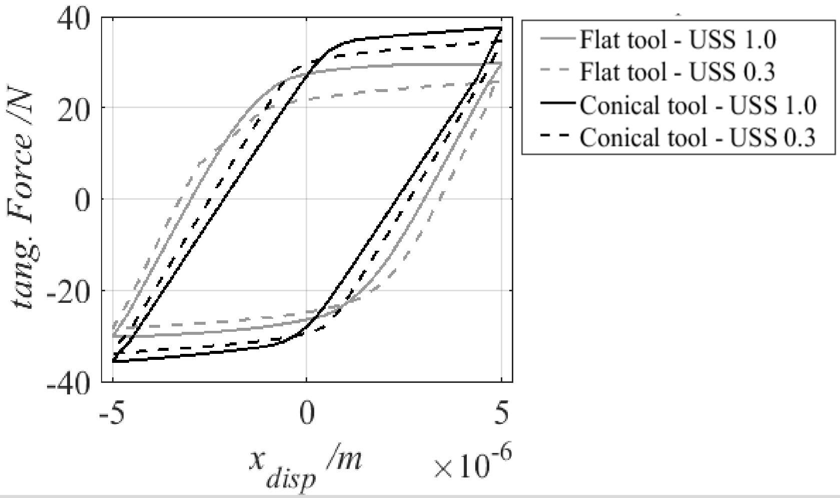


FE-Modelling:

- Vertical displacement due to applying constant vertical force (F_y)
- Mapping US-softening (USS)
- Tool excitation: 5 µm (vib. amplitude)

Tangential force transmission:

- Conical tool: 25% to 35% higher tangential force
- Conical form fit prevents tool from gross slippage ➔ high clamping force

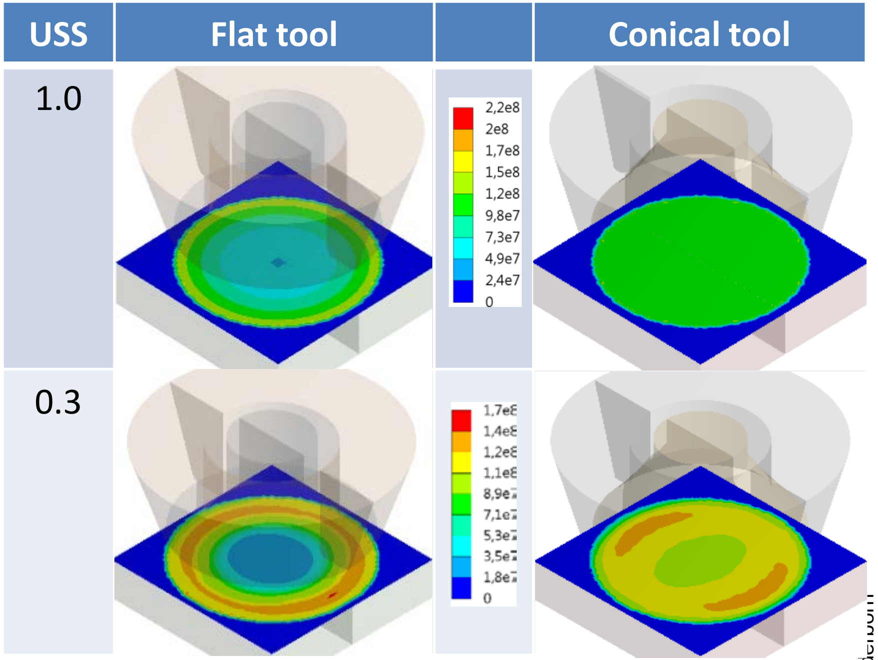


Finite element modeling of multi-dimensional bonding

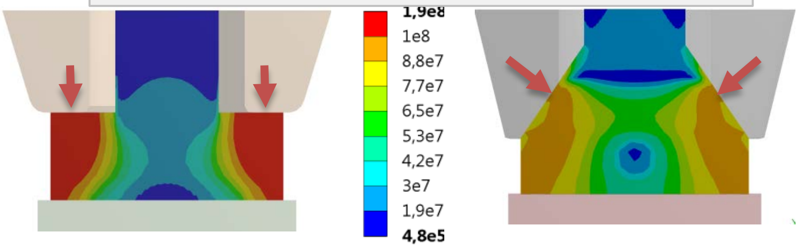
Mechanical analysis of contact section

Pressure distribution:

- High impact of bonding
- Non-homogeneous pressure
  ➔ parts sliding or sticking
- USS increases contact area pin/substrate
- Conical tool: relatively homogeneous
- Flat tool: distinct ring-shape
  Explanation:
  - Flow of force (Von Mises stress)
  - Hole in tool center



Von Mises stress ➔ flow of force

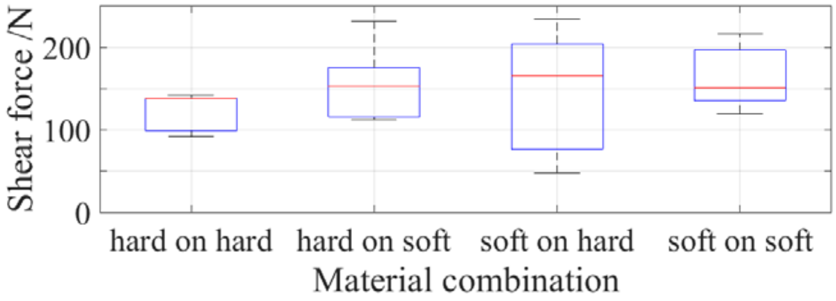


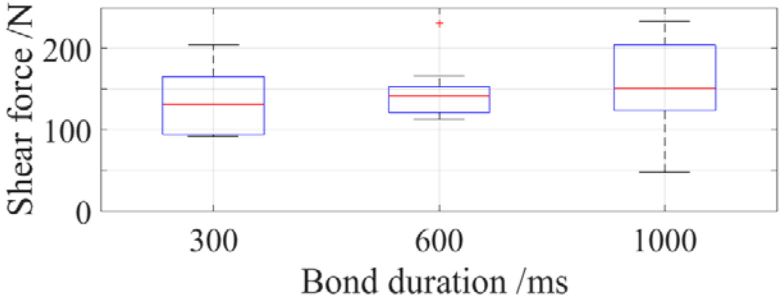
Experimental investigation and results

Bonding test

- Conical tool shape (top side) and convex bottom side are used in the following investigations
- Pin was annealed in vacuum to avoid high-temperature oxidation and achieve a lower hardness
- Shear force for 2D-Bonding of copper pins can rise up 240 N
- At least one contact partner should be soft
- Hard convex pin leads to high pressure/deformation and low slippage in contact area
- 300 ms bond duration are too short for reliable bonds
- 600 ms appr. optimum for bonding
- 1000 ms leads to overbonding

	Substrate (Cu)		Connector pin (CuSn6)	
	soft	hard	soft	hard
Hardness (Vickers)	90 HV	200 HV	106 HV	310 HV



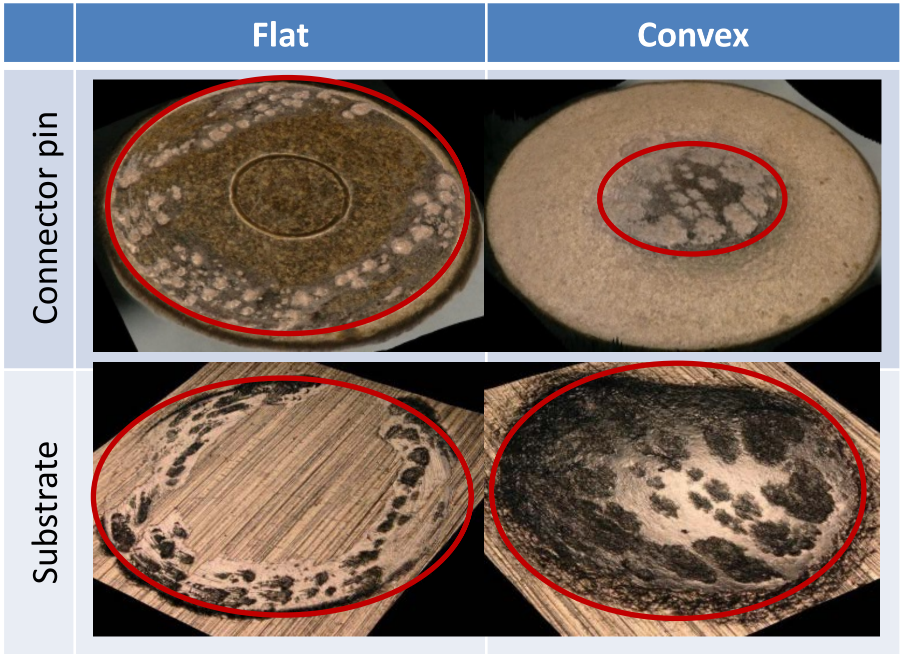


Experimental investigation and results

Inspection of shear area

- Bond duration: 300 ms

- Assumption: grey area ➔ friction due to relative motion pin/subst.
- Convex pin not completely in contact in comparison to flat pin
  - ➔ low pressure not sufficent to flatten convex pin shape
  - ➔ low US-softening due to insufficient ultrasonic power
- Micro welds form a ring, growing in direction of boundaries with increasing bonding time



Conclusion

- 2D trajectory approach for ultrasonic copper bonding of connector pin without increasing mechanical stress
- New rotationally symmetric tool design was introduced
- Harmonic FE-analysis of tool ➔ fulfilled dynamic demands in operation
- Static-mechanical FE-analysis ➔ design contact shape tool/pin
- Tool geometry (conical in comparison to flat):
  - Maximum transmittable tangential force for conical shape ➔ low slippage tool/pin
  - Advantage pressure distribution pin/substrate ➔ high slippage pin /subst.
- FE-results were verified via bonding test
- Shear force up to 240 N applying a circular trajectory can be reached

➔ Newly designed capillary tool for nail-shaped bonding pieces works well

➔ 2D high power bonding process shows promising bonding results

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Thank you
for your attention!

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