Heraeus

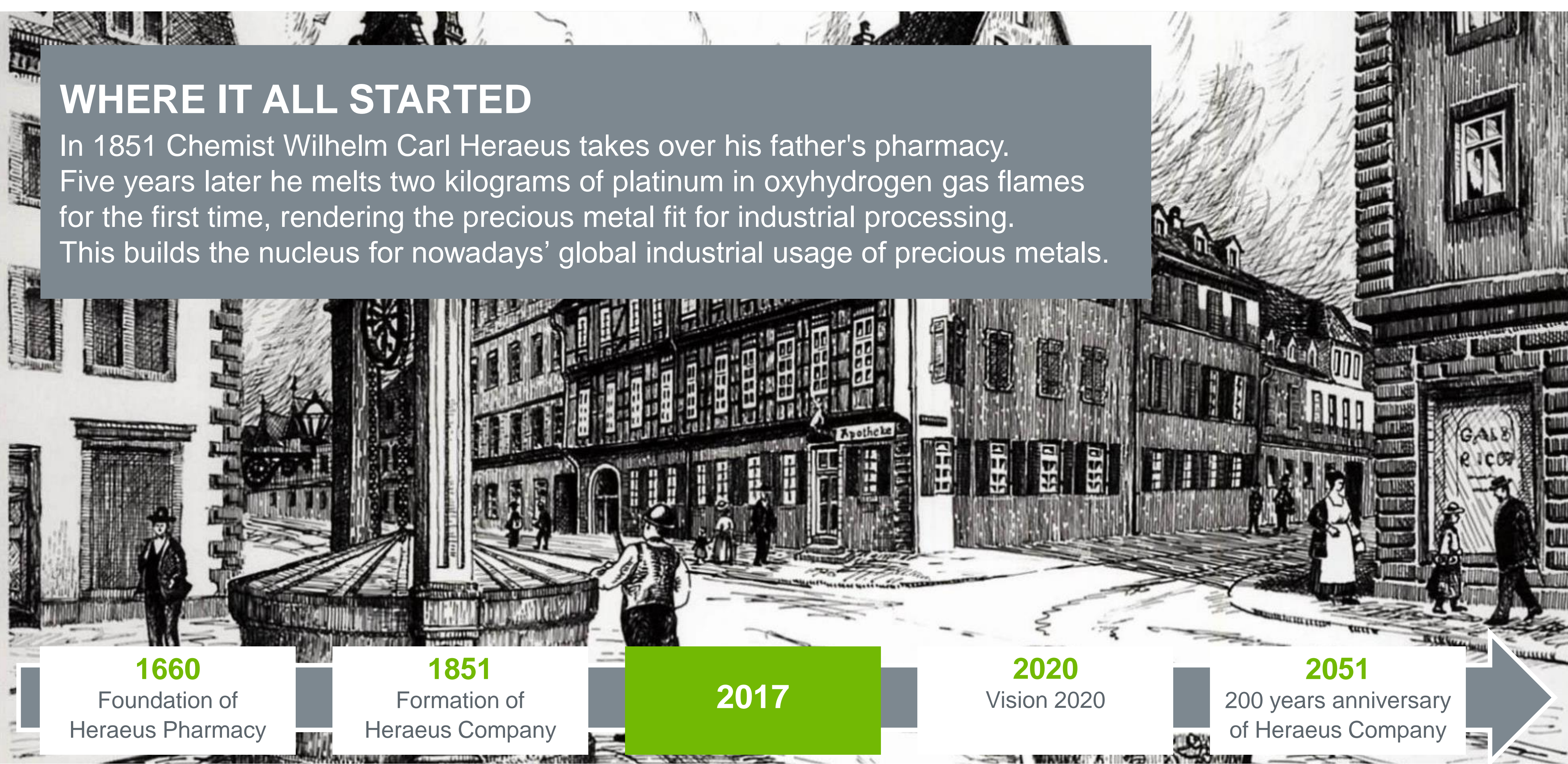
NEW SOLDERING PASTES FOR DIFFUSION BASED JOINING TECHNOLOGIES

Chemnitz, 12.06.2018, S.Käss, S.Fritzsche, J.Strueben, J.Trodler

CONTENT OF PRESENTATION

1. **Introduction of Heraeus Electronics**
2. **Introduction for New soldering pastes for diffusion based joining technology**
   2.1 Target and Motivation of Hot Power Connection
   2.2 Solder Materials and Process
   2.3 Selection of solder materials
   2.4 Paste application
   2.5 Infiltration and intermetallic forming
   2.6 Solder joint analysis
   2.7 Comparison with solder process and sintering
   2.8 Paste requirements
   2.9. Reliability of diffusion soldering
3. **Conclusion and outlook**

Heraeus



HERAEUS BUSINESS SEGMENTS

9 Global Business Units (GBU)

Heraeus Emerging Businesses (HEB)
- Sensor Technologies and Electronic Chemicals

Heraeus Electro-Nite (HEN)
- World market leader in sensor and measurement systems (e.g. for steel)

Heraeus Electronics (HET)
- Matched materials solutions for the electronics packaging and component industry

Heraeus Medical (HME)
- Medical products for orthopaedic surgery and traumatology

Heraeus Medical Components (HMC)
- Components and solutions for the medial technology industry

Heraeus Noblelight (HNG)
- Special lamps with wavelengths from ultraviolet to infrared

Heraeus Precious Metals (HPM)
- Leading provider of precious metal services and products – from trading to recycling

Heraeus Photovoltaics (HPT)
- Focus on global photovoltaic industry based on silicon wafer technology

Heraeus Quarzglas (HQS)
- Technology leader for manufacture and processing of high-purity quartz glass

Incubator New Businesses (INB) for start-ups
- to foster new business ideas outside of a GBU structure

WE ARE HERAEUS ELECTRONICS.

10 production sites in 7 countries worldwide

1,400 employees worldwide

50+ countries where our products are sold

YOUR MATERIALS SOLUTIONS PARTNER.

WE ARE FOCUSED on providing innovative materials and matched materials solutions for the electronics packaging and component industry.

CLOSE to your development centers and factories we have experts located in Asia, US and Europe to grant fast reaction and easy access without language barriers.

TRUST & RELIABILITY have been the basis of our cooperation for more than **160 years**, founded on leading compliance and environmental standards, transparency, and our financial stability.

PROVIDING SOLUTIONS FOR THE ELECTRONICS INDUSTRY

LED

Communications

Consumer Electronics & Computing

Automotive

Industrial

High-Power LED
Automotive headlamps;...

SMT; Advanced packaging
System in Package (SiP);...

Power Electronics; SMT
Transmission control;...

Power Electronics
IGBT modules

RF Power
RF amplification systems;...

Metal Ceramic Substrates
Thick Film Pastes
Sinter Materials
Metal Substrates
Bonding Wires
Solder Materials
Adhesives

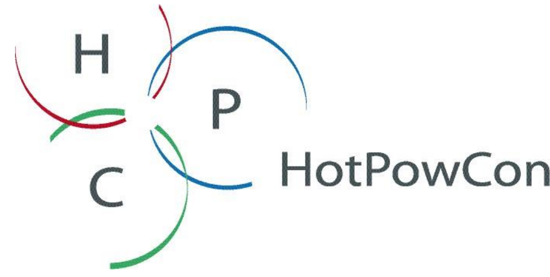
Heraeus

NEW SOLDERING PASTES FOR DIFFUSION BASED JOINING TECHNOLOGIES

Chemnitz, 12.06.2018, S.Käss, S.Fritzsche, J.Strueben, J.Trodler

BOSCH Heraeus

NEW REFLOW SOLDER TECHNOLOGY FOR ELECRONIC ASSEMBLIES UNTIL 300°C

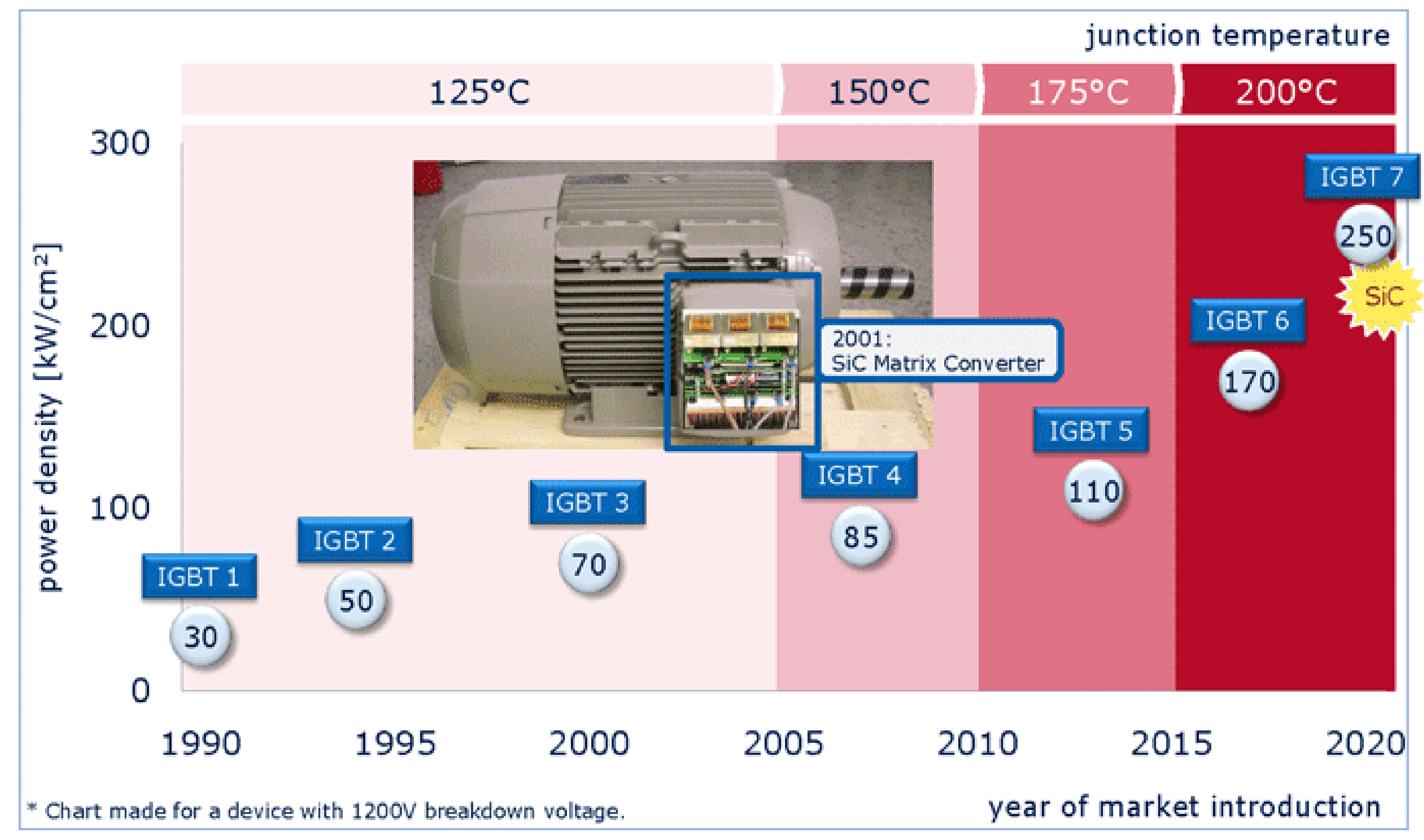


BOSCH **Konsortialführung: Dr. Andreas Fix, andreas.fix@de.bosch.com**

Andreas Fix, Timo Herberholz, Robert Bosch GmbH, Schwieberdingen
Mathias Nowottnick, Andrej Novikov, Regina Lange, Universität Rostock, Rostock
Jörg Trodler, Jürgen Schulze, Heraeus Materials Technology GmbH & Co. KG, Hanau
Matthias Hutter, Christian Ehrhardt, Hans Walter, Fraunhofer IZM, Berlin
Rainer Dudek, Ralf Döring, Remi Pantou, Fraunhofer ENAS, Chemnitz
Klaus Wilke, Jörg Strogies, Hans-Jürgen Albrecht, Siemens AG, Berlin
Bettina Seiler, Michael Dost, Kerstin Kreyßig, Chemnitzer Werkstoffmechanik GmbH, Chemnitz
Andreas Reinhardt, Volker Liedke, Sonja Wege, Rolf Diehm, Seho Systems GmbH, Kreuzwertheim
Thomas Zerna, Alexander Klemm, Technische Universität Dresden, Dresden
Uwe Pape, Christian Mertens, Volkswagen AG, Wolfsburg
Jürgen Freytag, Ralf Ghetto, Daimler AG, Sindelfingen

SIEMENS DAIMLER

DEVELOPMENT OF JUNCTION TEMPERATURE OF IGBTS OVER THE YEARS



OVERVIEW OF EXISTING SOLDERING MATERIALS

Operating Temperature / °C

300
275
250
225
200
175
150
125
100
75

$T_h = 1$

$T_h = 0.8$

Zn95Al5
Au97Si3
Au88Ge12
Pb95Sn5
Au80Sn20
Bi97.5Ag2.5
Sn96.5Ag3Cu0.5
Sn63Pb37

75 100 125 150 175 200 225 250 275 300 325 350 375 400 425

Solder Melting Temperature / C°

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

MOTIVATIONS FOR „HOT-POWER-CONNECTION“

Reduction of costs

- Material costs (solder vs. Silver sintering)
  - 1g Ag ~ 0,45 €
  - 1g Sn ~ 0,017 €
- Production costs
- System costs

Enable for

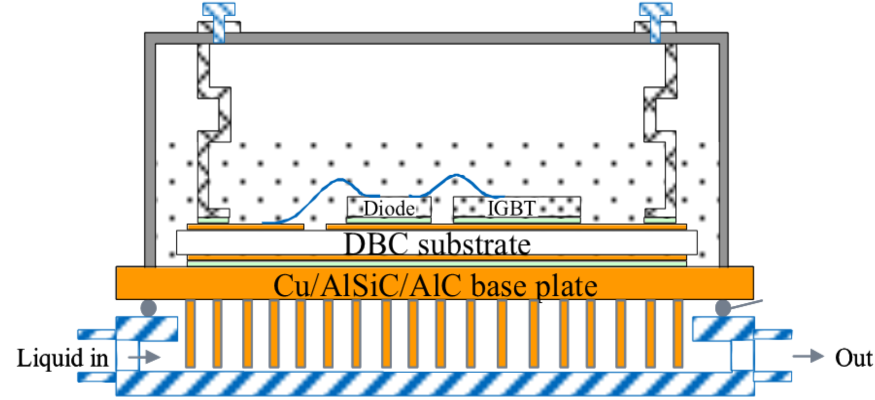
- miniaturization of performance assembly
- Integration of sensors
- Ability for reflow processes

Reliability

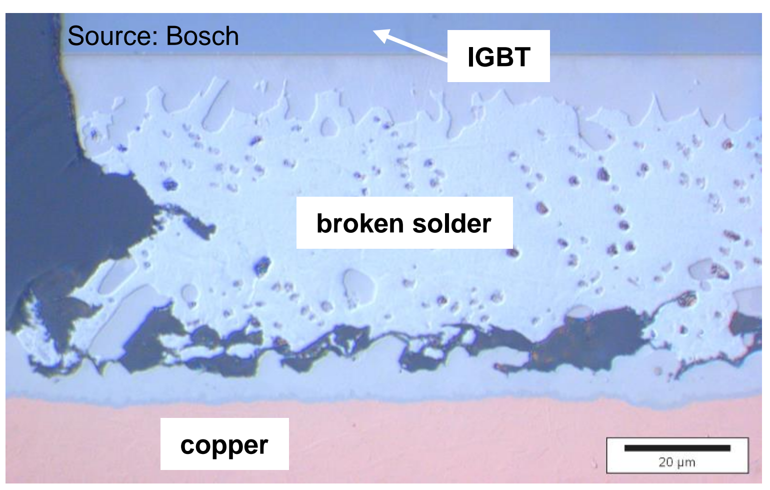
- Operating temperature for conventional lead free solder limited
- No hard solder for low temperature available

Laws

- Prohibition of PbSn5



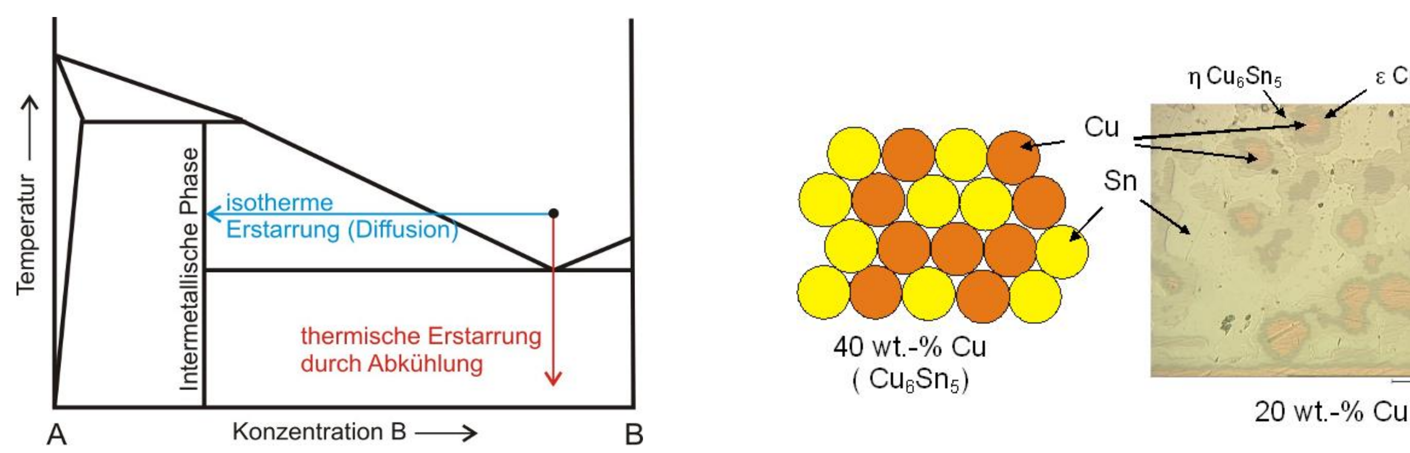
Assembly of a power module



Broken solder alloy of an IGBT

ISOTHERMAL SOLDIFICATION AS BASIS FOR MATERIALS

Combination of thermal solidification and isothermal solidification could be the basis for a new quality of interconnection



Phase diagram of a two element system

- Structure design through high melting intermetallic by using soft solder alloys based on solder paste
- soft solder alloy will be used based on Sn with a high metal concentration and additives
- Isothermal solidification at low/standard solder temperatures

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

POSSIBLE ELEMENTS FOR ISOTHERMAL SOLDIFICACTION

Haupt- gruppen

I	II	III	IV	V	VI	VII	VIII

Nebengruppen

Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu

Sn

❌ Metallurgical Unsuitable

€ Too Expensive

Nuclear

Non Metal

Toxic

MATERIAL SELECTION – THERMAL ASPECTS

Forbidden zone

Target area

Reference

Ni_3Sn_4

Cu_3Sn

Cu_6Sn_5

AuGe12

AuSi3

Pb100

PbSn5

Bi100

PbIn20

AuSn20

SnSb10

SnSb5

Sn100

SnAg3Cu0.5

SnPb37

In100

BiSn42

Junction temperature referred to $T_h = 0{,}8$

0 100 200 300 400 500 600

0 10 20 30 40 50 60 70 80 90 100

Thermal conductivity W/mK

ALLOY SYSTEM OF CHOICE (SN-CU)

Weight Percent Tin

β,γ,δ,ε,ζ,η = intermetallic phases

L

(Cu)

Temperature °C

isothermic soldification =
η- Phase Cu_6Sn_5

Initial point $T > T_m$

Thermic soldification

(Sn)

Cu — Atomic Percent Tin — Sn

Temperatur

Intermetallische Phase

isotherme Erstarrung (Diffusion)

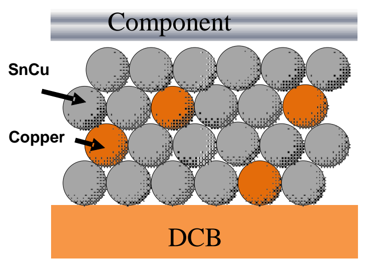
thermische Erstarrung durch Abkühlung

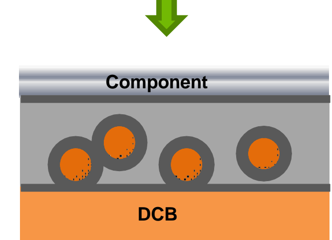
A — Konzentration B ⟶ — B

Alloy system with partially solubility

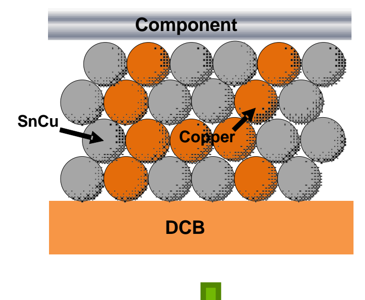
FIRST TRIALS COPPER POWDER IN SOLDER PASTE

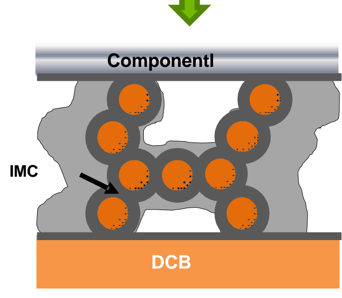
Copper < 20w%

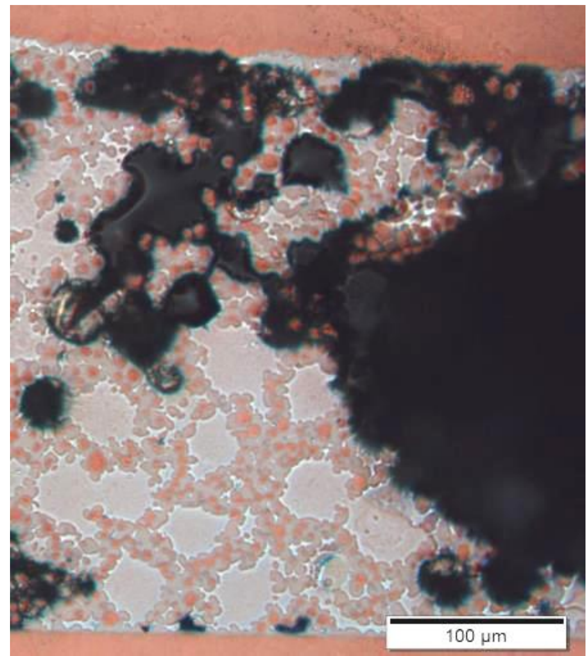




Copper > 20w%







Cu Intermetallic with Cu >20 w%

Construction of an mechanical stable Cu + IMC and due to shrinking of SnCu paste by app. 50% creates 3D failures by using high Cu content (>20 w%)

GEFÖRDERT VOM
Bundesministerium
für Bildung
und Forschung

NEW CONCEPTS OF PASTE APPLICATIONS

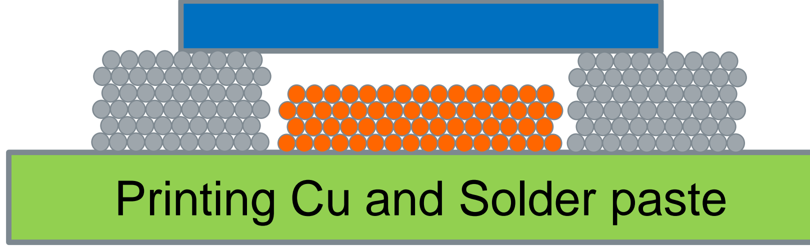
vertical infiltration	lateral Infiltration
Chip solder copper Fließrichtung flüssiges Lot	Chip Lot Kupfer

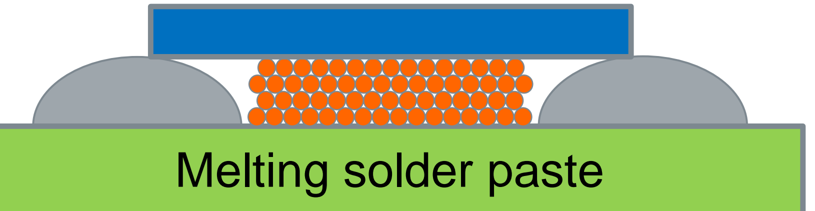
Chip
one sided attachement
Copper
200 µm

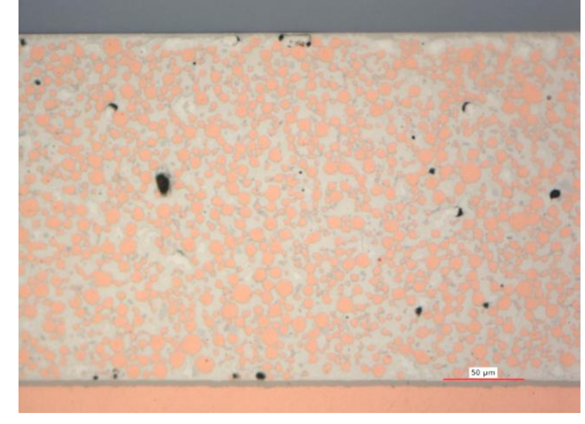
Continous attachment
100 µm

- Vertical infiltration: so far not successful, separating layer
- lateral infiltration: successful, continuous attachment of the joining partners

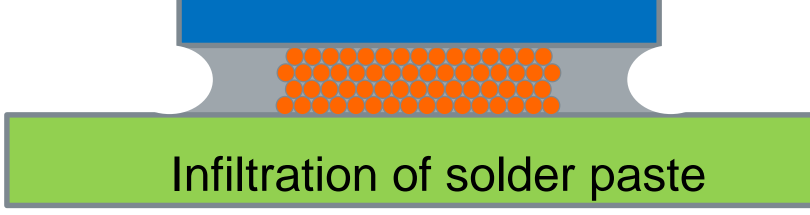
MECHANISM OF THE INFILTRATION

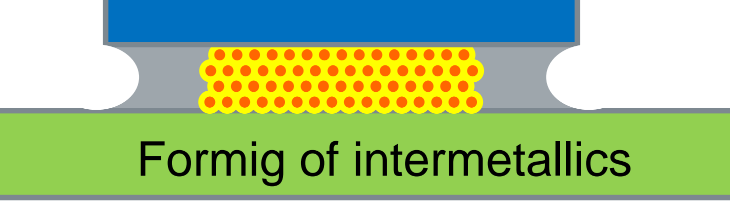


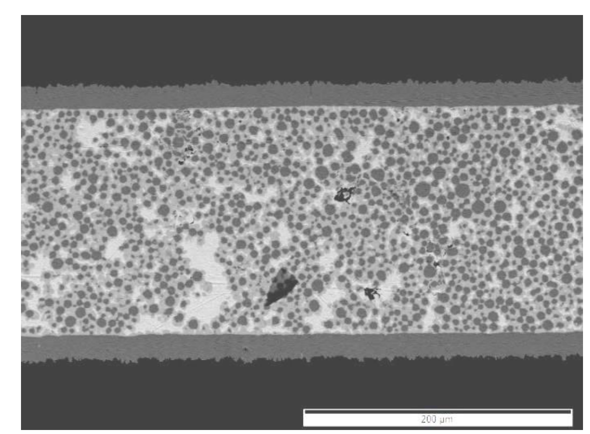




Cross section: Detail with light optical microscope.



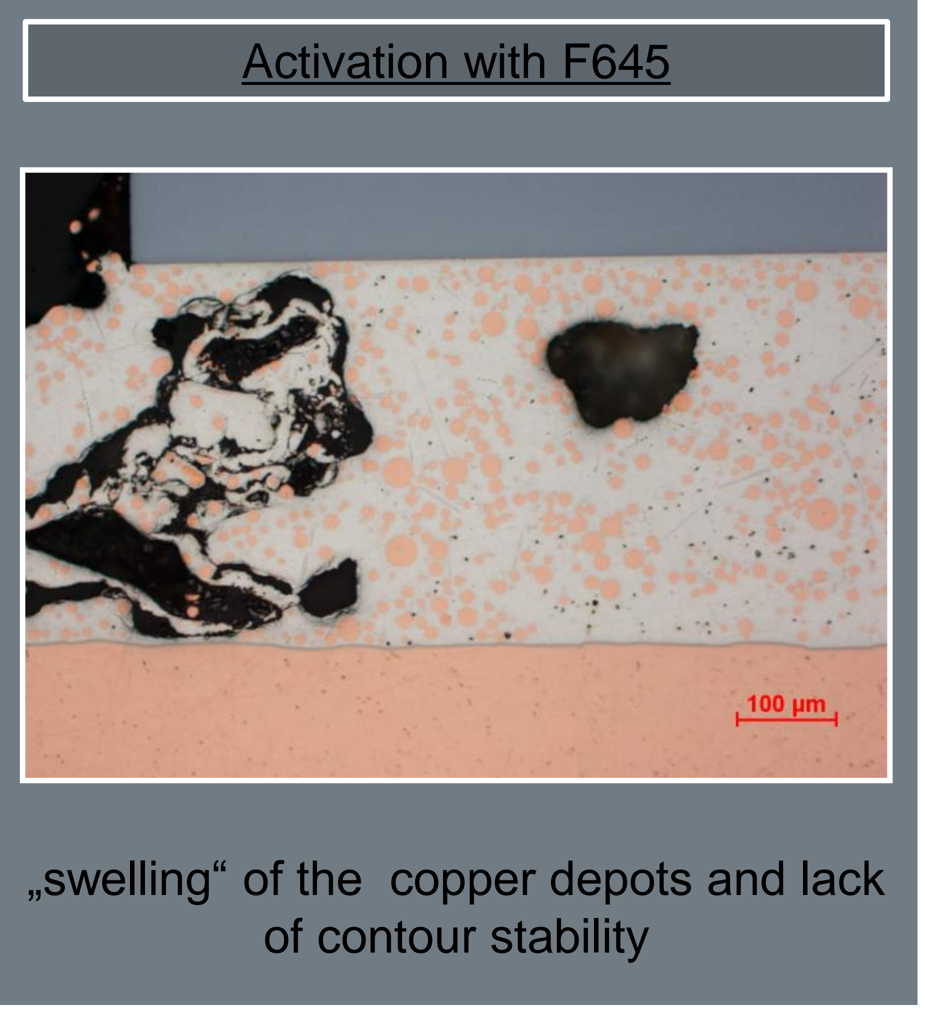




SEM analyses with pcb/pcb sandwich

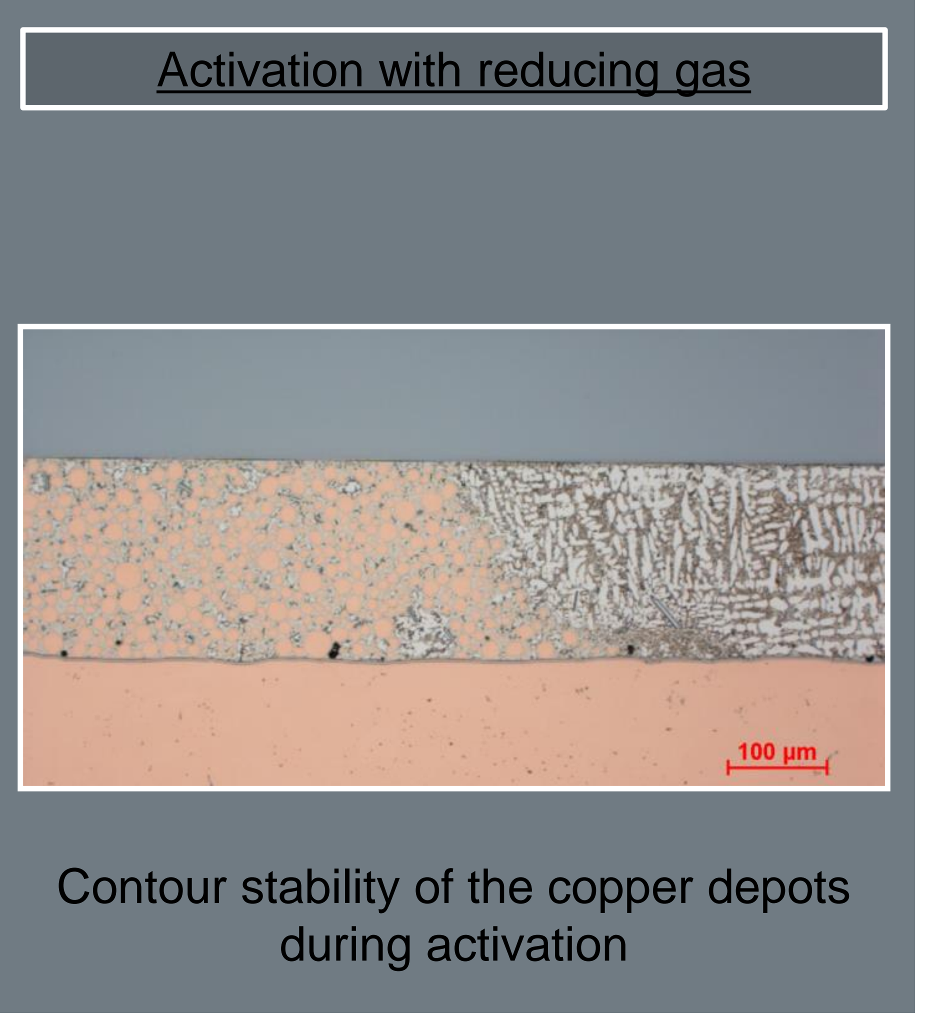
GEFÖRDERT VOM
Bundesministerium
für Bildung
und Forschung

ACTIVATION OF THE SOLDER JOINT



Activation with F645

„swelling“ of the copper depots and lack of contour stability



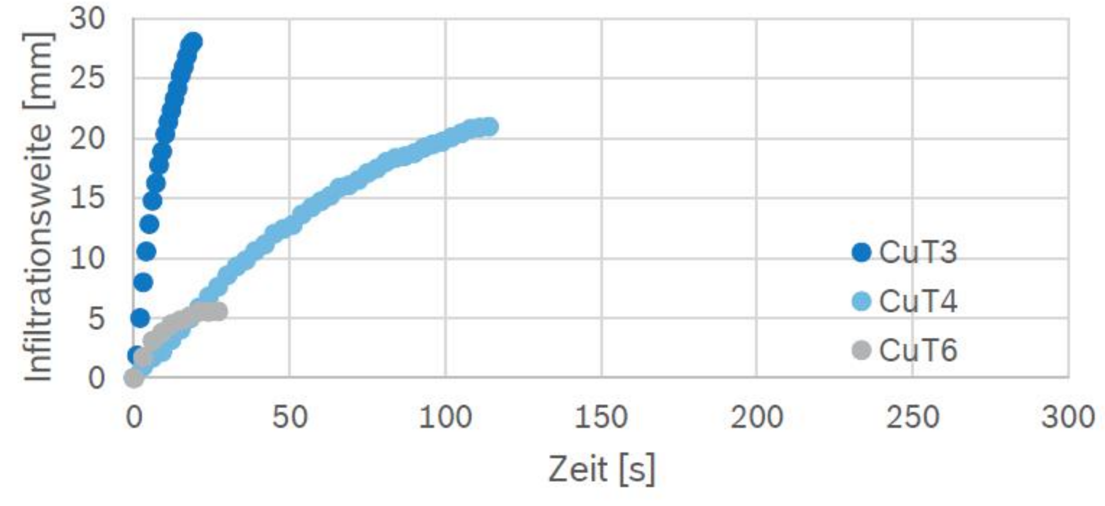
Activation with reducing gas

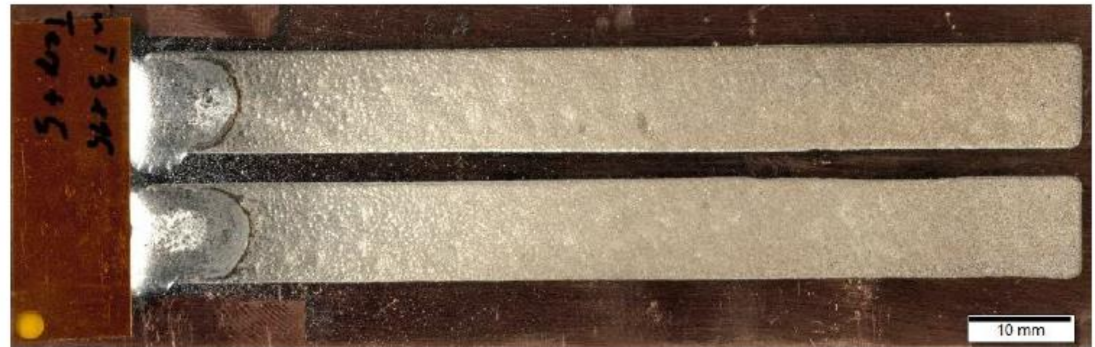
Contour stability of the copper depots during activation

BOSCH Heraeus

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

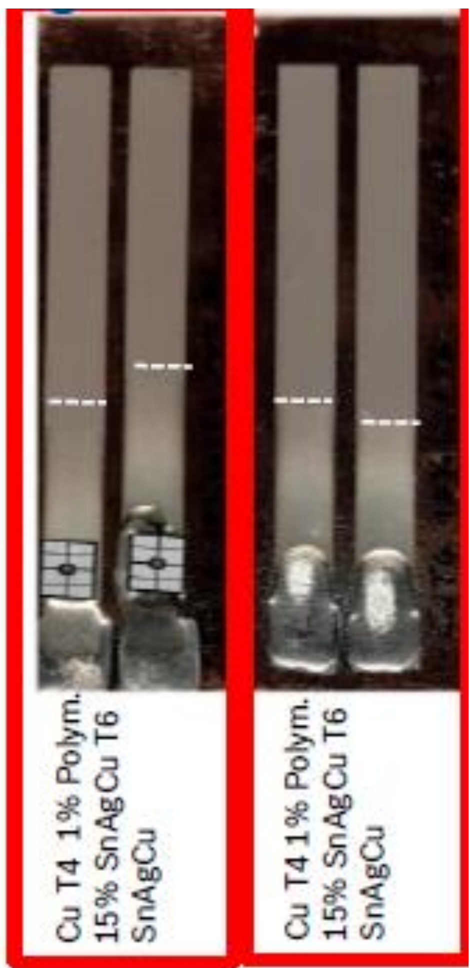
CU PASTE DEPENDENCY OF THE INFILTRATION DEPTH AS FUNCTION OF TIME



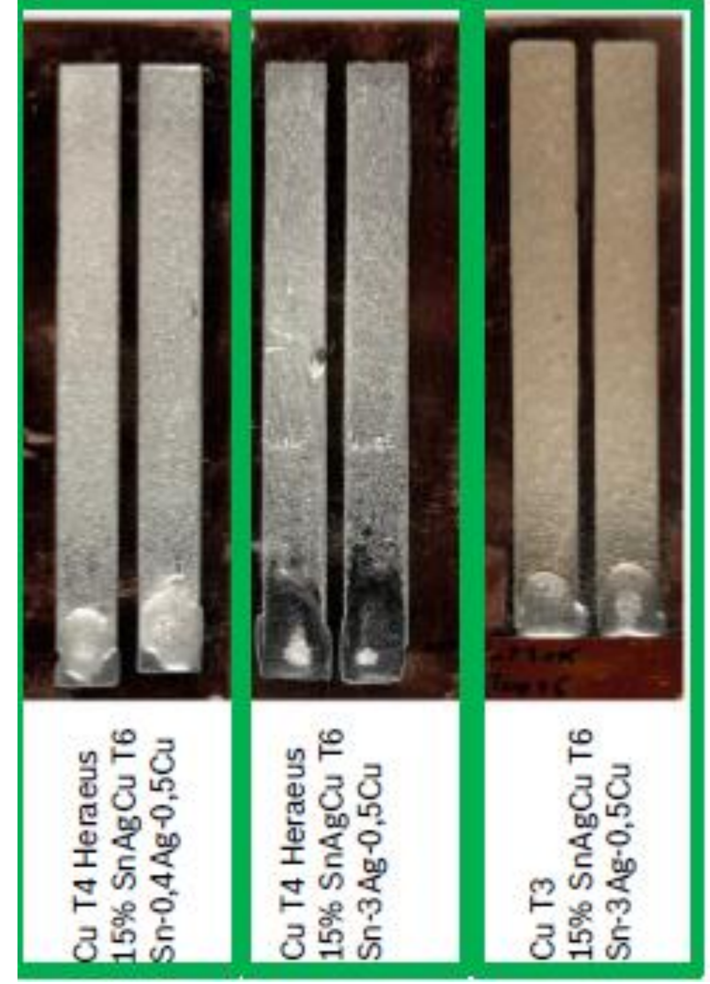


DEPENDENCY OF INFILTRATION ON ACTIVATION

Flux with Resin



Flux without Resin



SOLDER JOINT ANALYSIS

#1 #2 #3 #4

50 µm

Spot #1 (Cu-Phase)

Element	Atomic %	Weight %
Cu	91.5	85.2
Sn	8.2	14.3
Ag	0.4	0.6

Spot #2 (Cu_3Sn)

Element	Atomic %	Weight %
Cu	72.9	59.1
Sn	26.3	39.8
Ag	0.8	1.1

Spot #3 (Cu_6Sn_5)

Element	Atomic %	Weight %
Cu	54.1	39.8
Sn	43.9	58.8
Ag	2.0	2.5

Spot #4 (residual solder)

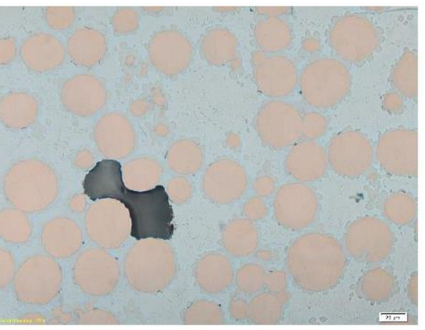
Element	Atomic %	Weight %
Cu	20.5	12.2
Sn	79.0	87.4
Ag	0.5	0.5

Source: D. Feil, et al.,Highly variable Sn-Cu diffusion soldering process for high performance power electronics, Microelectronics Reliability (2017)

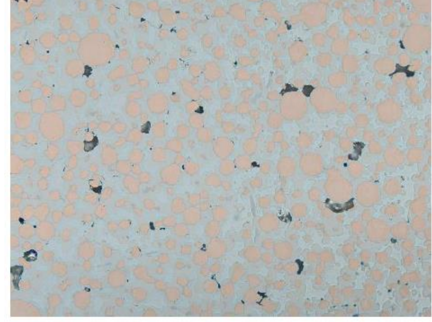
SOLDER JOINT ANALYSIS OF DIFFERENT CU-POWDERS

- samples without vehicle
- Powder with additional 15 % SAC 305 type 6
- Solder joint analysis after soldering

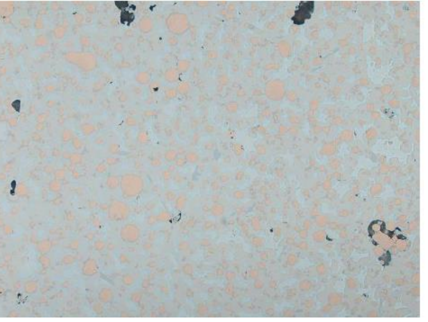
Phase proportion [%Vol]	Cu T3	Cu T4	Cu T6
Cu-Phase	41	31	15
IMC	25	47	63
Residual solder	33	16	18



CuT3



CuT4



CuT6

BOSCH Heraeus

PASTE REQUIREMENTS

	Cu-Paste	Solder paste
Application	Stencil printing / Screen printing	stencil printing/dispensing
Printability/dispense ability	Like available solder pastes	Like available solder pastes
Hot slump	0,2-0,4 (acc. IPC)	0,2-0,4 (acc. IPC)
Powder size	Type 4	tbd
Infiltration	> = 100 mm	> = 100 mm
Tackiness	High enough to fix die/component	High enough to fix die/component
Process	Vacuum soldering with reducing gas	Vacuum soldering with reducing gas

BOSCH Heraeus

COMPARISION DIFFUSION SOLDERING WITH OTHER DIE ATTACH PROCESSES

Printing Cu-Paste

Drying

Printing solder paste

Pick and place

Soldering with reducing gas

Printing Solder paste

Pick and place

Soldering

Printing Cu-Paste

Drying

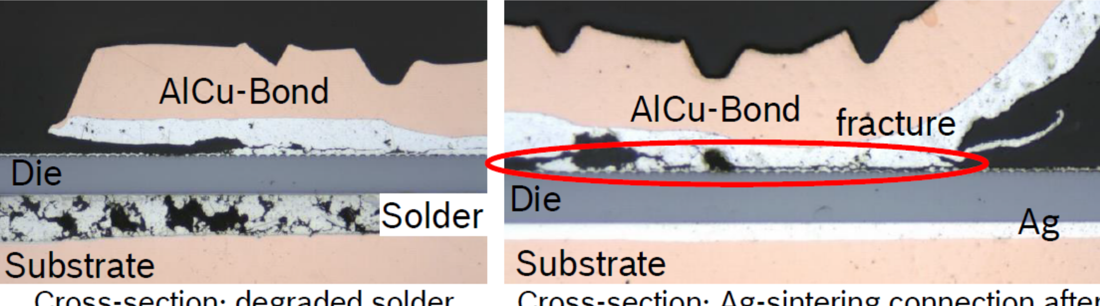
Pick and place

Pressure sintering

RELIABILITY OF DIFFUSION SOLDERING

Performance – Power cycling results

- Solder materials failure around 25 k cycles
  - R_{th}-drift due to solder degradation
  - No significant improvement with SnSb5-solder
- Ag-Sintering and HotPowCon
  - 10 fold lifetime increase towards soldering
  - No failure in die attach materials (Bond failure)
  - Significant deviation between Ag-sintering and HPC
- Starting Conditions
  - Higher system Rth of Ag-Sinter samples
  - Lower currents due to temperature controlled testing



Cross-section: degraded solder connection after power cycling

Cross-section: Ag-sintering connection after power cycling with bond failure.

Die-attach	avg. cycles till failure	Failure mode
SnAgCu305	25 k	Die-attach failure
SnSb5	26 k	Die-attach failure
Sinter-Ag	364 k	Bond failure
HotPowCon	273 k	Bond failure

© Robert Bosch GmbH 2017. All rights reserved, also regarding any disposal, exploitation, reproduction, editing, distribution, as well as in the event of applications for industrial property rights.

CONCLUSION

- For the future IGBT technology with higher junction temperature new joining materials are needed
- A possibility of such a material is the forming of a IMC of Cu Sn Alloys (Cu_6Sn_5,Cu_3Sn) which are formed by isothermal soldification
- lateral infiltration of a Cu Pastes and Sn Pastes are needed to produce these joints.
- The formation of the IMCs in the joint are dependent on the Cu-Paste system (PSD of the Cu-Powder)
- It is possible to infiltrate a area until 100 mm^2 this is also dependent on the Cu-Paste system
- The process of the diffusion soldering is in comparison to the solder process and sinter process more complex but can be done with existing machines
- The reliability of the Hot Pow Con layer is comparable to Ag-sintering and is much higher than soldering

OUTLOOK

- **Diffusion soldering have high potential to be a material for IGBTs and Cu-baseplates with high joining temperature as joining material**
- **The diffusion solder process can be used as material to solder bigger areas instead of more expensive silver sintering**
- **First experience have to be collected for joining base plates**
- **The process is not fixed yet further improvements are in evaluation**
- **The vehicle system have to be improved to full fill all paste requirements**

Heraeus