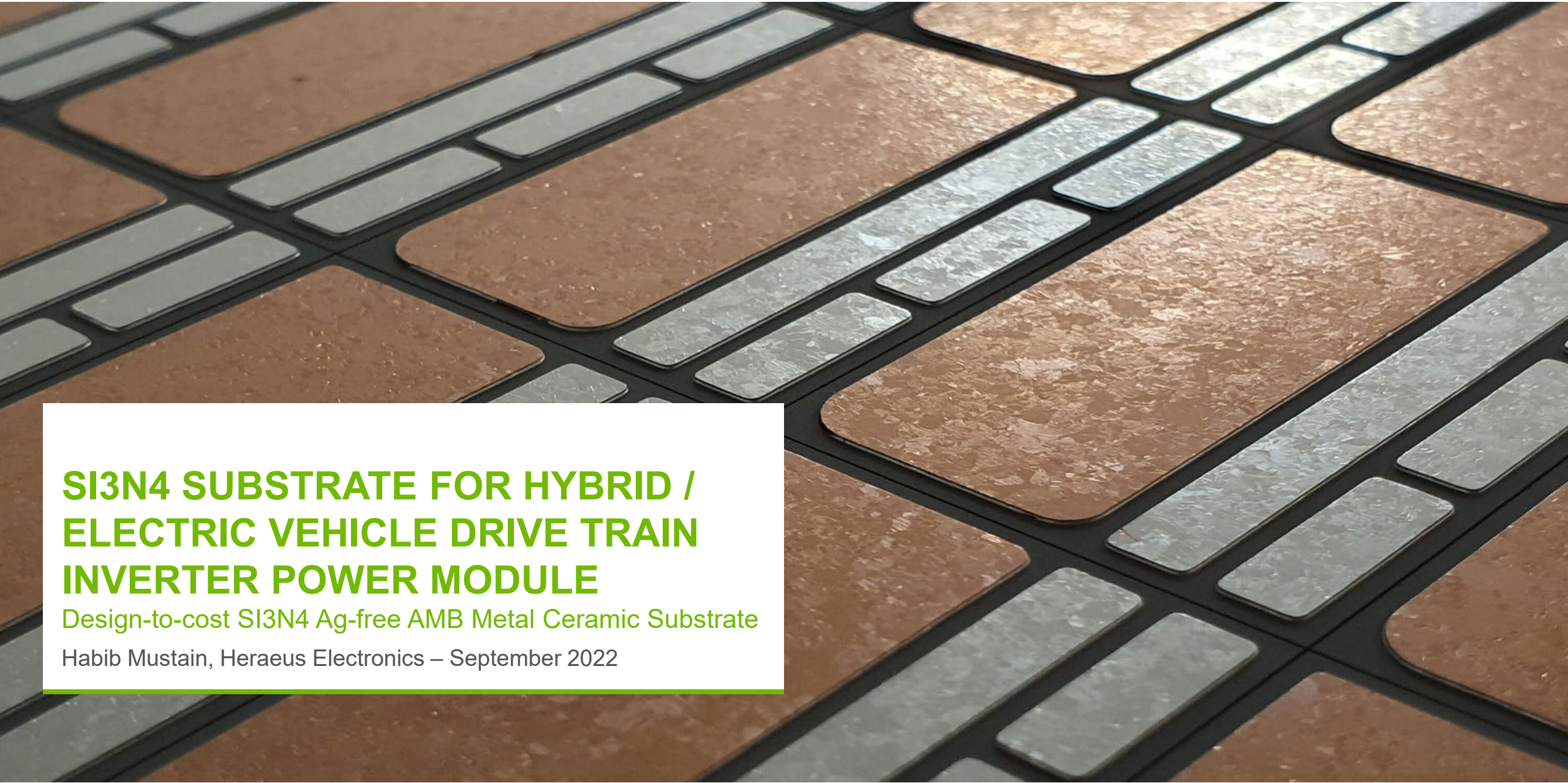
Heraeus

Electronics



SI3N4 SUBSTRATE FOR HYBRID / ELECTRIC VEHICLE DRIVE TRAIN INVERTER POWER MODULE

Design-to-cost SI3N4 Ag-free AMB Metal Ceramic Substrate

Habib Mustain, Heraeus Electronics – September 2022

OUTLINE

1 | Company overview

2 | Market trends for EV/HEV drivetrain inverter applications

3 | Power module packaging trends for automotive applications

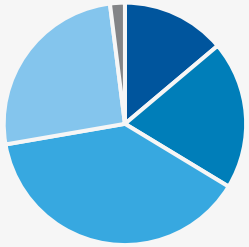
4 | Metal ceramic silicon nitride substrate

5 | Reliability results

6 | Summary

A GLOBALLY SUCCESSFUL PORTFOLIO COMPANY

29.5 bn. €
(34.9 bn. US$)
TOTAL REVENUE
in 2021



Germany 14%
Rest of Europe 20%
Asia 39%
America 26%
Africa/Australia 2%

US$ calculated with 2021 average exchange rate (1€ = 1.1827 US$)

Region breakdown based on revenues excl. Precious Metals

6% expenditures
for RESEARCH &
DEVELOPMENT

based on revenues excl. Precious Metals

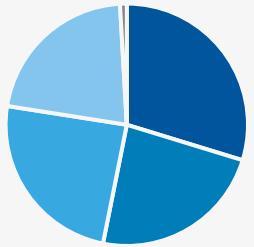
12 market-oriented
GLOBAL BUSINESS UNITS

TOP 10
FAMILY-OWNED COMPANIES
in Germany

Listed in
FORTUNE
Global **500**

More than
100 SITES in
40 COUNTRIES

Approx.
16,200
EMPLOYEES
in 2021

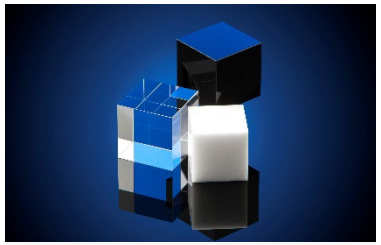


Germany 33%
Rest of Europe 16%
Asia 27%
America 24%
Africa/Australia 1%

including staff leasing

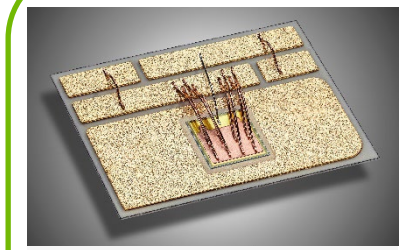
BUSINESS PORTFOLIO – LEADING IN GLOBAL MARKETS

Heraeus **Comvance**



Heraeus **Conamic**

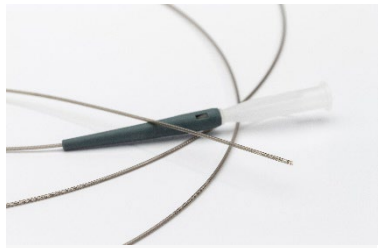
Heraeus **Electro-Nite**



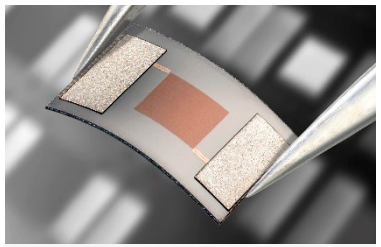
Heraeus **Electronics**

Heraeus **Epurio**

Heraeus **Medical**



Heraeus **Medical Components**



Heraeus **Nexensos**

Heraeus **Noblelight**

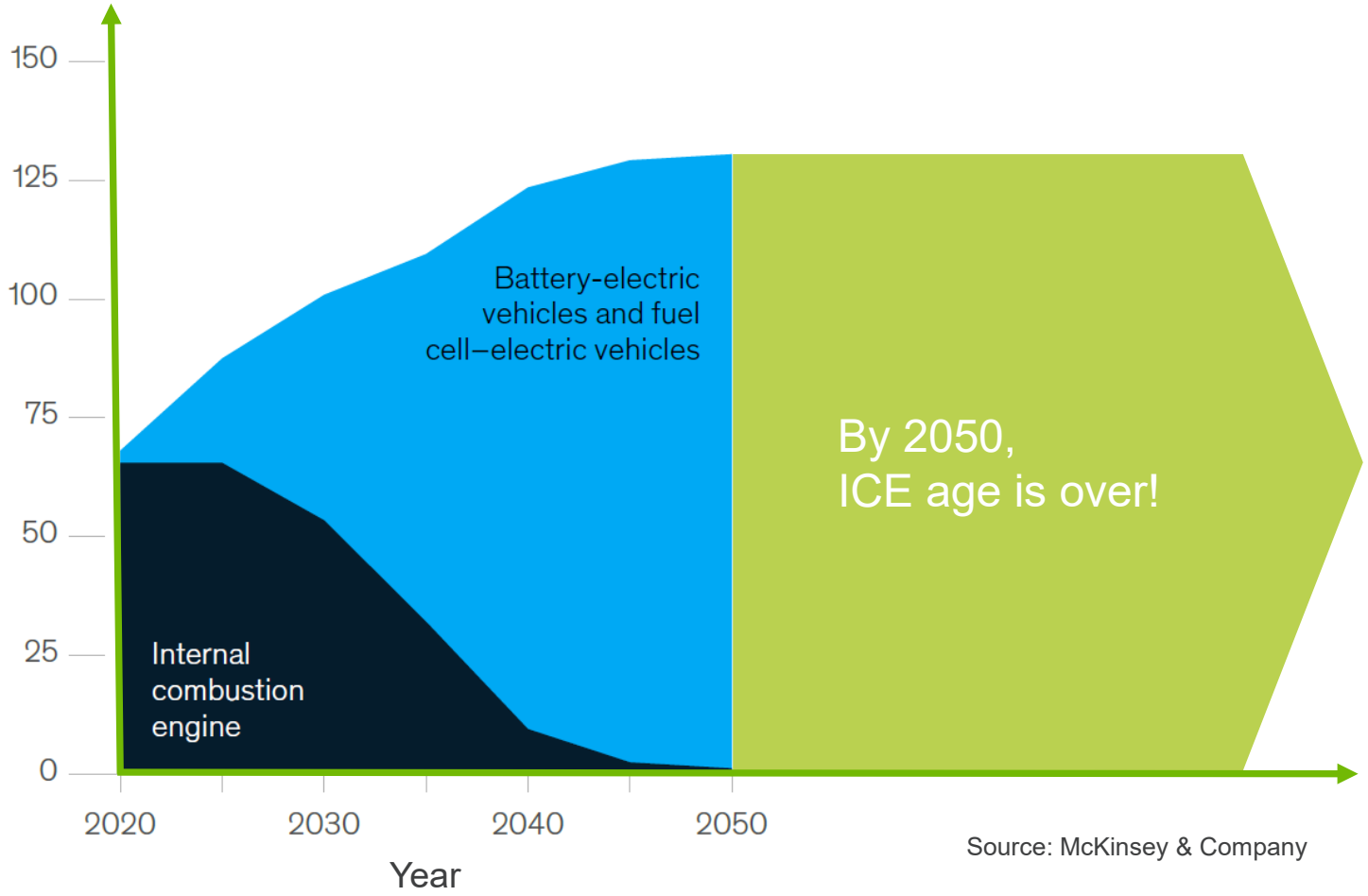
Heraeus **Photovoltaics**

Heraeus **Precious Metals**

Norwood Medical

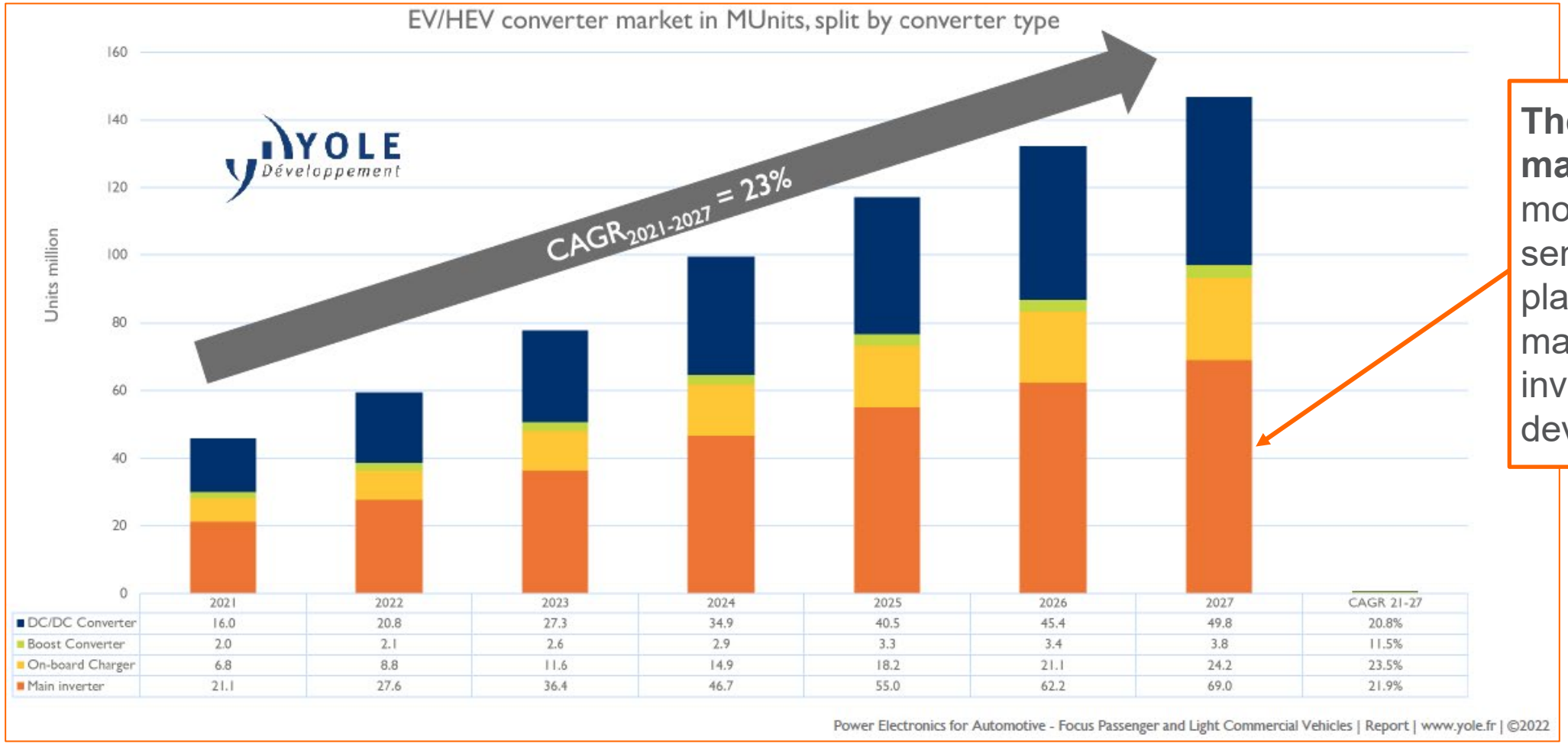
MARKET TRENDS

New cars sold
(in million units)



Source: McKinsey & Company

2021-2027 GLOBAL XEV CONVERTER MARKET SPLIT BY DEVICE TYPE



	2021	2022	2023	2024	2025	2026	2027	CAGR 21-27
DC/DC Converter	16.0	20.8	27.3	34.9	40.5	45.4	49.8	20.8%
Boost Converter	2.0	2.1	2.6	2.9	3.3	3.4	3.8	11.5%
On-board Charger	6.8	8.8	11.6	14.9	18.2	21.1	24.2	23.5%
Main inverter	21.1	27.6	36.4	46.7	55.0	62.2	69.0	21.9%

Power Electronics for Automotive - Focus Passenger and Light Commercial Vehicles | Report | www.yole.fr | ©2022

The largest market segment: most power semiconductor players focus on main drivetrain inverter development

POWER MODULE PACKAGING TRENDS IN AUTOMOTIVE APPLICATIONS

Power Module

- Many custom designs
- Technology challenges

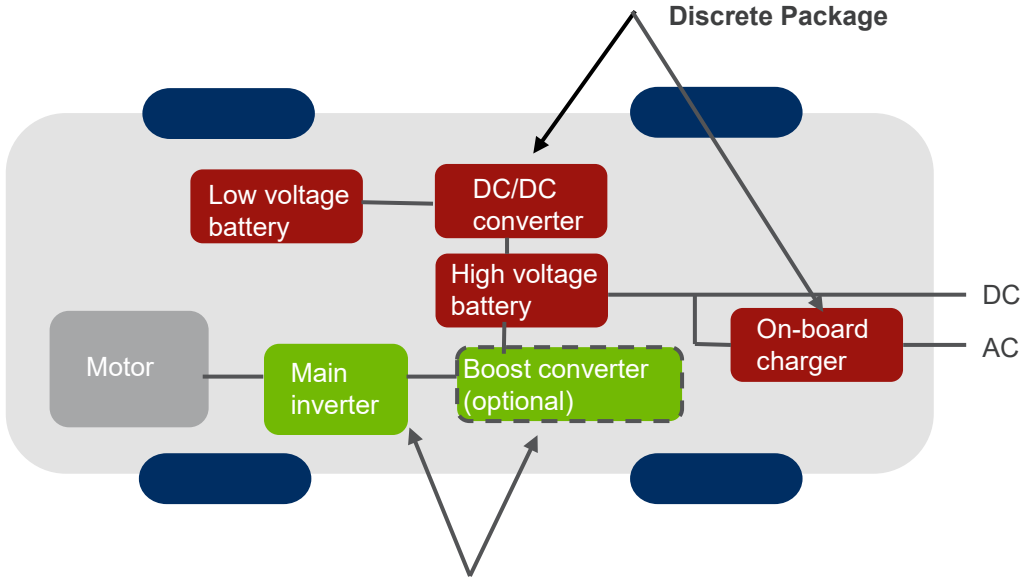
Overmolded Module

- Fewer chips in module
- Flexibility in system design and size
- Less investment
- Scalability
- Adopt discrete device supply chain, manufacturing processes and tools

Discrete Package

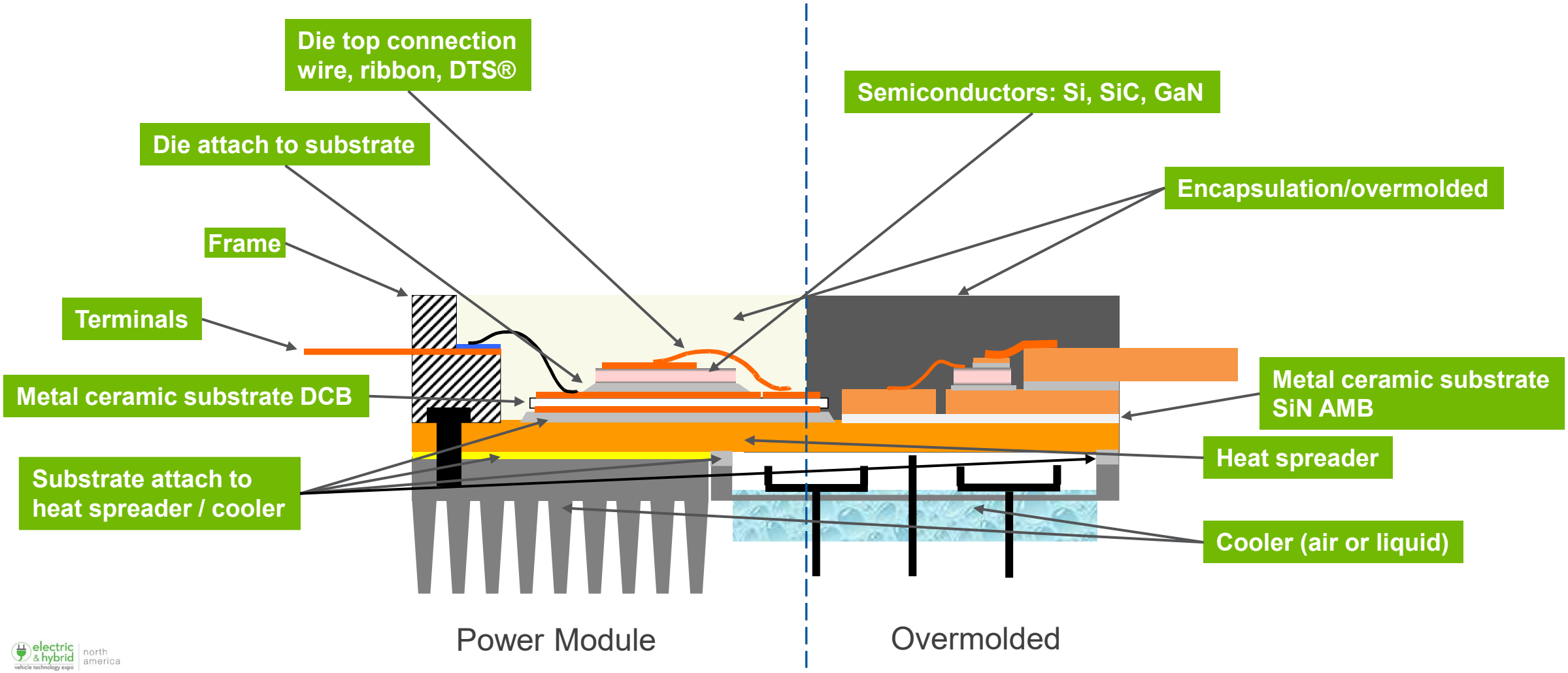
- High level of standardization
- High volume manufacturing

Battery/Hybrid Electric Vehicle



Power Module/overmolded mainly used

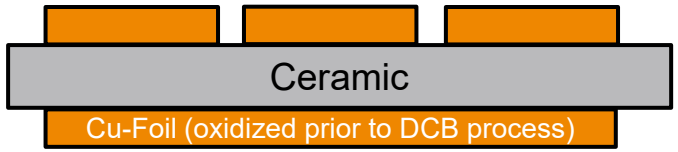
PACKAGING MATERIALS IN POWER MODULES



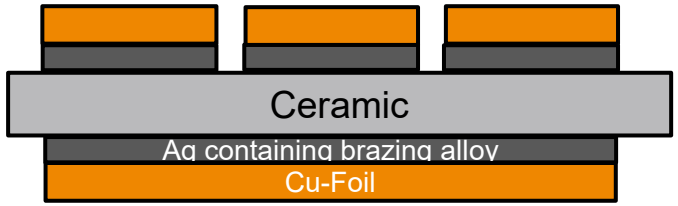
SI_3N_4 WITH OVERALL BEST PERFORMANCE, CHALLENGE: COST EFFECTIVENESS

	Al_2O_3	ZTA	Si_3N_4
Thermal conductivity	0	0	++
Bonding process (Cu)	DCB	DCB	AMB
Substrate reliability	0	+	+++
Cu layer thickness	-	0	+++
Substrate cost	+++	++	-

DCB: Direct copper bonding



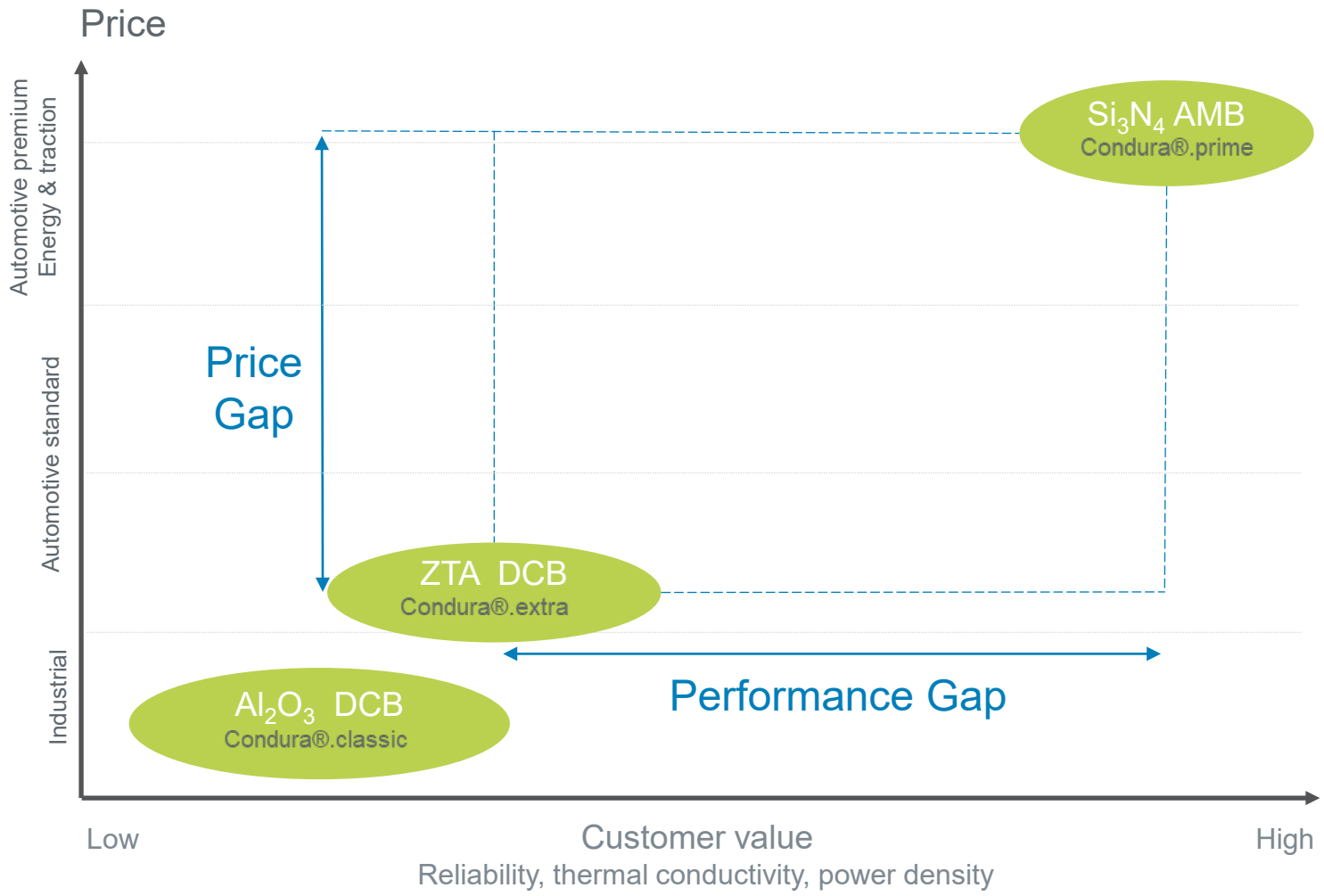
AMB: Active metal brazing



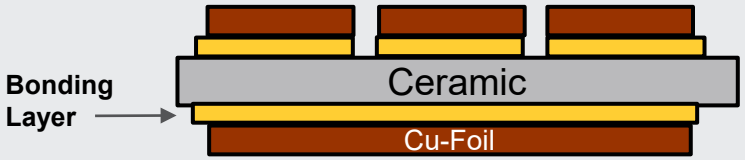
- Oxide based MCS offers sufficient reliability at moderate cost
  - Manufactured by DCB process
- Si_3N_4 based MCS are typically manufactured by AMB process using Ag based brazing pastes
- Si_3N_4 based MCS offer high reliability but cost effectiveness is a challenge
- Heraeus Electronics addresses this gap by Ag free Si_3N_4 AMB technology

Source:
Challenges of New Packaging Solutions for Power Modules, Prof. R. Eisele FH Kiel, Anton Miric HDE, PCIM Conference May 2021
Silver-free thick film copper bonding for highly reliable metal ceramic substrates, Dr. Andre Schwöbel HDE, CIPS Conference 2022

STANDARD MCS POSITIONING



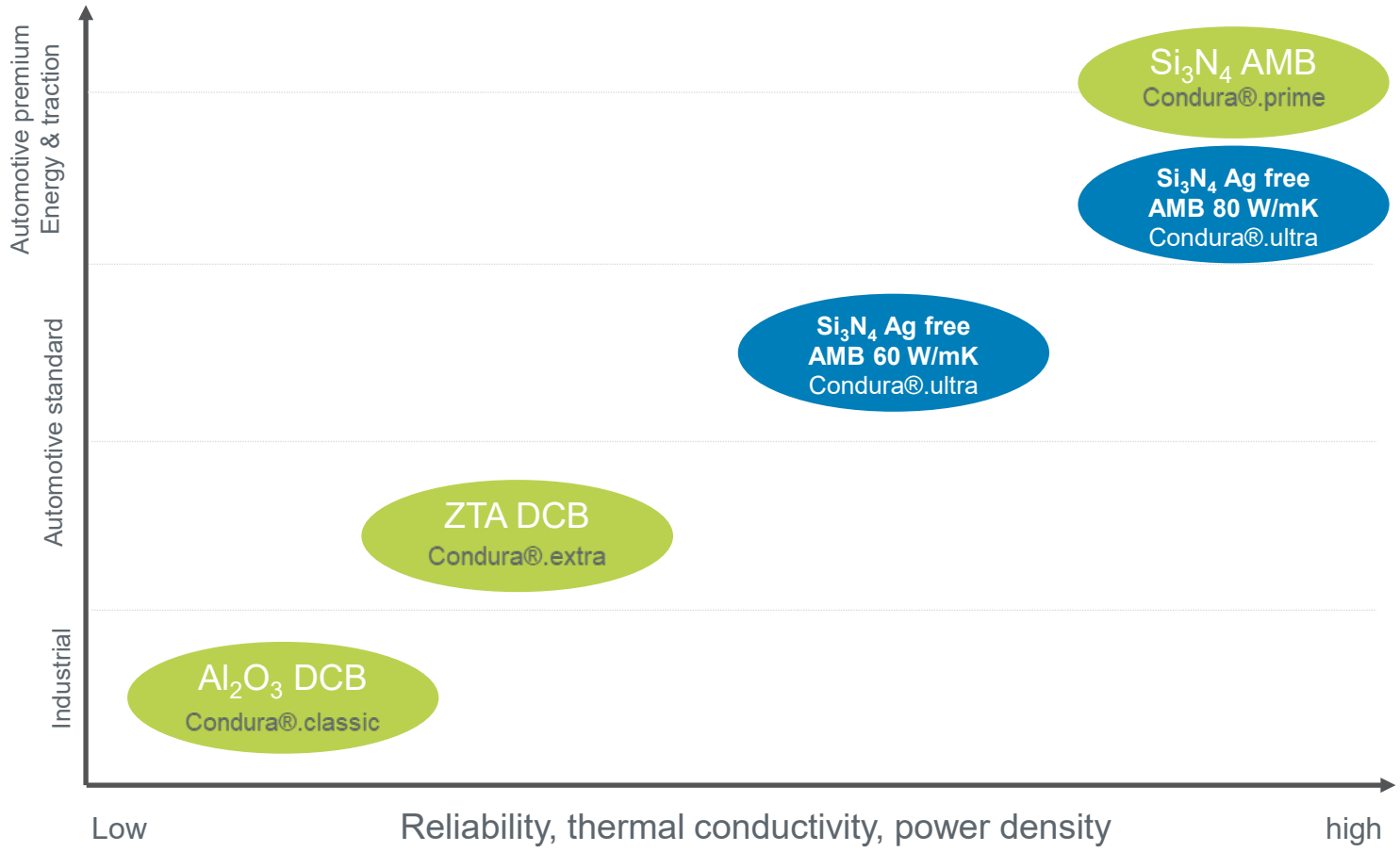
Metal ceramic substrates



▪ Al_2O_3 DCB	industrial, automotive, Si / solder
▪ ZTA DCB	automotive standard, Si / solder
▪ Si_3N_4 AMB	automotive premium, SiC / sinter

- There is a significant cost & performance gap between ZTA and Si_3N_4 AMB

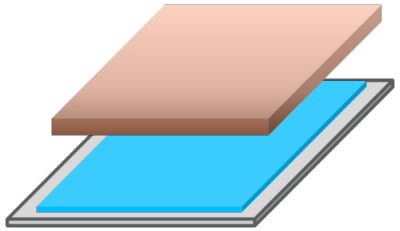
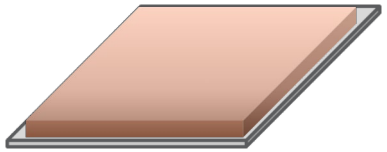
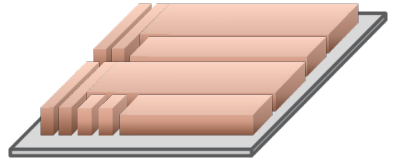
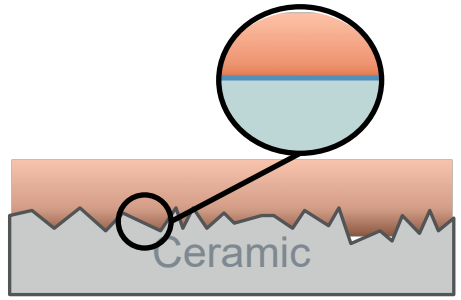
PRODUCT POSITIONING FOR Si_3N_4 AG FREE AMB®



Meeting Market Needs

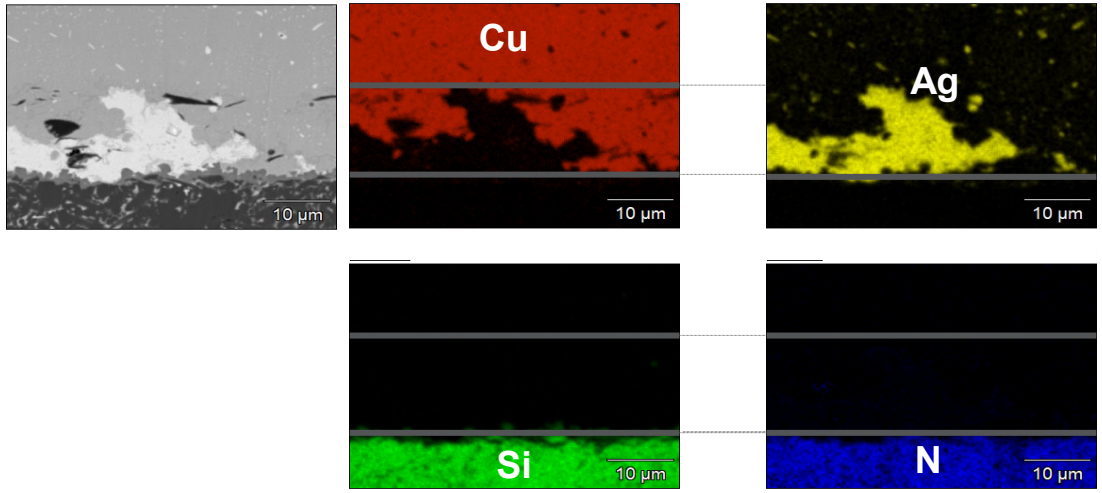
- Si_3N_4 is the ceramic material of choice for advanced metal ceramic substrates in automotive
- Si_3N_4 Ag free AMB 80 W/mK offers AMB standard performance with commercial benefits
- Si_3N_4 Ag free AMB 60 W/mK offers AMB standard performance with tailored Rth "Design to cost ceramic"

PRODUCTION OF NITRIDE CERAMIC-BASED SUBSTRATES

	Paste print and stacking	Bonding Process	Finishing	Conclusion
AMB	› Nitride ceramic printed with active metal braze paste › Copper foil stacked on both sides	› Copper and ceramic stack fired in vacuum › Long process time	› Masking and etching › Laser scribing and surface finish	› Ag-based brazing paste › Higher costs
				
Ag free AMB	Heraeus AMB Process		› Masking and etching › Laser scribing and surface finish	› Ag-free process › Reduced costs › no Ag migration Risk

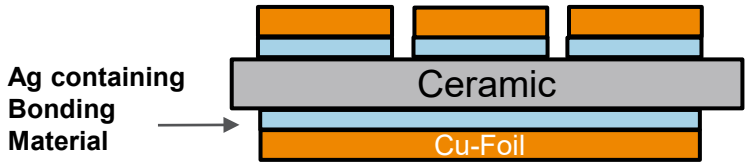
Source:
Silver-free thick film copper bonding for highly reliable metal ceramic substrates, Dr. Andre Schwöbel HDE, CIPS Conference 2022

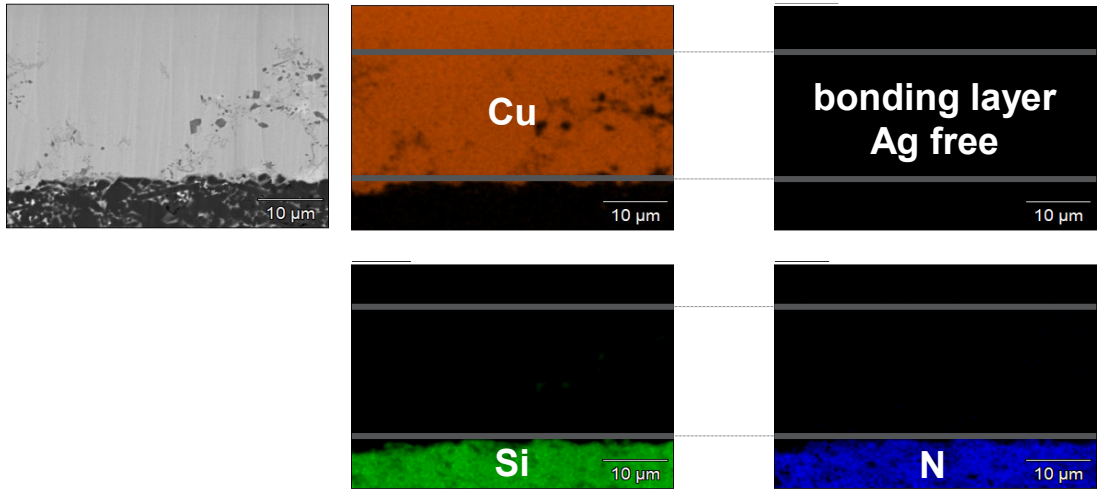
MATERIAL MAPPING EDS (ENERGY DISPERSIVE SPECTROSCOPY)



AMB STANDARD

- Typical AMB brazing pastes contain >60 weight % Ag



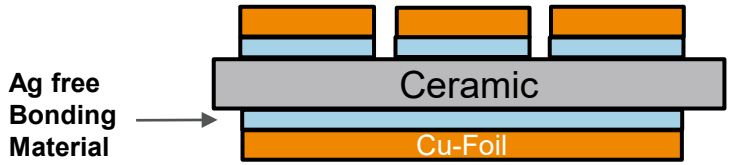


!

NEW BONDING TECHNOLOGY

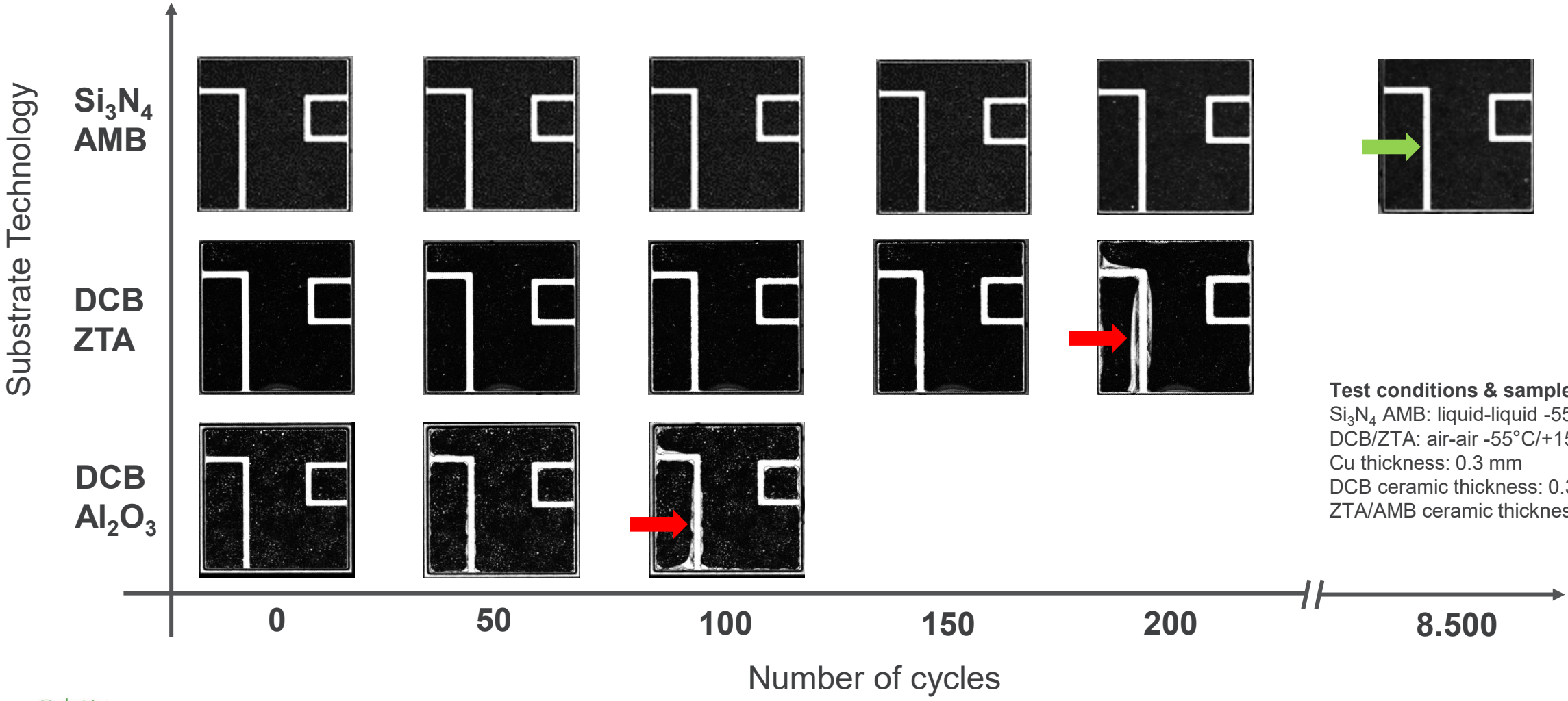
- Bonding material is **Ag-free**

  Effect: reduce costs / avoid Ag-migration



Source: Challenges of New Packaging Solutions for Power Modules, Prof. R. Eisele FH Kiel, Anton Miric HDE, PCIM Conference May 2021

SAM EVALUATIONS OF VARIOUS MCS TYPES AFTER THERMAL CYCLING

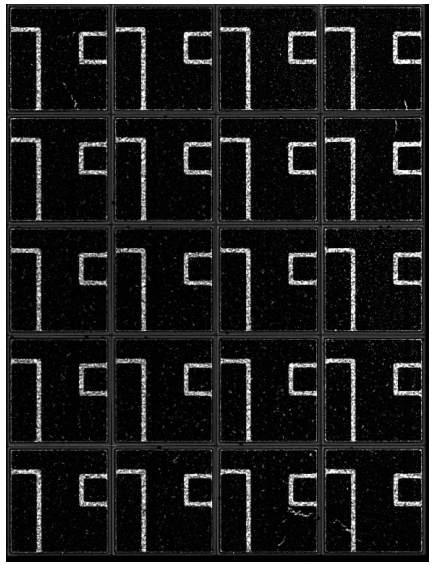


Test conditions & sample geometry
Si_3N_4 AMB: liquid-liquid -55°C/+150°C
DCB/ZTA: air-air -55°C/+150°C
Cu thickness: 0.3 mm
DCB ceramic thickness: 0.38 mm
ZTA/AMB ceramic thickness: 0.32 mm

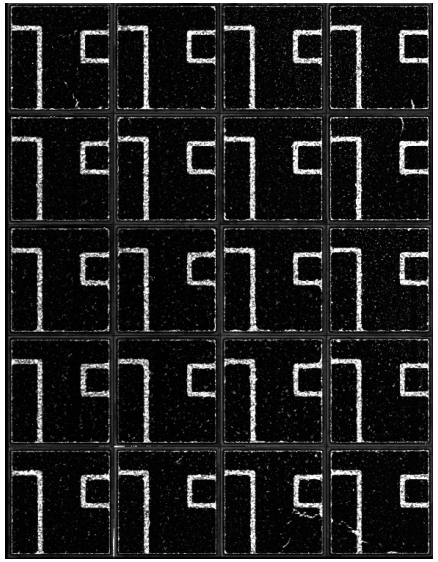
THERMAL SHOCK PERFORMANCE OF SI_3N_4 Ag FREE AMB

SAM measurements

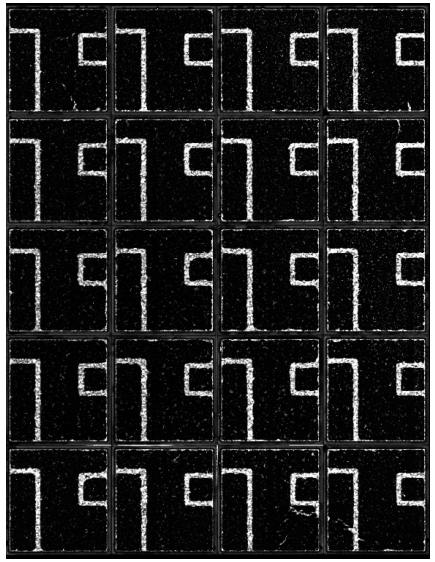
0 cycles



1000 cycles



5000 cycles



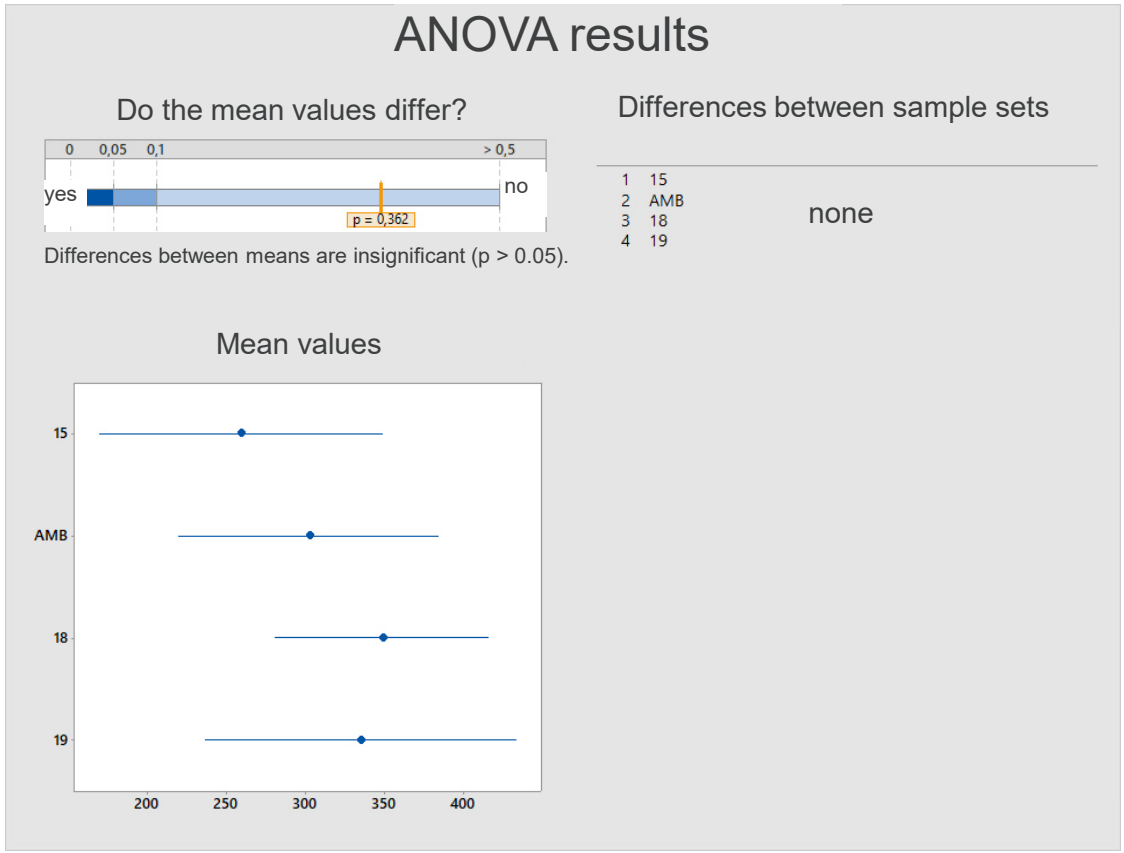
Conclusion

- No major degradation until 5000 cycles thermal shock observed.
- Si_3N_4 Ag free AMB is suitable for high reliability applications.

Material combination: 0.5 mm Cu & 0.32 mm Si_3N_4 ceramic
Test condition: -55°C/+150°C, 5 min dwell time

POWER CYCLING: COMPARISON STANDARD AND AG FREE AMB

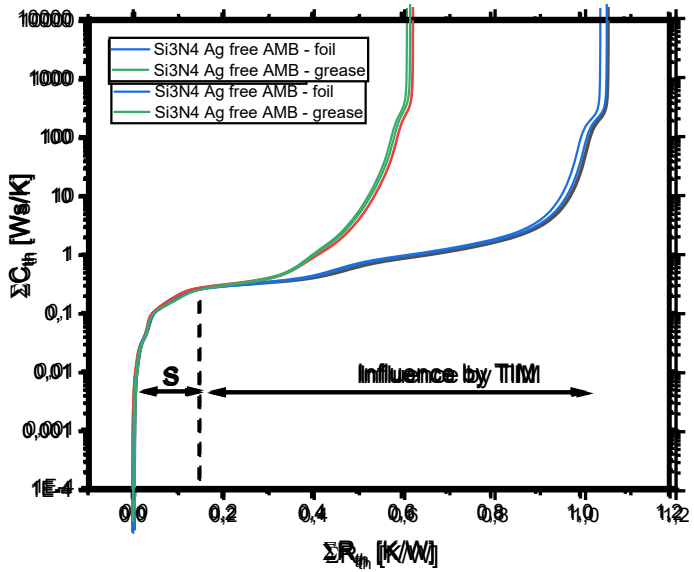
- IISB layout (0.5 / 0.32 / 0.5)
- Die (SKCD81) sintered with ASP338-28, based plate soldered
- CucorAL 0,3mm;
- dT=85K; Pcmin (ton 7 s)
- **No significant difference observed in power cycling compared with standard AMB**



SI_3N_4 Ag FREE AMB – THERMAL PERFORMANCE – R_{TH} ASSESSMENT

Initial status - R_{th}

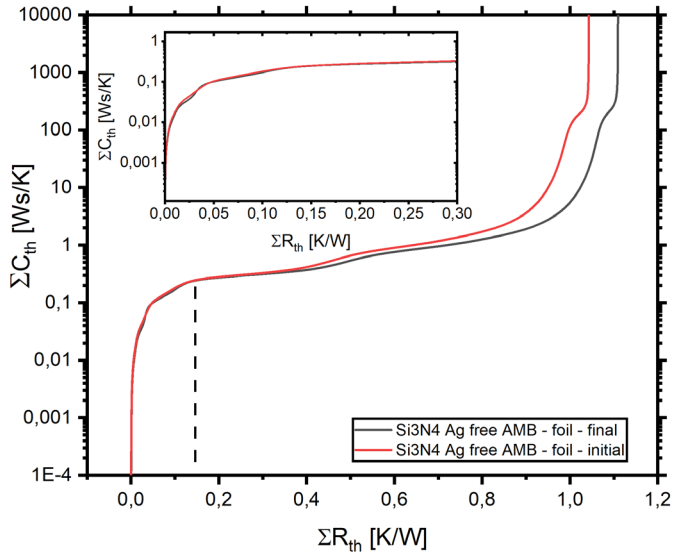
- R_{th} assessed by Transient Dual Interface methodology.
- Cooling curve measurement of MCS with sintered diode and different TIMs.
- Point of divergence indicates R_{th} of assembly without TIM.



S = metal ceramic substrate

After HTS - R_{th}

- Substrates were aged by high temperature storage (HTS)
  - 1000h
  - 175°C

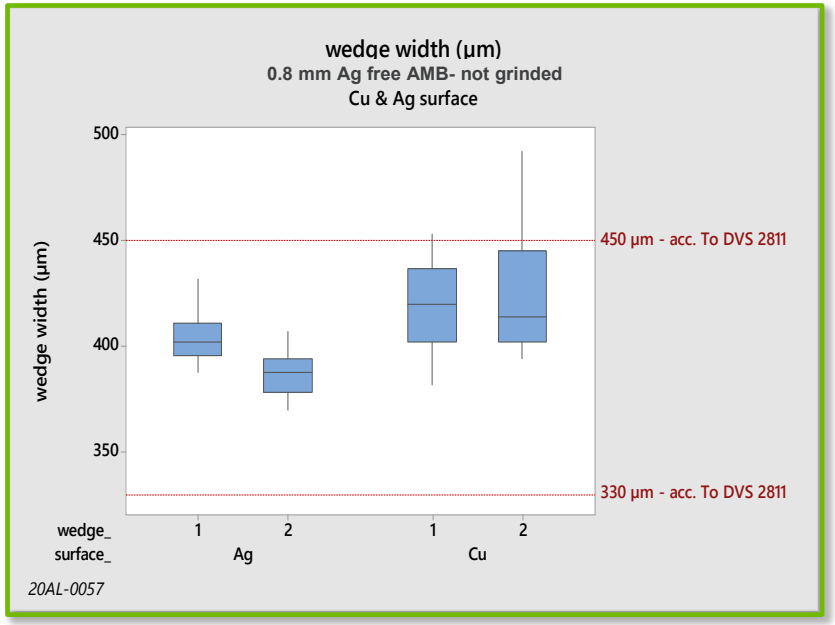


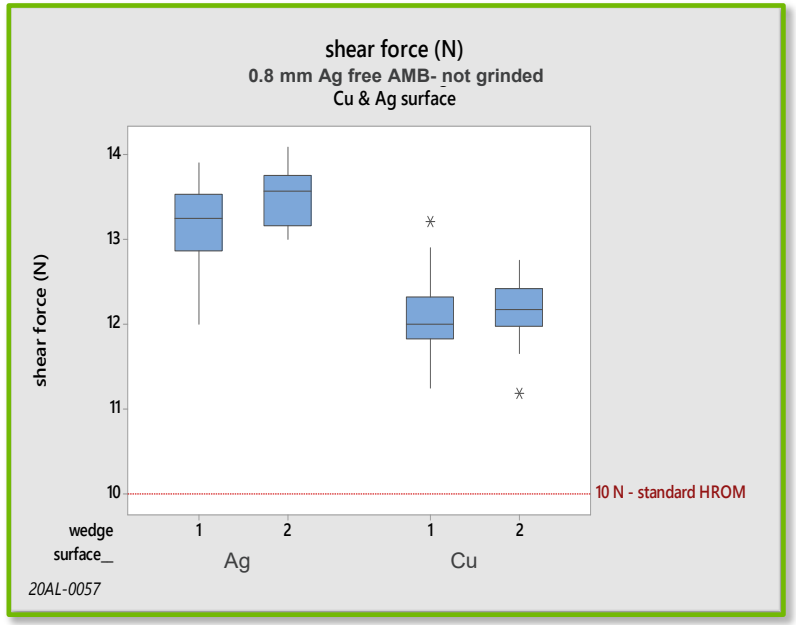
Conclusion

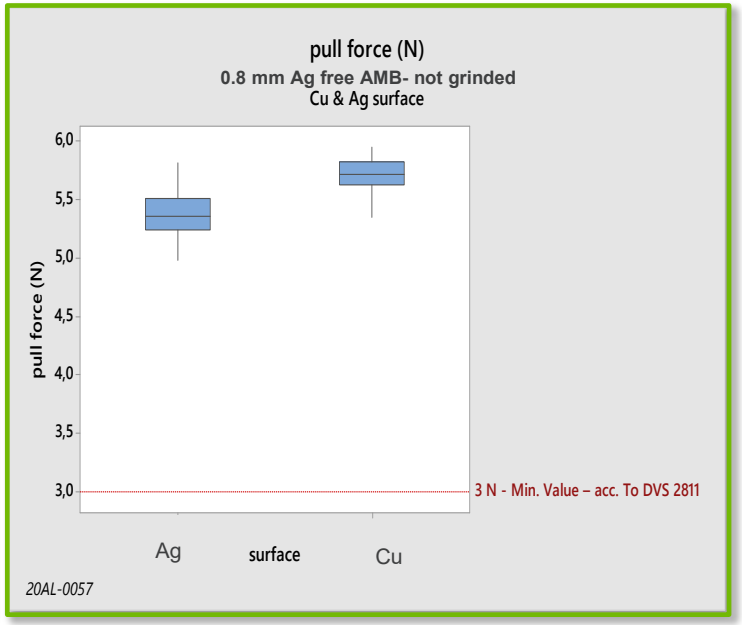
- No difference in R_{th} between our reference Si_3N_4 AMB and Si_3N_4 Ag free AMB.
- HTS does not induce a change in R_{th} on Si_3N_4 Ag free AMB substrates.

SI_3N_4 Ag FREE AMB – WIRE BONDABILITY

- IISB layout (0.5 / 0.32 / 0.5)
- Wire: 300µm Al-H11
- Tool: 127 153 - 12B Standard
- Shear test (XYZTEC) 1000µm shear tool / Pull test (XYZTEC) 600µm hook
- **All in spec**



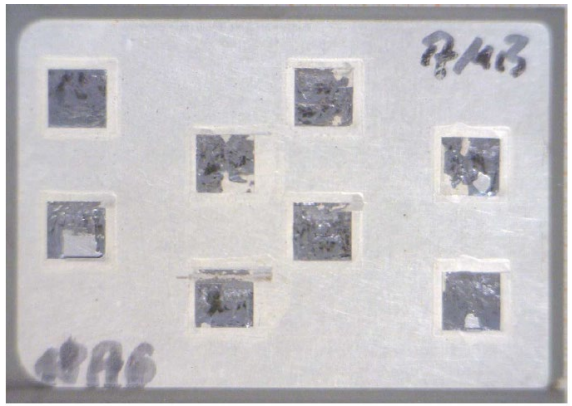


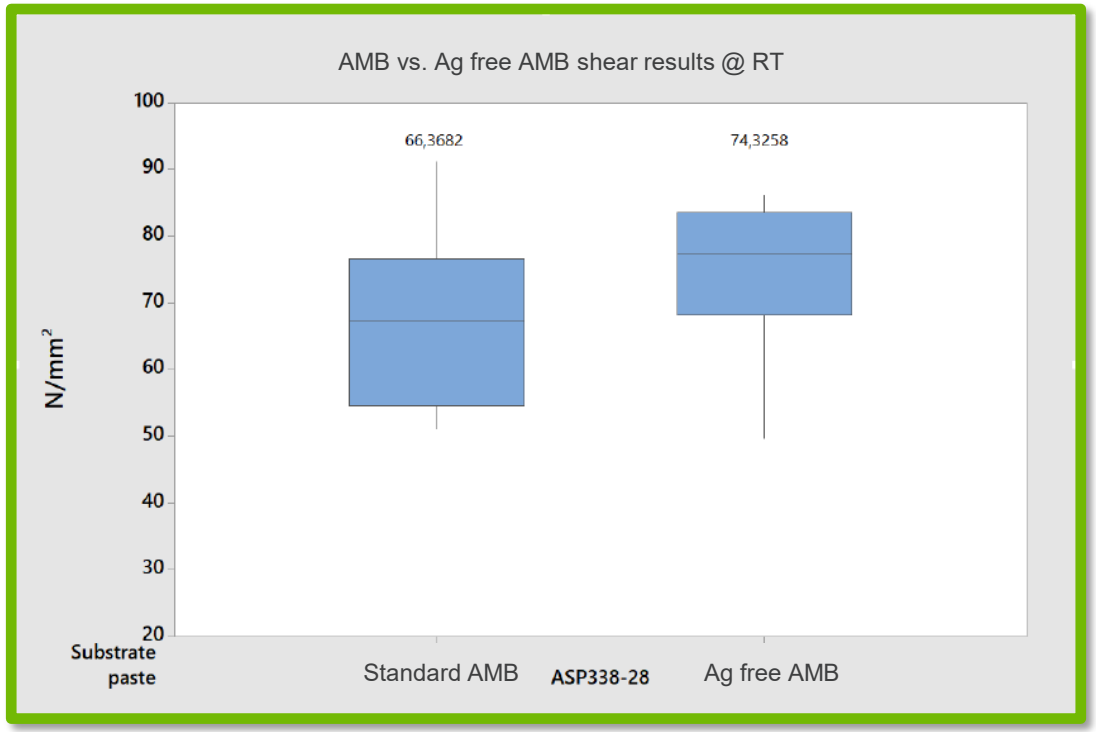


SI_3N_4 Ag FREE AMB – SINTERABILITY

- IISB layout (0.5 / 0.32 / 0.5)
- Paste: ASP338-28
- Diode: SKCD16 (4x4x0.24 mm) Ag metallization
- Pressure: 20 MPa; Time 5 min

- **No significant difference observed compared with AMB in shear force and failure mode (mixed failure mode.**

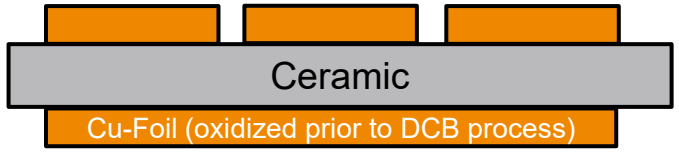




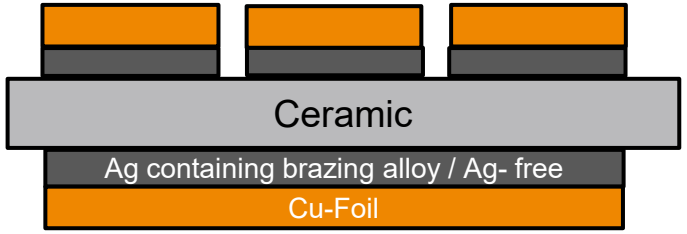
FINAL COMPARISON MCS SUBSTRATE PORTFOLIO

	Al_2O_3 Condura®.classic	ZTA Condura®.extra	Si_3N_4 Condura®.prime	Si_3N_4 (80W/mK) Condura®.ultra	Si_3N_4 (60W/mK) Condura®.ultra
Thermal conductivity	+-	+-	++	++	+
Bonding process (Cu)	DCB	DCB	AMB	AMB Ag free	AMB Ag free
Substrate reliability	+-	+	+++	+++	+++
Cu layer thickness	-	+-	+++	+++	+++
Substrate cost	+++	++	-	+-	+

DCB: Direct copper bonding



AMB: Active metal brazing



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Silver-free thick film copper bonding for highly reliable metal ceramic substrates, Dr. Andre Schwöbel HDE, CIPS Conference 2022

CONDURA ®.ULTRA SI_3N_4 AG FREE AMB PRODUCT TIMELINE AND AVAILABILITY

Samples available — NOW !

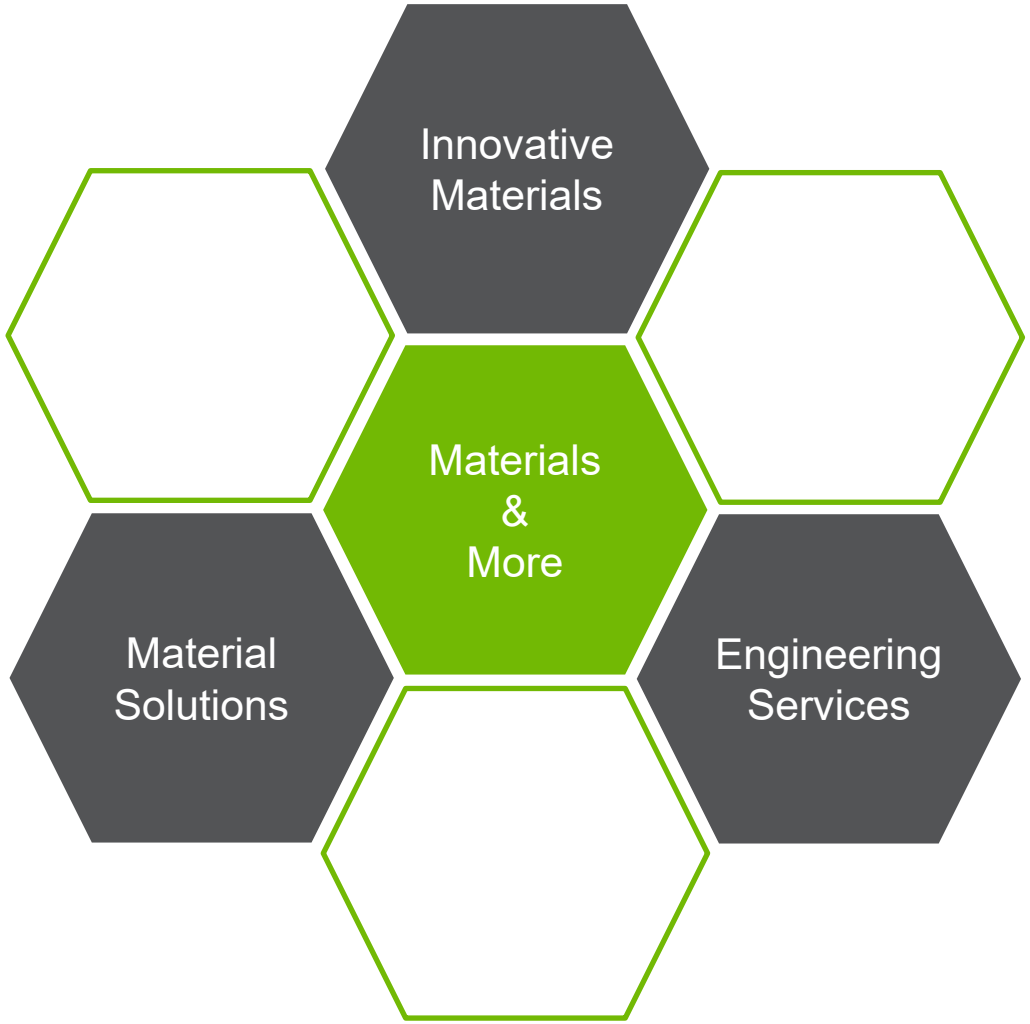
Qualification — 2022

SOP — 2023

SUMMARY

Si_3N_4 Ag free AMB fully levers the advantages of the highly reliable Si_3N_4 ceramics:

- Si_3N_4 Ag free AMB shows similar thermal cycling capability as AMB
- No difference in R_{th} vs Si_3N_4 AMB
- No influence by HTS
- No risk of Ag migration
- Same processability as Si_3N_4 AMB (confirmed by lead customers)



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habib.mustain@heraeus.com