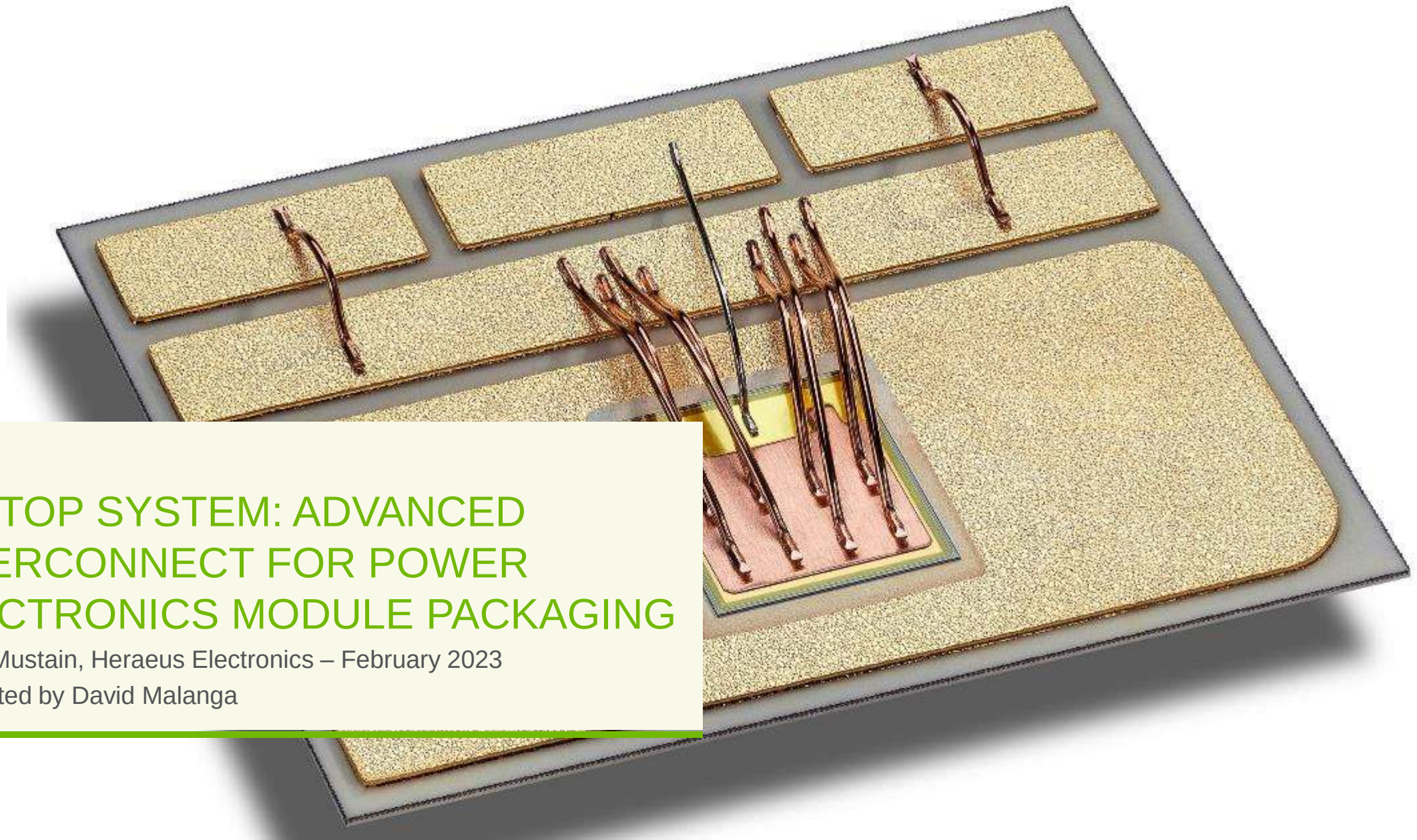
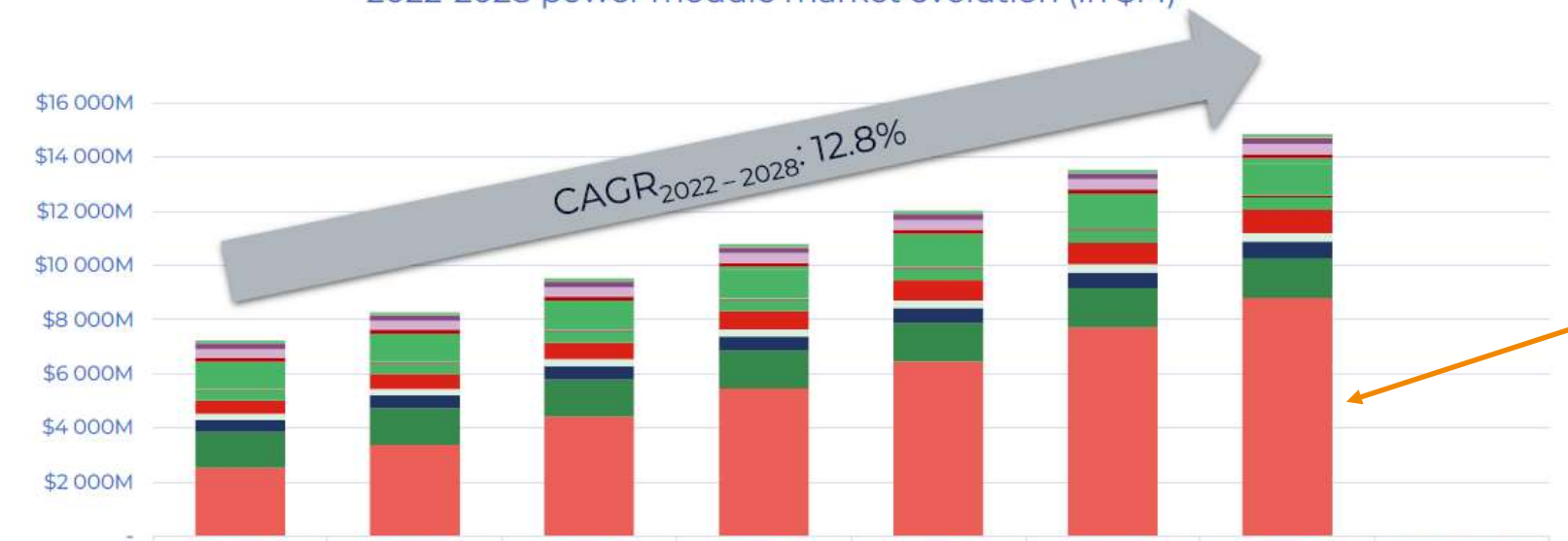


DIE TOP SYSTEM: ADVANCED INTERCONNECT FOR POWER ELECTRONICS MODULE PACKAGING

Habib Mustain, Heraeus Electronics – February 2023
Presented by David Malanga

OUTLINE

POWER MODULE MARKET SIZE, IN $M



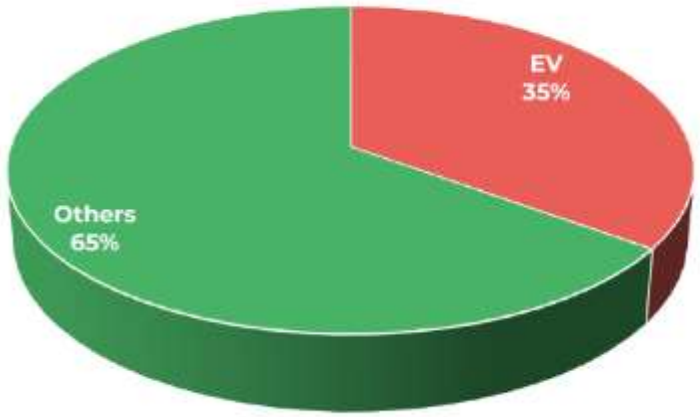
	2022	2023	2024	2025	2026	2027	2028	CAGR 2022-2028
Others	$104 M	$108 M	$112 M	$114 M	$119 M	$122 M	$125 M	3,1%
BESS	$3 M	$4 M	$5 M	$7 M	$9 M	$11 M	$14 M	28,1%
Automotive	$201 M	$201 M	$202 M	$202 M	$205 M	$210 M	$213 M	1,0%
HVDC	$322 M	$336 M	$351 M	$361 M	$372 M	$382 M	$392 M	3,4%
Medical	$147 M	$150 M	$146 M	$146 M	$146 M	$146 M	$146 M	-0,1%
EV_DC_Chargers	$31 M	$44 M	$65 M	$96 M	$135 M	$183 M	$225 M	39,4%
Home_appliances	$969 M	$1 002 M	$1 039 M	$1 072 M	$1 104 M	$1 127 M	$1 157 M	3,0%
Consumer	$19 M	$17 M	$17 M	$16 M	$16 M	$15 M	$14 M	-4,3%
Telecom	$38 M	$40 M	$43 M	$45 M	$48 M	$50 M	$53 M	5,7%
Rail	$376 M	$383 M	$395 M	$405 M	$421 M	$441 M	$457 M	3,3%
Wind	$503 M	$556 M	$613 M	$672 M	$734 M	$800 M	$863 M	9,4%
UPS	$219 M	$235 M	$252 M	$270 M	$287 M	$304 M	$321 M	6,6%
PV	$445 M	$472 M	$493 M	$519 M	$548 M	$574 M	$601 M	5,1%
Industrial Motors	$1 326 M	$1 349 M	$1 365 M	$1 408 M	$1 429 M	$1 457 M	$1 481 M	1,9%
EV	$2 526 M	$3 379 M	$4 428 M	$5 455 M	$6 454 M	$7 713 M	$8 798 M	23,1%
Total	$7 227 M	$8 277 M	$9 526 M	$10 789 M	$12 025 M	$13 534 M	$14 860 M	12,8%

Status of the Power Module Packaging Industry 2023 | Report | www.yolegroup.com

Market growth will be driven mainly by EV/HEV

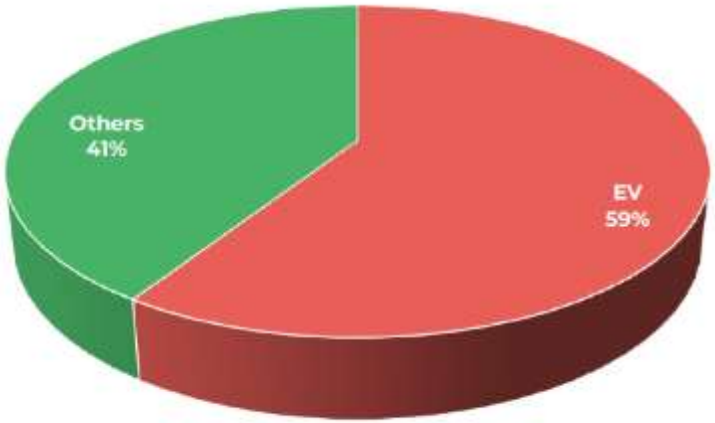
EV/HEV SHARE IN OVERALL POWER MODULE MARKET

Share represented by EV/HEV power module level as of 2022 ($M)



2022 Total:$7.2 B

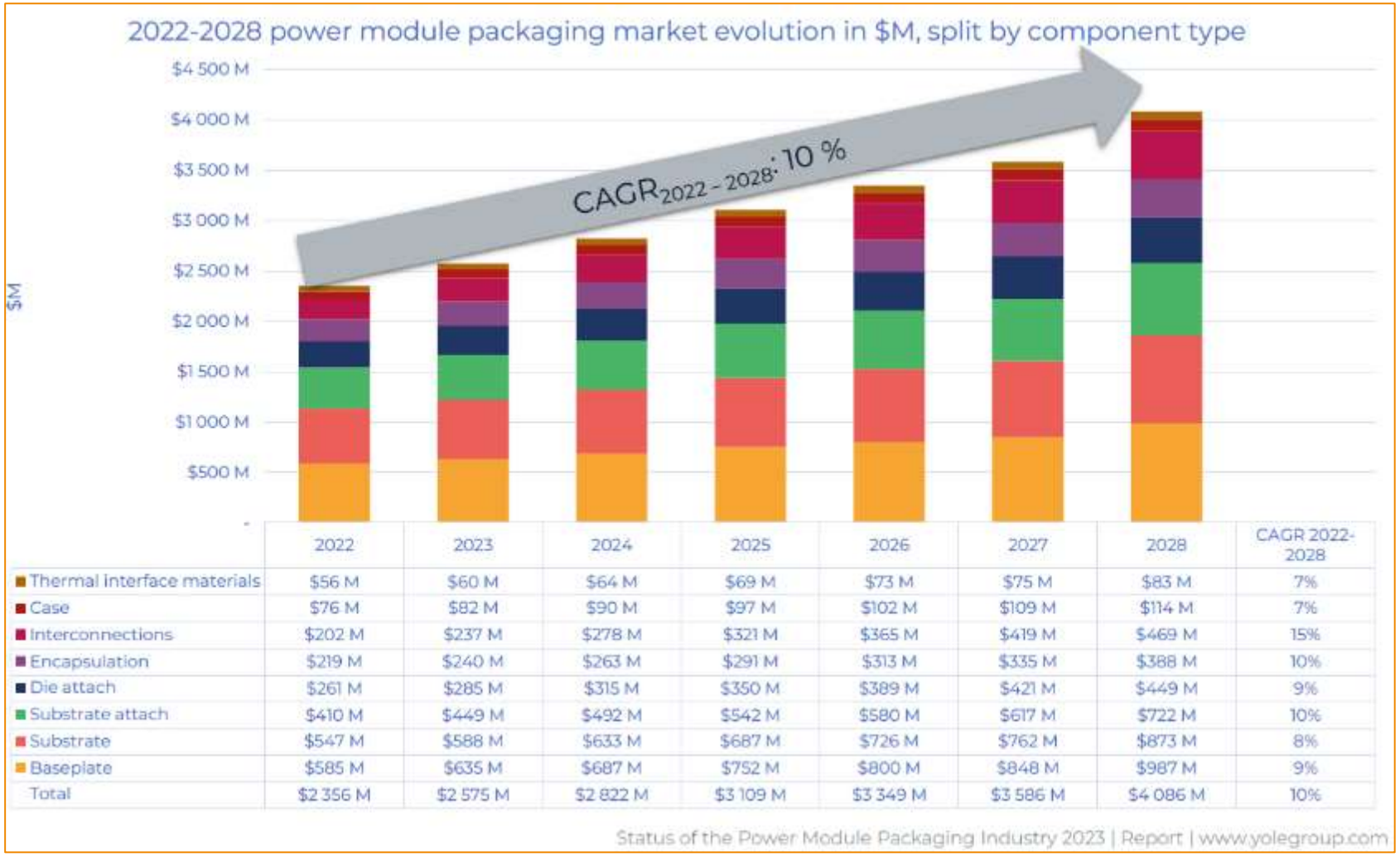
Share represented by EV/HEV power module level as of 2028 ($M)



2028 Total:$14.8 B

Courtesy of Yole

2022-2028: POWER MODULE PACKAGING MARKET SIZE: SPLIT BY COMPONENT

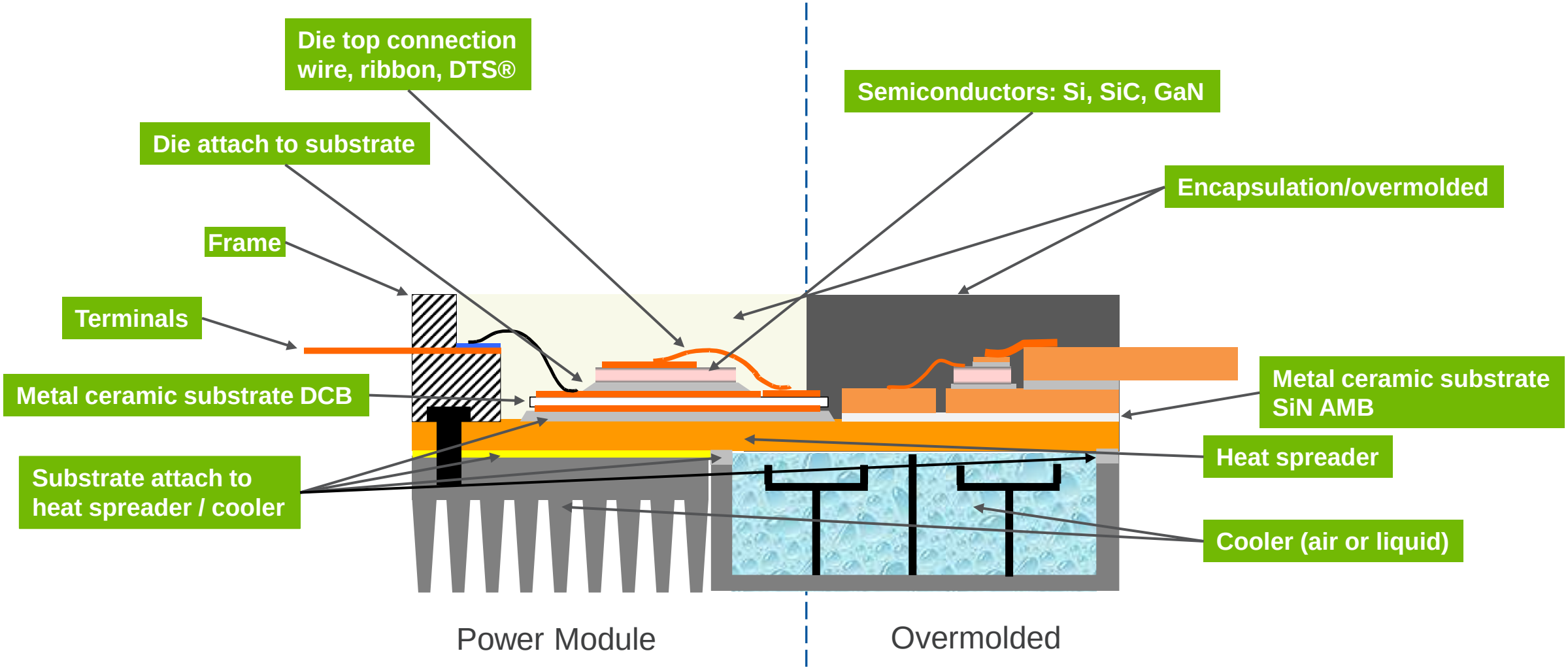


	2022	2023	2024	2025	2026	2027	2028	CAGR 2022-2028
Thermal interface materials	$56 M	$60 M	$64 M	$69 M	$73 M	$75 M	$83 M	7%
Case	$76 M	$82 M	$90 M	$97 M	$102 M	$109 M	$114 M	7%
Interconnections	$202 M	$237 M	$278 M	$321 M	$365 M	$419 M	$469 M	15%
Encapsulation	$219 M	$240 M	$263 M	$291 M	$313 M	$335 M	$388 M	10%
Die attach	$261 M	$285 M	$315 M	$350 M	$389 M	$421 M	$449 M	9%
Substrate attach	$410 M	$449 M	$492 M	$542 M	$580 M	$617 M	$722 M	10%
Substrate	$547 M	$588 M	$633 M	$687 M	$726 M	$762 M	$873 M	8%
Baseplate	$585 M	$635 M	$687 M	$752 M	$800 M	$848 M	$987 M	9%
Total	$2 356 M	$2 575 M	$2 822 M	$3 109 M	$3 349 M	$3 586 M	$4 086 M	10%

Status of the Power Module Packaging Industry 2023 | Report | www.yolegroup.com

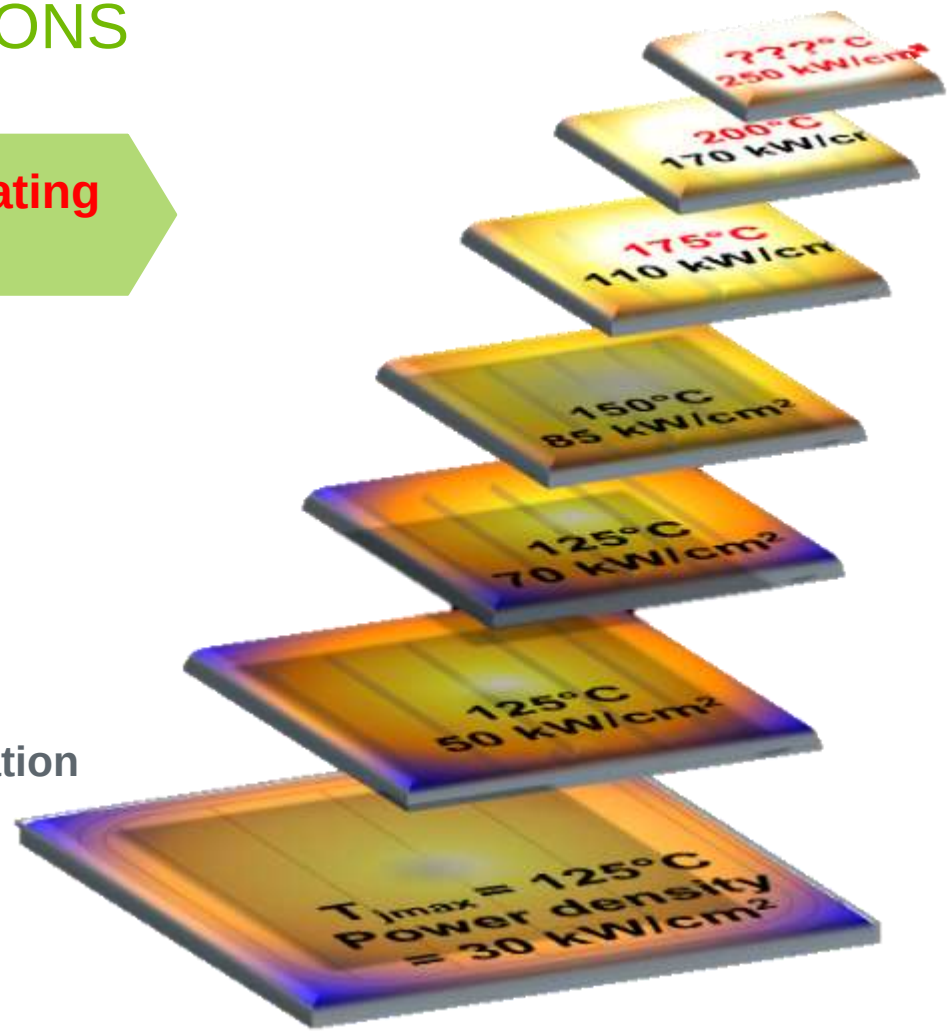
The Power module packaging market will reach almost $4.1B by 2028

PACKAGING MATERIALS IN POWER MODULES



POWER SEMICONDUCTORS AND NEED FOR NEW PACKAGING MATERIALS SOLUTIONS

Smaller and Thinner Dies → **Increased Power Density** → **Higher Operating Temperature**



Benefit through smaller dies

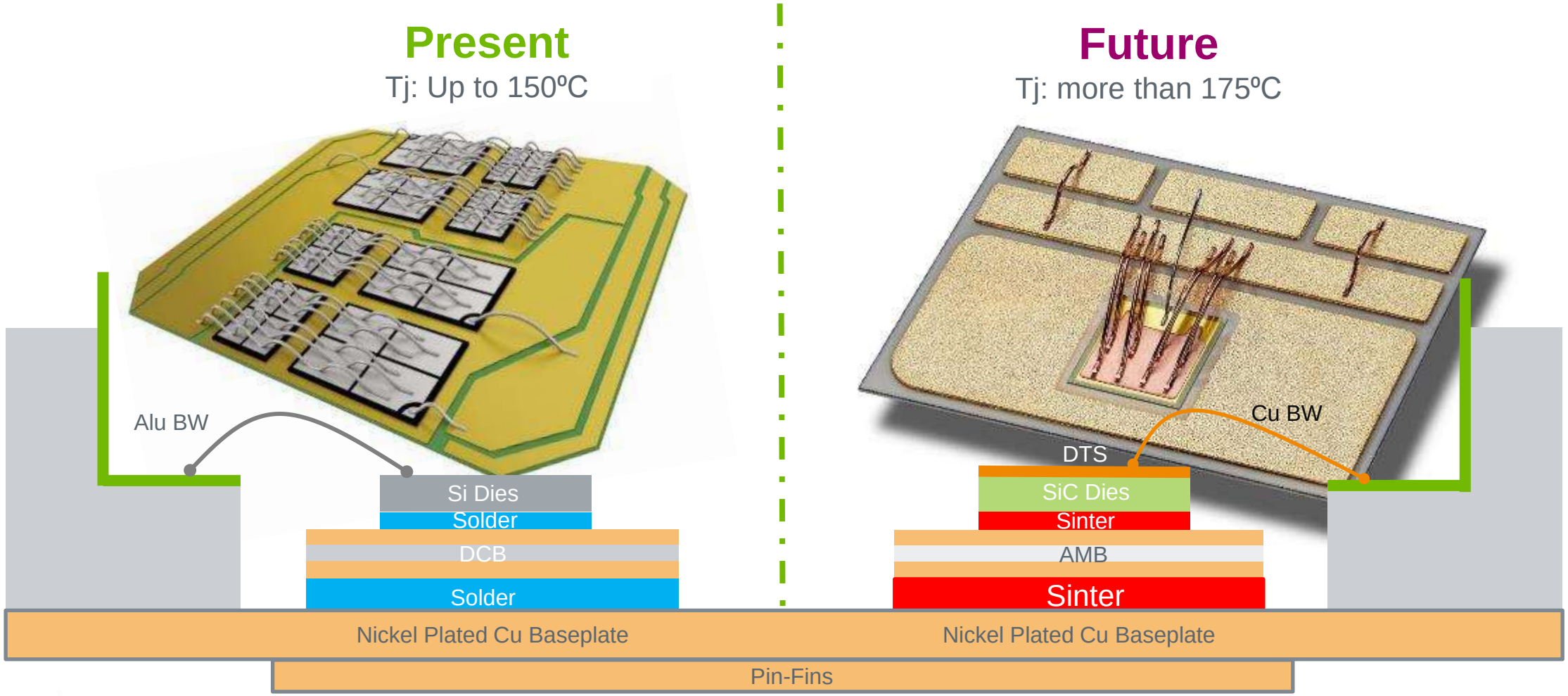
- Reduction of chip size / cost
- Lower losses / higher efficiency
- Increase of power & current density per chip

Packaging challenges

- Increased power loss per chip area requires materials with **better heat dissipation**
- More power needs better **current carrying capability** of packaging materials
- Increased operating temperatures and **reliability** challenges
- Low inductance packaging solutions for SiC/GaN Power Devices

REVOLUTION OF POWER ELECTRONICS PACKAGING

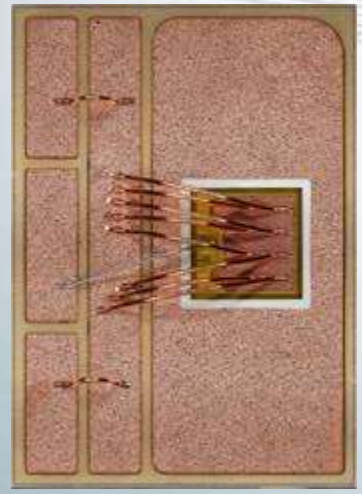
TRANSITION TO HIGH POWER DENSITY MODULE PACKAGING

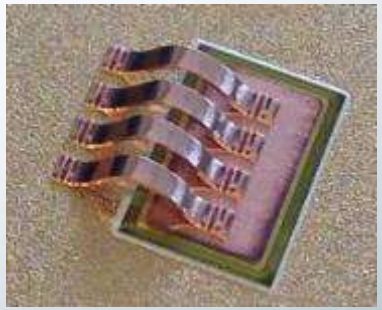


DTS® MAXIMIZES POWER DENSITY AND RELIABILITY THROUGH SUPERIOR PERFORMANCE OF SINTERING AND CU BONDING TECHNOLOGY

The Die Top System (DTS®) is a Material System consisting of:

- Copper foil with functional surfaces
- Pre-applied sinter paste
- Optional adhesive for DTS® fixation prior to sintering
- Matched copper bonding wires





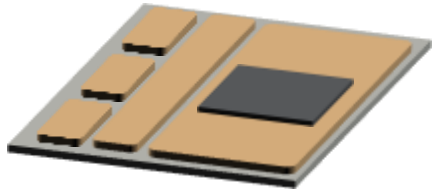
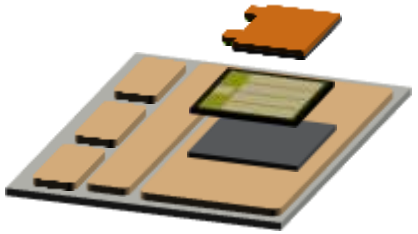
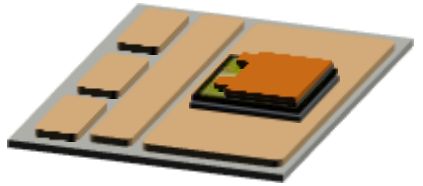
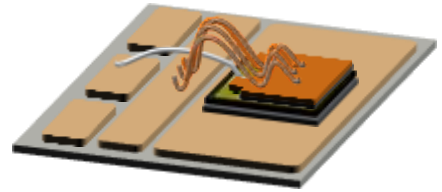
DTS® MAXIMIZES POWER DENSITY AND RELIABILITY THROUGH SUPERIOR PERFORMANCE OF SINTERING AND CU BONDING TECHNOLOGY

Key Benefits on System Level:

- Maximize power / current density
- Increase die current capability vs. Al-wire by > 50%
- Superior reliability or die shrink versus :
  - Modules with solder die attach and Al-wire
  - Modules with sinter die attach and clip solutions
- Reduced peak temperature across the die
- Compatible for high temperature semiconductors, enabling high junction temperatures of ≥200 °C

DTS® PROCESS STEPS

DIE TOP SYSTEM®

Die Attach

Substrate
- Die Attach: Printing Sinter Paste

Dry

Drying oven
- Die Attach: Dry wet sinter paste

Pick and Place

P&P from wafer
- Die on substrate
- Die Top System on die
- One machine with wafer handler or two bond heads / two machines

Sinter

Pressure Sintering
- One-step sintering: die + DTS®
- E.g. 20MPa, 5min, 250°C
- Soft tool
- Inert atmosphere, controlled cool down

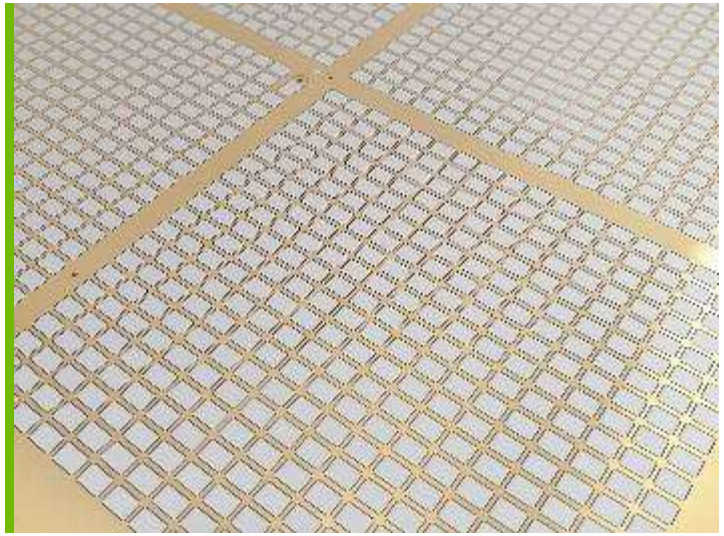
Wire Bonding

Wire Bonding
- Gate Wires
- Thick Cu wires (up to 500µm PowerCu soft)
- Or Cu ribbon (e.g. 0.2mm x 2mm)

INTRODUCING DTS® WAFER

DTS provided on wafer frames

- Top view of the 8“ taped wafer frame with singulated DTS out of a copper foil
- Number of DTS per wafer depends on the part size
  - Approx. 200 pcs to 1700 pcs



Pre-applied sinter paste

- Below view of the copper foil
- optional: fixation dot to speed up placement (Pre-Applied Adhesive – PAA)

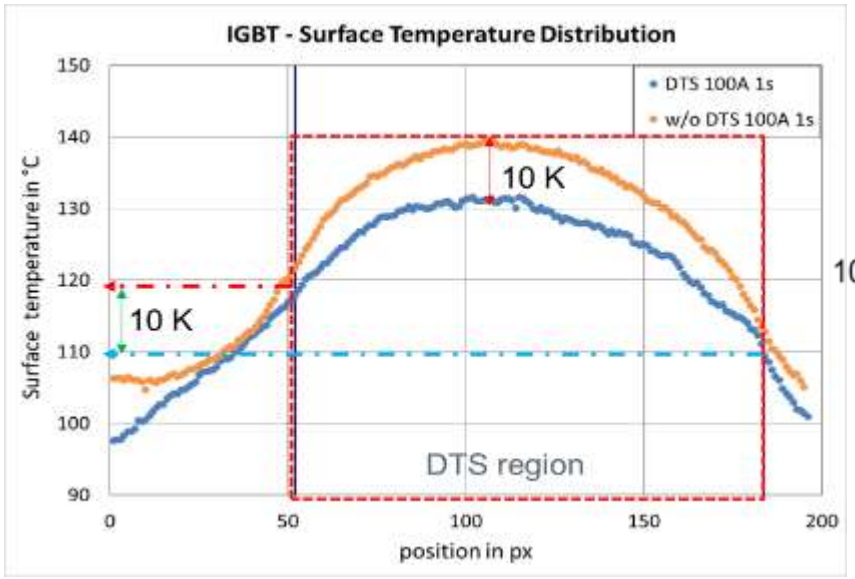
DTS wafer ready for pick & place

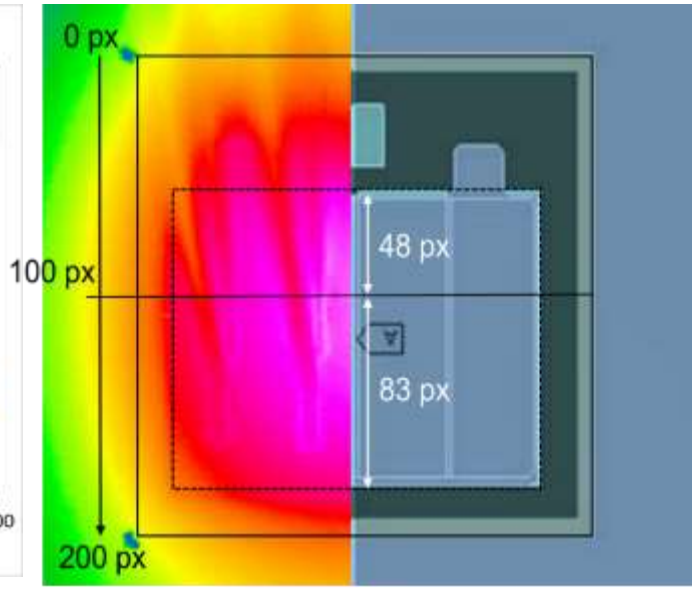
- Wafer ready for pick & place with industry standard die bonding

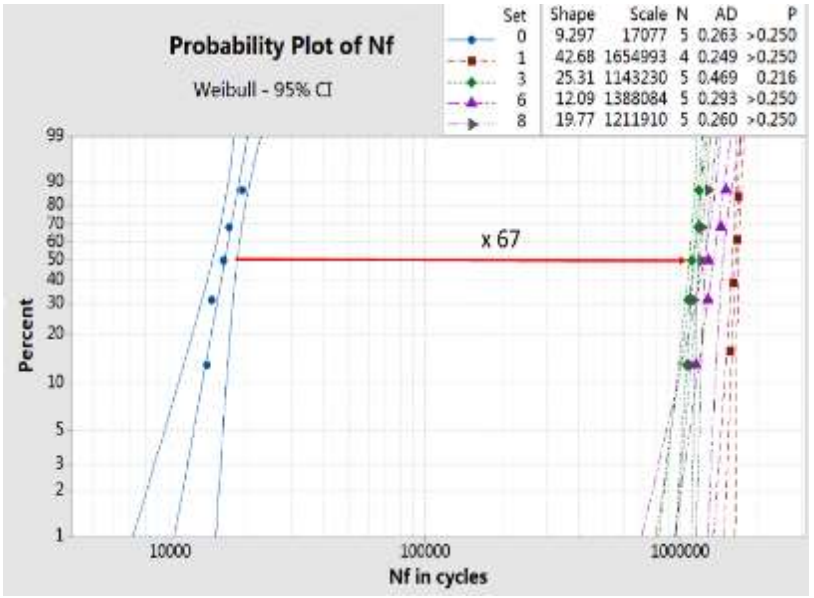
DTS® POWER CYCLING CAPABILITY

Comparison Al-wire bonded soldered die with Cu-wire bonded (DTS®) sintered die

- Homogeneous heat distribution
- Increase of lifetime by factor 67

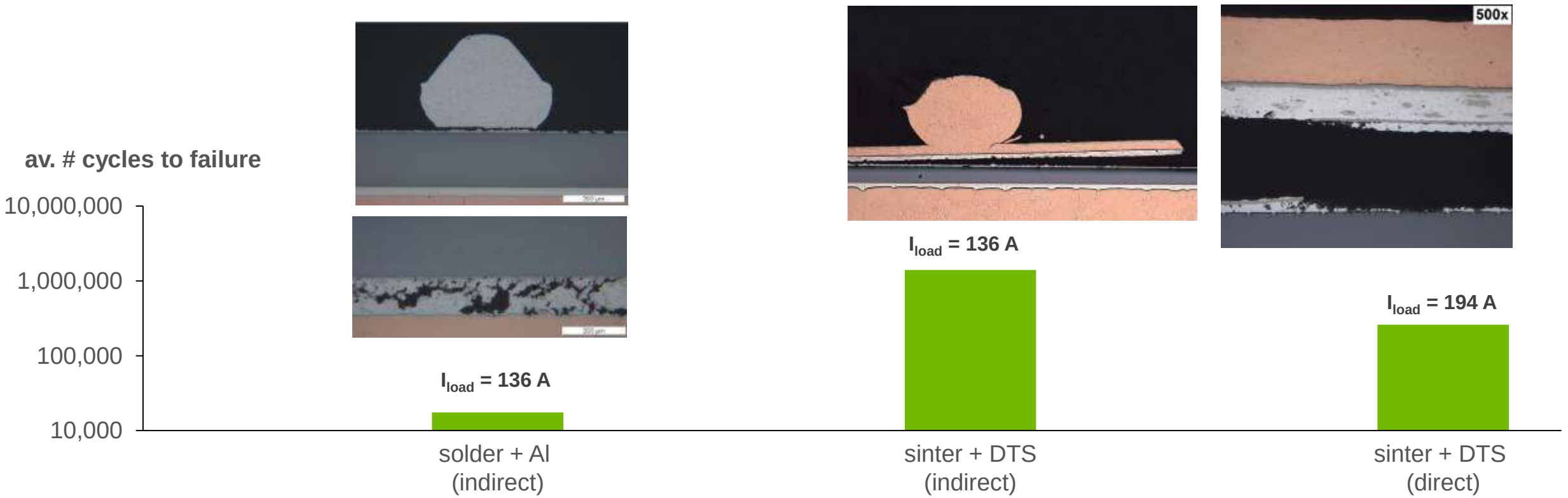






DTS® SIGNIFICANTLY INCREASES THE NUMBER OF CYCLES TO FAILURE

DTS® failure due to crack propagation in die top metallization (no die attach degradation or wire lift-off)



DIE TOP SYSTEM VS CLIP BONDING

DTS®

- Wire bonding the most common and proven interconnect technology in Electronics
- Customization to any die geometry
- Same equipment covers all layout variances from pilot to serial production
- Die bottom and top attach in one step
- Excellent proven reliability performance
- Even heat distribution during power take-up
- Use existing & known know-how and processes incl. equipment (small adaptation)

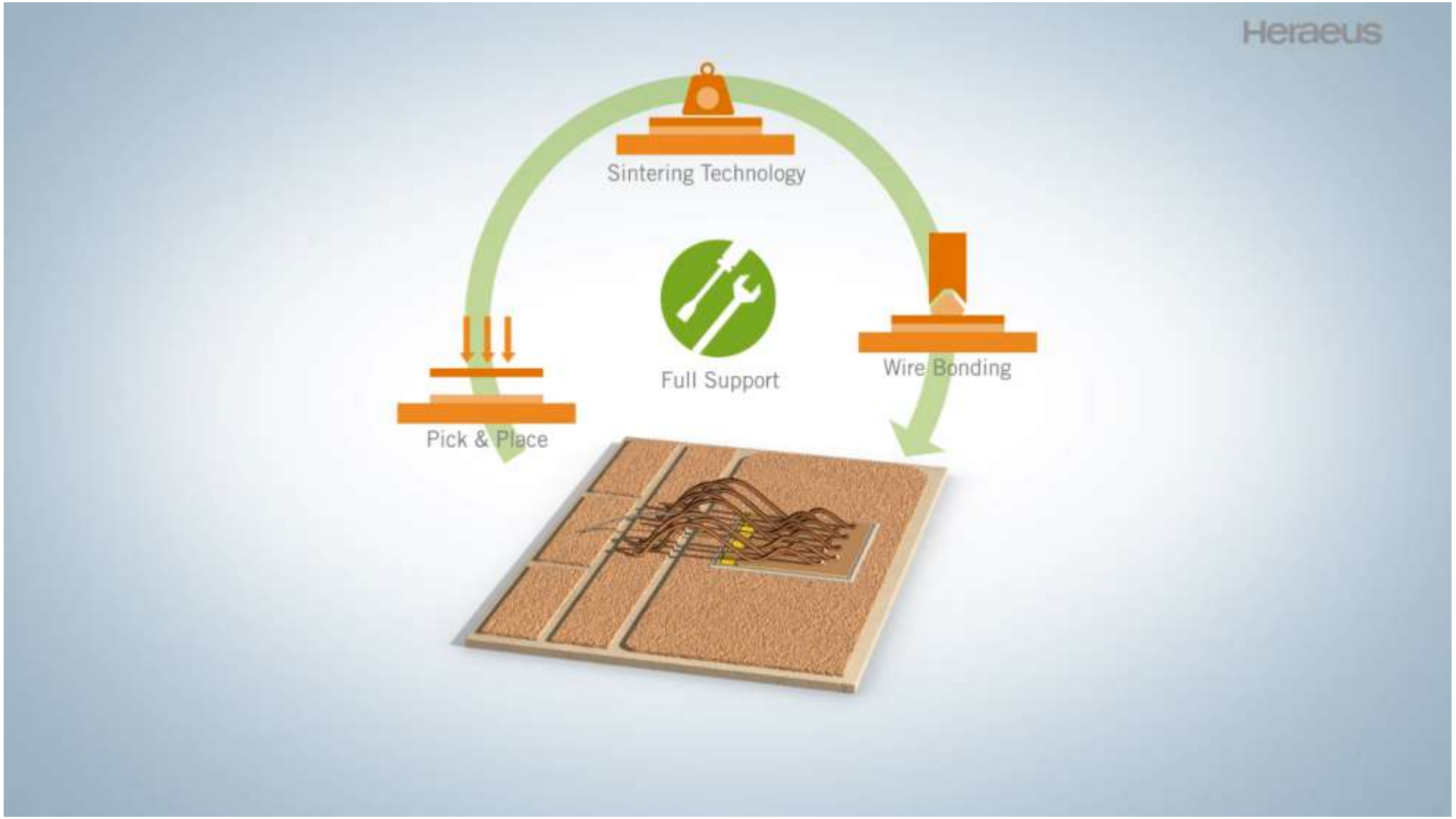
Clip Solution

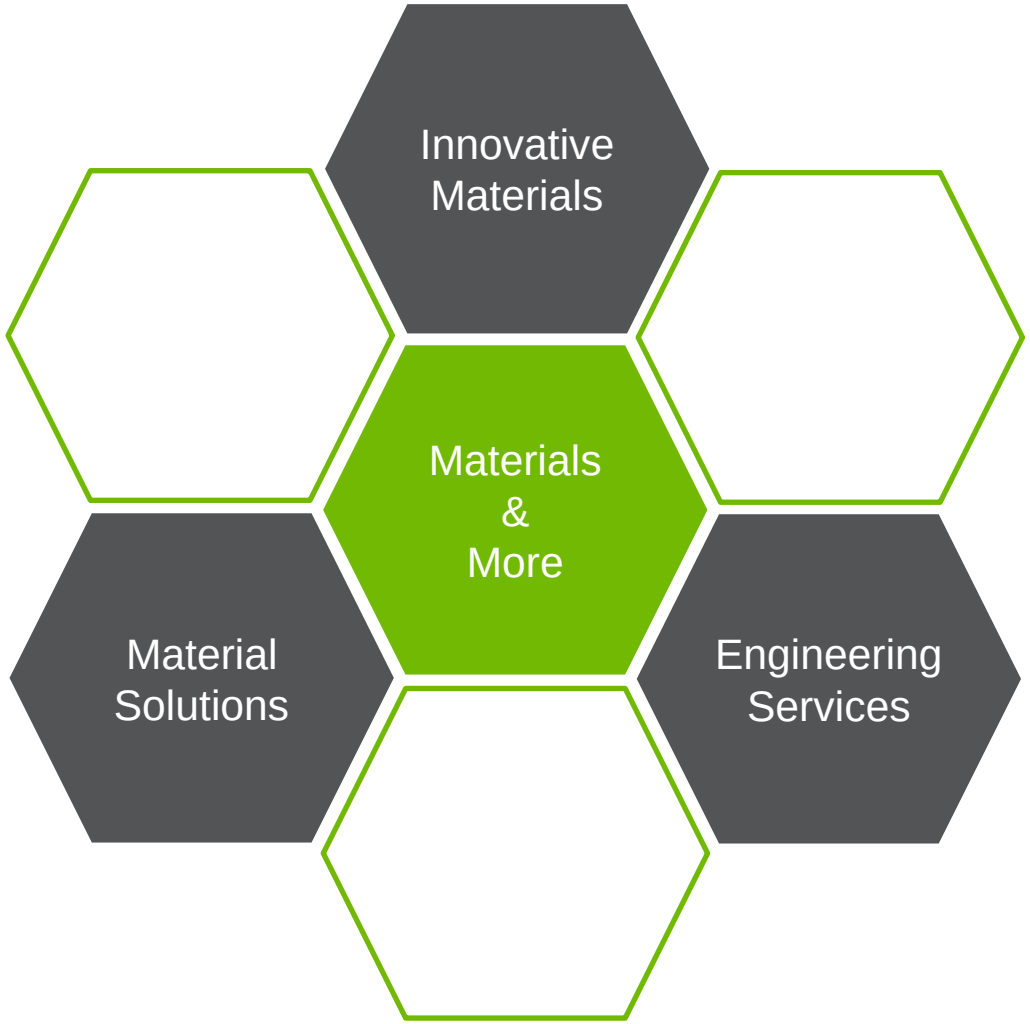
- New stamping tool for each layout variance
- Suitable for large volumes
- Die bottom and top attach in 2 process step
- Mechanical stress due to non-symmetrical design & inferior flexibility vs. bond wire
- Stress relieve leads to uneven thermal distribution
- Risk of voids under foil structure during insulation potting

SUMMARY

- Expected significant growth of Power Module in EV/HEV applications
- Power module packaging components will have significant growth
- Die top system maximizes
  - **Power density and reliability** of interconnect
  - Use industry standard die bonder reduces equipment cost
  - Increase power cycling capability to improve lifetime and reliability of the Power module

DIE TOP SYSTEM





Thank you for your attention.
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