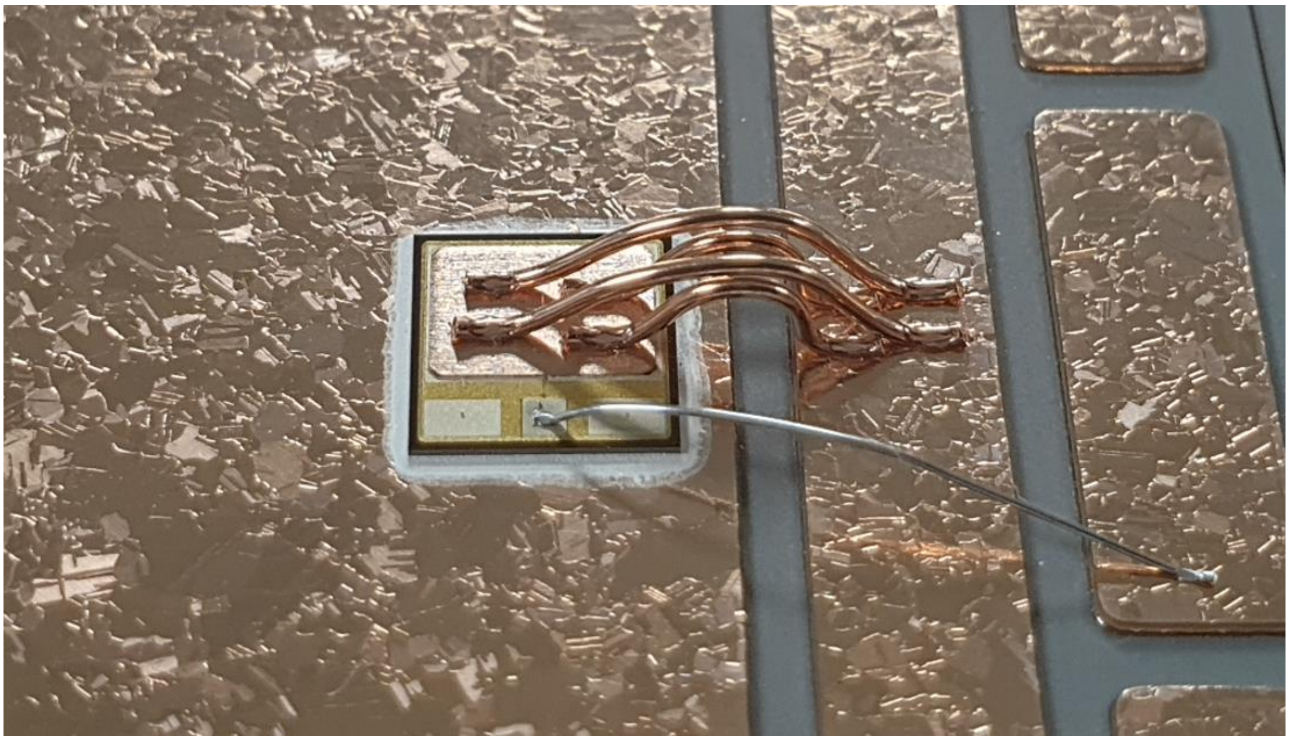
APPLICATION NOTE PRD-07969

SINTERING CONSIDERATIONS AND THE DIE TOP SYSTEM



Wolfspeed Power Applications

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CONTENTS

1. DIE SINTERING REQUIREMENTS

1.1 OVERVIEW

Sintering is a die interconnection method that is becoming more common in power electronics applications thanks to its ability to increase reliability and decrease thermal resistance of the die attach. It can now also be used as a replacement of traditional Al wire bond connections to the topside source pads of the die when used with solutions like Heraeus's Die Top System (DTS®).

Sintering requires unique processes that can include elevated temperature, pressure and time variables that impact the strength of the attachment accordingly. This application note will cover requirements from the die for sintering and sintering process details when using Heraeus' silver sinter paste and DTS®.

1.2 FRONT AND BACKSIDE METALLIZATION

Wolfspeed dies have various metallization stacks to allow for different interconnections to the die based on the application. To sinter to both sides of the die (for example when using backside die attach and topside Die Top System), 'D' metal can be used since both sides of the die have a nickel/palladium/gold metal stack. The other metal stack that can be used for sintering is 'E'. Die with 'E' metal can be sintered on the backside, but the topside requires aluminum wire bonds since Al is the top metal in this stack. All metal stacks currently offered by Wolfspeed are shown in the table below.

Wolfspeed Metallization Types	A Top: Al Bot: Ni/Au	D Top: Ni/Pd/Au Bot: Ni/Pd /Au	E Top: Al Bot: Ni/Pd/Au	J Top: AlCu Bot: Ni/Pd/Au
Topside Soldering		●		
Topside Sintering		●		
Backside Soldering	●	●	●	●
Backside Sintering		●	●	●
Al Wire Bonding	●		●	●
Cu Wire Bonding		●*		
New Designs	●	●	●	●

*Cu wire bonding enabled with the use of the Heraeus Die Top System

Table 1: Wolfspeed metallization stacks.

Ni/Pd/Au ('D' metal stack as shown in Table 1 above and Figure 1 below) is a common metal stack used for sintering. Nickel is the main layer connected during the sintering process. The palladium layer is included to prevent nickel migration, and the gold layer serves to protect the other metal layers from any oxidation before the sintering process.

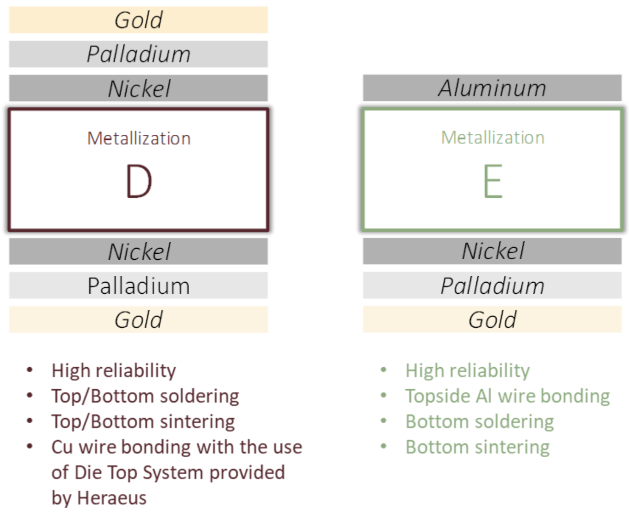


Figure 1: Wolfspeed sinterable die metals.

1.3 DIE LAYOUT

Wolfspeed dies have different layouts to help accommodate varying packaging needs. Careful consideration is needed when selecting the die layout to be used. It is critical to ensure that package inductances are low (keeping wire bond paths short) and that a gate and Kelvin connection can easily be wire bonded without obstructing other connections to the die.

This application note focuses on the D1 layout. The D1 layout has a center gate configuration with two Kelvin source pads on either side to allow for flexibility in adding a Kelvin source. The rest of the die area (the other two source pads) can be utilized for the Die Top System. The die layout is shown in Figure 2 below.

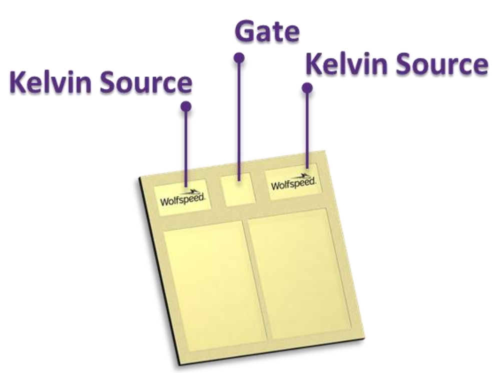


Figure 2: Labeled die image.

Having a large, isolated area of the die dedicated to source power bonds helps to decouple the gate and source loops. It also helps with thermal management and power density because a large area of the die can be dedicated to the Die Top System being sintered on top.

1.4 WOLFSPEED SINTERING RECOMMENDATIONS

As will be discussed further in the application note, different sintering profiles can be used that will impact the effectiveness of the sinter joint. The main factors that influence this are time, pressure, and temperature. To get the best sintering connections, it is recommended to run a Design of Experiments (DOE) to determine which profile delivers the best outcome.

For sintering pressure limits, Wolfspeed recommends a target pressure level of 20 MPa and an absolute maximum pressure level of 30 MPa. Careful consideration also needs to be put into ensuring that there is an even distribution of pressure over the die. Using a soft tool is usually preferred. More information on this is included in the following sections.

2. PROCESS FLOW OVERVIEW

The following table provides an overview on the process steps for die-attach and DTS®-attach with equipment proposals and starting process parameters. The subsequent chapters go into more detail.

Paste application on bare copper substrate	→	Pre-drying of printed paste	→	Hot die placement + DTS®	→	Sintering Die and DTS® in one step
Equipment: DEK printer (Stencil printing)		**Equipment:** Binder Convection Oven		**Equipment:** Datacon pick-and-place-equipment (fully automatic)		**Equipment:** PINK Sinterstar 200+
Sinter Paste: ASP 338-28		**Temperature:** 140°C		**Heating plate temperature:** 110°C w/ PAA / up to 150°C w/o PAA		**Protective foil:** 500 µm PTFE on top side
Stencil thickness: 80 µm		**Drying time:** 20 min		**Placement pressure:** Chip: 3,5 kg; DTS®: 400 g w/PAA/3,5 kg w/o PAA		**Pressure:** 20 MPa
Stencil aperture: 5,5 x 5,5 mm (For Chip 5 x 5 mm)		**Drying atmosphere** N_2		**Placement time:** Chip: 3 s; DTS®: 1 s w/PAA/1-10 s w/o PAA		**Temperature:** 250°C
Alternatively: HET substrate with pre-applied Sinterpaste			→			**Time:** 3 to 5 min
						Cool down: 250 °C to 50 °C in 5 min

Table 2: Process flow overview.

2.1 PRINTING

The sintering process starts with a printing step where a layer of silver sinter paste is applied onto a bare copper substrate. The objective is to achieve a homogeneous, defect-free sinter paste pad for die attach. With a stencil thickness of 80 µm, the bond line thickness (BLT) will reduce to approximately 25-30 µm. This is the recommended minimum BLT to cover substrate height variations underneath the die. The stencil aperture is supposed to exceed the die dimension by 100 - 250 µm on each side due to the typical ramps caused by the stencil printing process. With less overprinting, the required placement accuracy increases.
The necessary printing speed depends on the package layout. A good starting value is 10 mm/sec, but this can be increased if the quality check reveals no issues. The squeegee blade should be free of damage. If the

squeegee is not free of damage, the printed layer will not be even, and it is therefore important to replace the squeegee blade if it is damaged or not working correctly.

A three-dimensional measuring step is recommended for process control. This type of measuring, referred to as automated optical inspection (AOI), is needed to verify the height of the paste to check for printing quality. Systems used for automatic solder paste inspection (SPI) can also be used for this purpose.

2.2 DRYING

Sinter usually comes in the form of a paste to allow for an easier printing step. After printing, a drying step is needed to evaporate the solvents. This sets the paste powder in the shape of the stencil and allows it to remain in place. A drying step is needed in pressured sintering to sinter correctly.

If bare copper surfaces are exposed in the substrate during the drying step, the drying atmosphere should use nitrogen to avoid copper oxidation. An adequate ventilation process to draw out the solvents effectively is 20 minutes at 140 °C. For larger oven loadings, drying time will need to be increased due to the larger volume of paste to be dried. The drying temperature must be below 150 °C to avoid starting the sintering process. In consideration of areas with insufficient ventilation inside the oven, using a convection oven and an exhaust will provide improved air circulation, helping remove the evaporated solvents.

While drying is a necessary step in pressured sintering, pressureless sintering does not need a drying step since the die is put directly onto the sinter paste and the tackiness keeps the die in place. The downside of using pressureless sintering is that although there is no drying step, the solvents still need to evaporate so if the die is too large, the solvents can get trapped and this can cause voids. Also, the same density is not achievable from pressureless sintering, hence pressured sintering is recommended for high-power applications.

2.3 PICK AND PLACE DIE AND DTS®

2.3.1 DIE PICK AND PLACE

The needle ejector (shown in Figure 3 below) elevates the die from below. The die is then picked up with a hard pick-up tool (steel or plastic). The pick-up tool needs to be a hard tool in order to apply slight solid pressure to the paste pad. After being picked up with the hard tool, the die is then tacked onto the hot substrate, which is laying on a heating plate. The pick-up tool does not necessarily need to be heated, because it is vacuum-assisted, but the die does need to be placed on a hot surface. Since the paste has been dried (to remove the solvents), a tacking process is needed in order to keep the die in place. The tacking process is used to hold the die in place until it is fully sintered. This process involves some amount of heat and pressure applied for a set amount of time (not on the levels of the actual sinter process). Although the necessary tacking requirements can change based on other factors, starting recommendations are below:

- Heating plate temperature of 110 °C up to 150 °C maximum.

- Tacking pressure should be as high as necessary for stable placing, depending on die size and metallization interface: 3-4 kg (up to 1.5 MPa)
- Time for tacking step: 1 – 2 s.

2.3.2 DTS® PICK AND PLACE

The needle ejector must be turned off for pick and place of the DTS. Needles will damage the porous sinter layer on the Die Top System. Remove the needles and replace them by attaching a silicone layer to the top surface of the needle ejector.

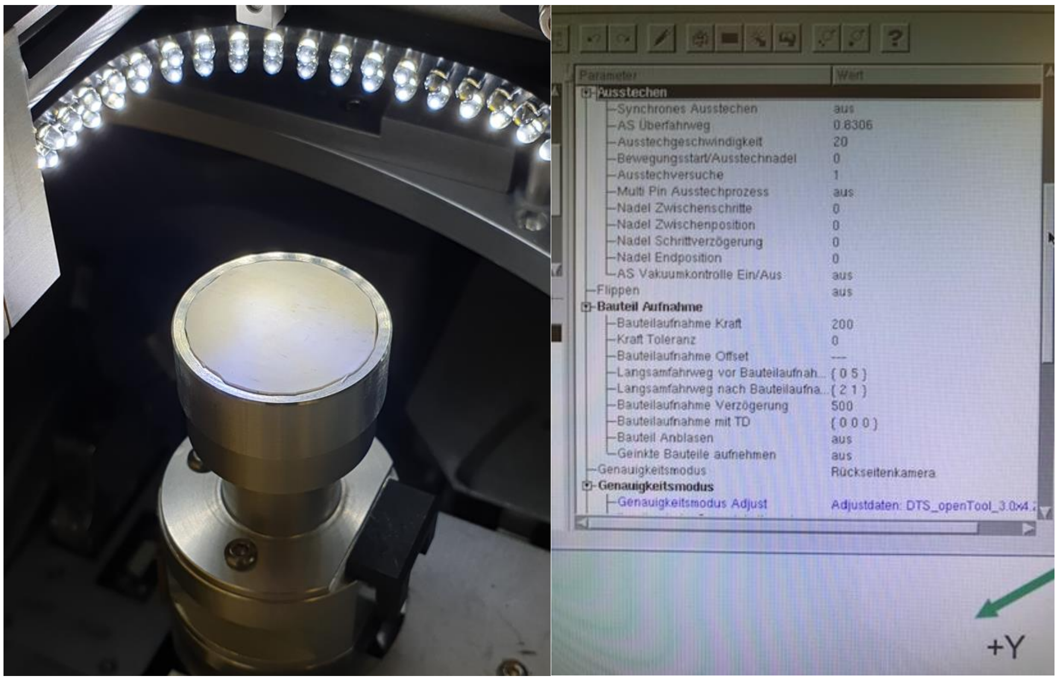


Figure 3 Left: Needle ejector with white silicone layer on top; 28 mm diameter, 2 mm thickness.
Right: Pick up parameter for Datacon 2200 evo.

The silicone top shown in Figure 3 is needed to push the DTS® wafer tape up by a few millimeters and stretch it. This will avoid vibration and enable a softer picking process, similar to peeling. Single silver particles will remain on the UV-tape since they are fixed in the adhesive film and detach from the porous layer. Bigger break outs (“paste chipping” as shown in Figure 4) should not appear.

Figure 4: DTS backside showing a "paste chipping" after picking.

Wafer clamping (black ring shown in Figure 6) should be limited to 3 kg. A larger clamping force can deform the wafer ring which can cause the DTS® to detach.

The DTS® pick tool is adapted to the DTS® size, but approximately 0.1 mm smaller (4.2 mm x 2.8 mm). It can be made of steel with vacuum holes added as shown in Figure 5.

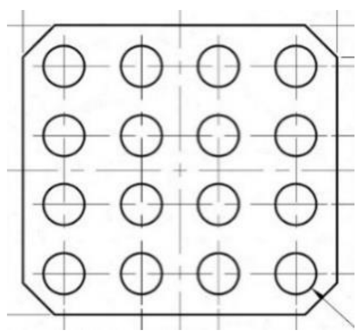


Figure 5: Example pick up tool design with vacuum holes.

Quality inspection: An automated optical inspection system that works from below is recommended for control of the paste integrity after picking the DTS®.

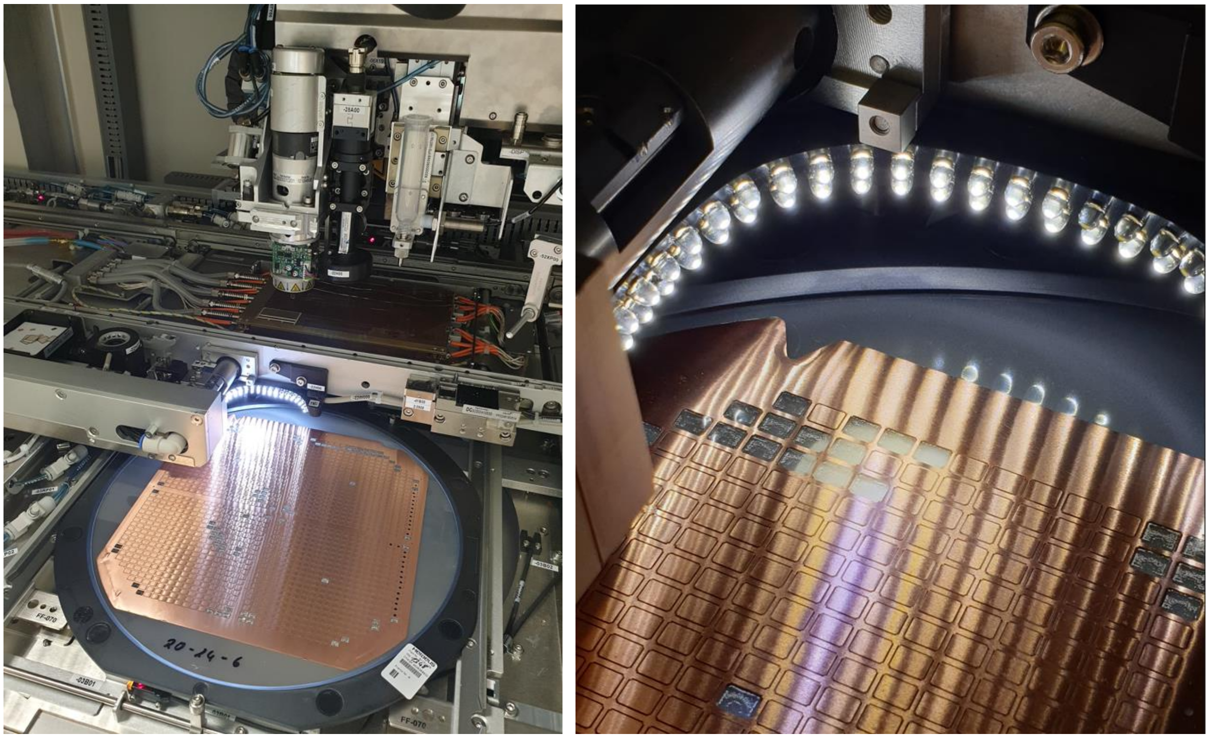


Figure 6: Left: Pick and place set up in Datacon 2200 evo. Right: Normal silver residues after picking.

The recommendations for the placing process of the DTS® vary depending on whether or not the PAA (pre-applied adhesive) is being used:

- Placing DTS® *without PAA* requires a tacking pressure of approx. 3-4 kg for 1-10 s depending on the DTS® silver adhesion to die metallization. A hard pick tool is needed, and the tacking temperature should be 110 – 145 °C max.
- Placing DTS® *with PAA* does not require a hard tool. It can be picked and placed with a silicone suction piece and approx. 200 g - 400 g for less than 1 s (such as 100 ms). The tacking temperature can be reduced to 80 °C minimum as this is needed to activate the PAA. The PAA equipped DTS® enables higher processing speed and offers a larger process window.

2.4 SINTERING DIE AND DTS®

There are two ways to process substrate with die and DTS®:

- Two-step-sintering means performing all of the die attach sintering in a first sinter step and then the DTS® sintering in a second step. Two individual sintering processes are needed, and each step requires pick and place before and cooling down afterwards.
- One-step-sintering means picking and placing all dies and DTS® on the substrate and performing only one sinter process for all components.

The key challenge is to ensure that the correct sinter temperature is achieved and remains homogeneous on all positions on the sintered part.

Typical temperature range for sintering is 230-260 °C at the position of the sinter paste. Although the optimal sintering temperature is much higher, the sintering process can actually start at 150 °C. WARNING: This temperature must not be exceeded during the drying process or component placement/tacking. Pre-sintered areas will block further densification during the pressure sintering step.

Sinter pressure is recommended at 20 MPa minimum to achieve sufficient silver densification to withstand high forces, such as the application of thick copper wire bonds. When using other bonding technologies on the DTS® top side with lower bonding forces such as laser-bonding, metallization (chip embedding process) or others, the sinter pressure can be lower than 20 MPa.

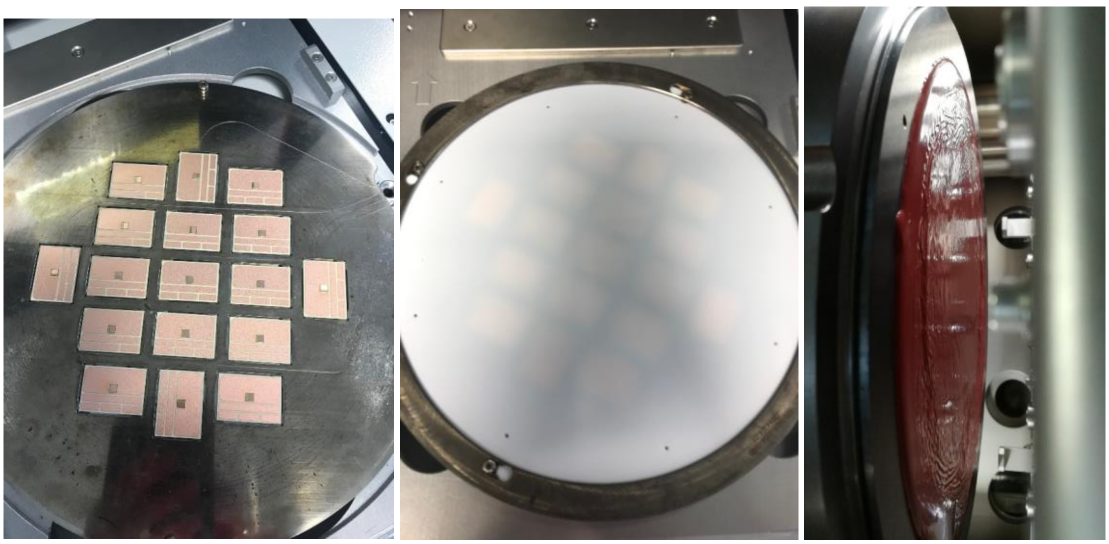


Figure 7: Sintering with pink press. Left: Nest is customized to substrate and stencil to prevent damaging the ceramic edges of the substrate. Middle: A 500 µm thick PTFE foil is used to separate the silicone from the product. Right: Schematic press set up (with courtesy of pink GmbH Thermosysteme).

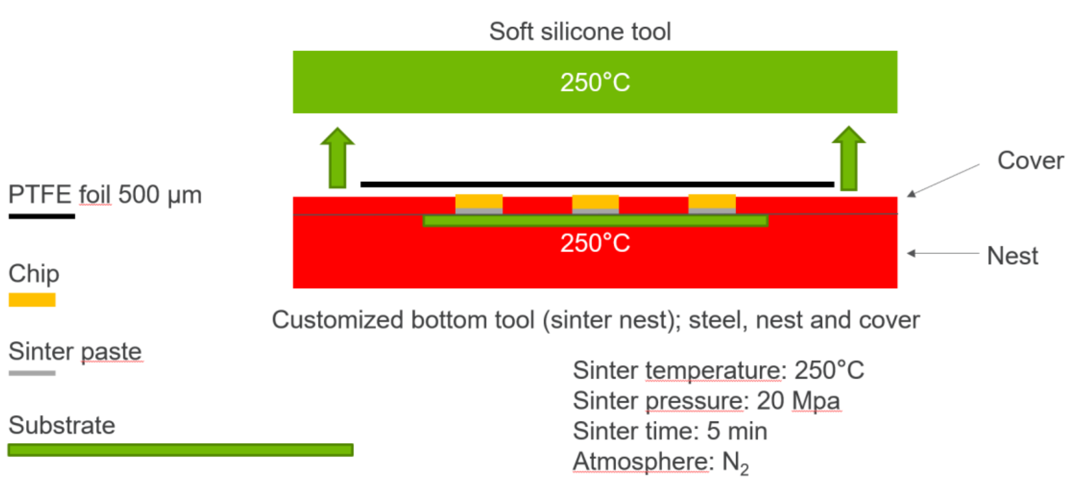


Figure 8: Schematic overview of sinter process. Chip comprises tacked DTS®.

The sinter process shown above is an example process. Additional sinter concepts are available on the market. Varying factors that can influence the process and need to be considered include:

- What are the height differences on the substrate? How can you balance different height levels?
- How is the pressure applied? Is a flat tool, individual stamps, or a silicone cushion required?
- Substrate arrangement: Single substrate vs. multiple substrate sintering. What is its warpage variation?
- What is the influence of sinter process on any inhomogeneity?
- Which cover material should be used? PTFE/PFA foils (conductive), silicone rubber, graphite sheets (good for using with a hard tool and does not squeeze out under pressure)

When starting to produce samples with DTS®, a sinter time of 3 to 5 minutes is recommended. Sinter time can be further reduced depending on the sinter process and equipment. The heat will make the PAA soft, but not liquid. Due to the sinter pressure, the PAA is pressed out and spreads usually along the DTS® copper edge (see picture in Figure 9). The more pressure that is applied above the PAA position, the more it will be pressed out.

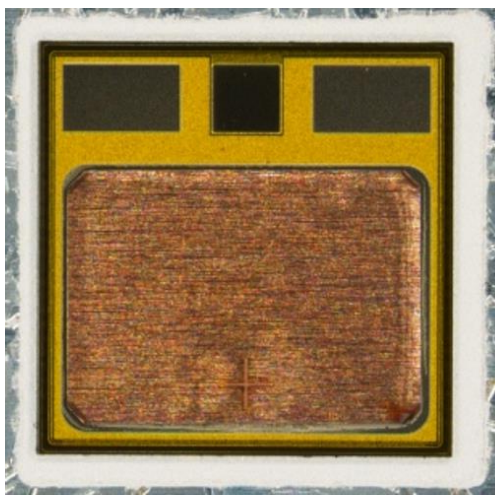


Figure 9: Sintered DTS® Open Tool with grey PAA residues close to laser cross.

The first cool-down step after sintering should not be too fast. A cooling rate from 250°C to 50°C in 5 minutes is an approximate guide to follow depending on the module structure and cooling method. After the initial cool down, the package is ready to withstand fast and high thermal cycles.

2.5 WIRE BONDING

Thick copper wires with a diameter of up to 500 µm and copper ribbons with dimension up to 2000 µm width and 200 µm thickness can be ultrasonic bonded to the DTS®. The gate pad is typically contacted with 125 - 150 µm Al-H11 wire. Up to 6 wires with 400 µm diameter (= 16 mil) can be arranged on the DTS® Open Tool.

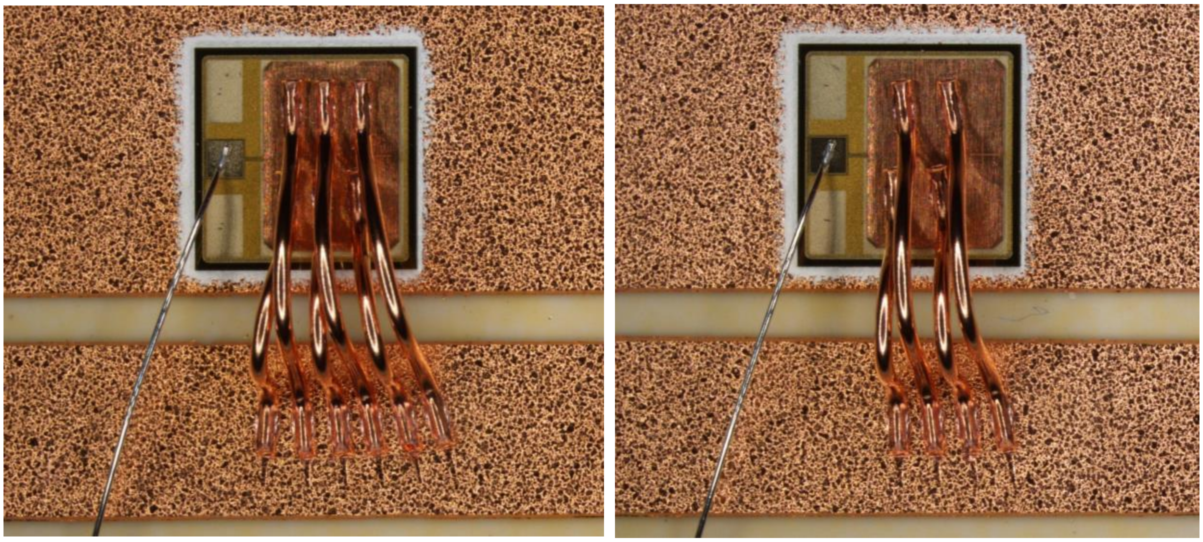


Figure 10: Wolfspeed die with DTS® Open Tool and 400 µm PowerCu Soft: Left image: 4-wire layout. Right image: 6-wire layout.

As an example, the following tables show all parameters for a 400 µm PowerCu-Soft:

Name	400 (16)-F-DTS-Std	400 (16)-DCB
Touch Force	1400	1400
Start Force	1700	1900
Bond Force	2000	2600
Start Power	100.0	115.0
Bond Power	120.0	140.0
Start Ramp Time	5	5
Bond Ramp Time	40	20
Bond Hold Time	110	140

Name	400 (16)-OE
Cut Depth Offset	0
Tail Length	1400
Break Distance	1000
Break Height	20
Break Angle	45
Cut Force	450
Clamp Close Force	1500

Table 3: Bond parameter for 400 µm PowerCu-Soft (left) and cut parameter (right).

Name	First Row	Second Row
Loop Type	Optimized	Optimized
Loop Control	Height	Height
Loop Factor	NA	NA
Loop Height	2200	2400
Loop Length	NA	NA
Step Fwd Angle	0	0

Name	First Row	Second Row
Min Wire Feed	700	700
Twist Height	700	700
Descent Advance	25	25
Max Loop Height	NA	NA
Min Loop Height	NA	NA
Arc Factor	NA	NA

Table 4: Loop parameter for 400 µm PowerCu-Soft.

The appropriate wire diameter and layout to use depends on the applied power. The following table provides an overview on the current carrying capability of different copper wire diameters (Heraeus PowerCu Soft) by showing the fusing current over loop length:

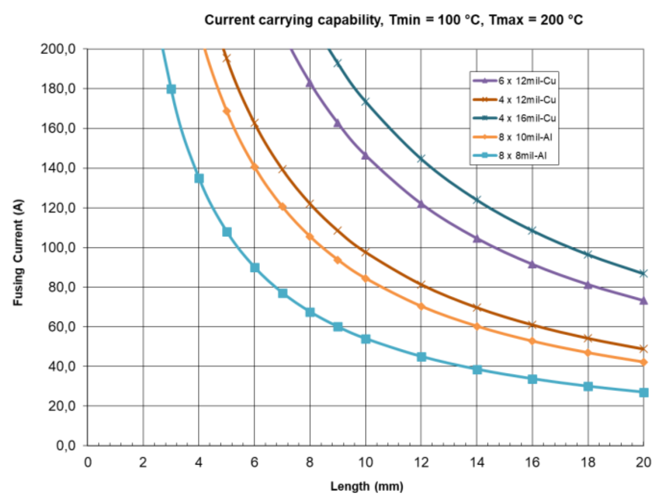


Figure 11: Current carrying capability of different copper wire diameters and number (Heraeus PowerCu Soft) showing the fusing current over loop length.

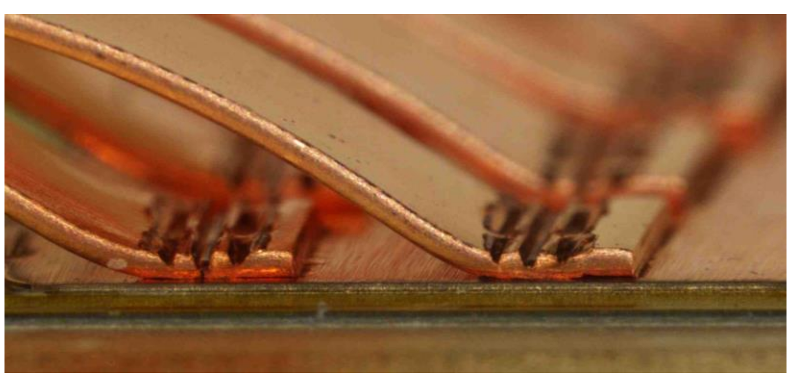


Figure 12: Heraeus PowerCu ribbon 1500 µm x 200 µm on 50 µm thick DTS®.

Furthermore, the DTS® also serves as a necessary interface for laser-bonding or laser-drilling to protect the die and provide the best interface connection.

3. DIE TOP SYSTEM REQUIREMENTS AND PROCESSING

3.1 DIE TOP SYSTEM LAYOUT

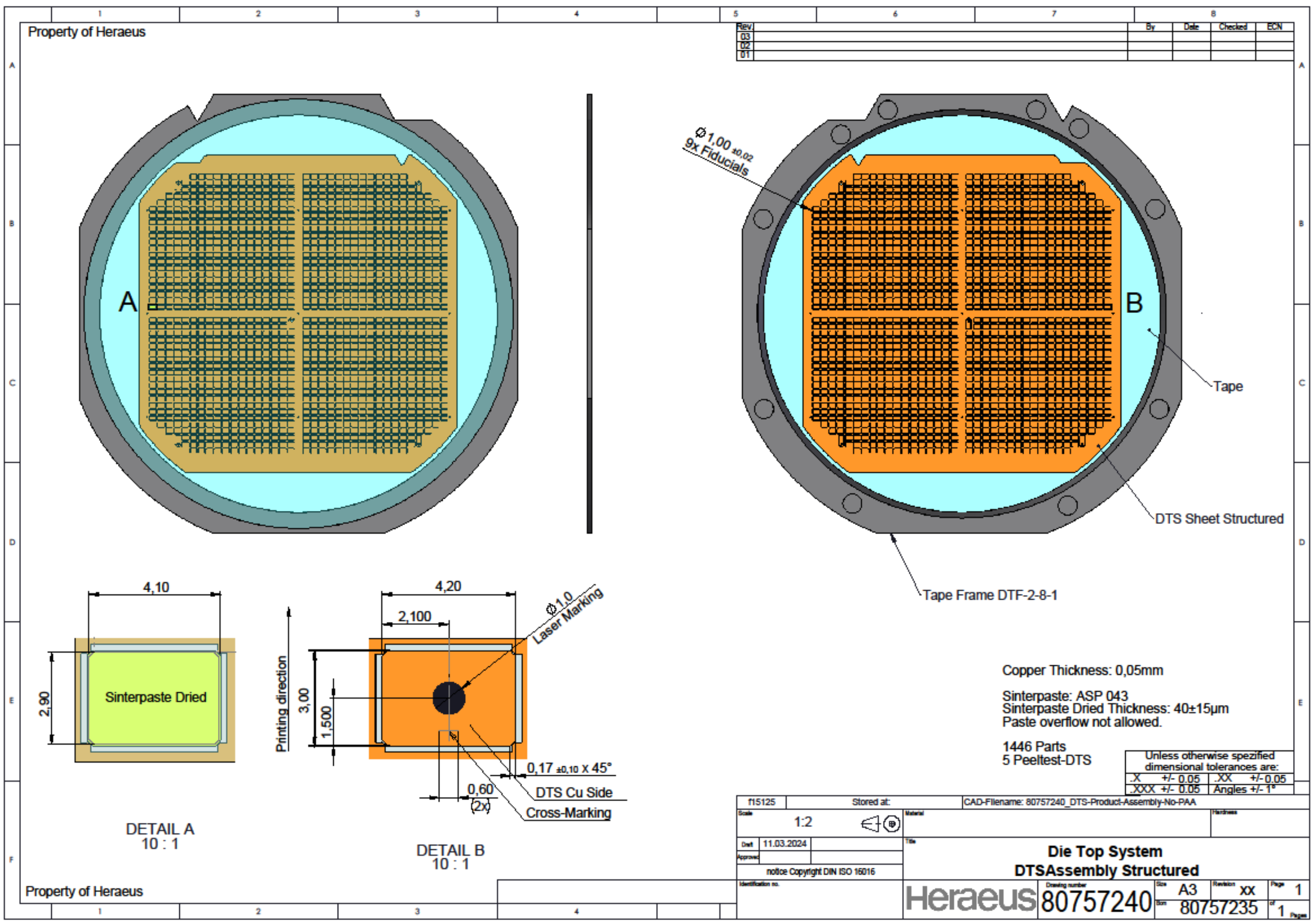
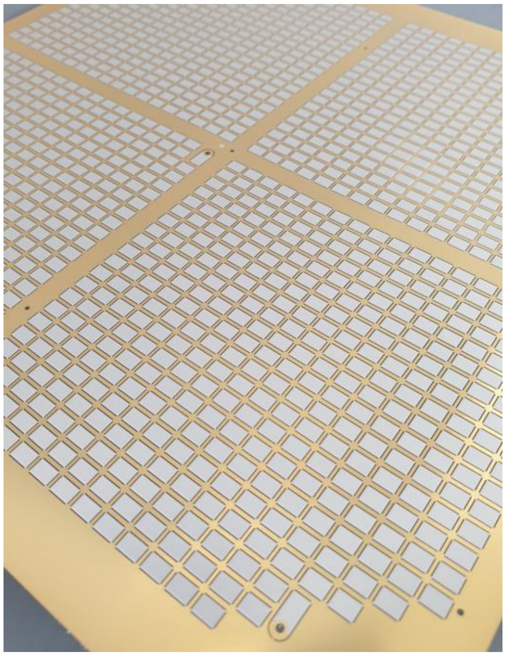


Figure 13: DTS® Open Tool drawing.

When centered on the die source pad, the DTS® Open Tool with 4.2 mm x 3.0 mm outline has an 0.1 mm offset on each side to cover all tolerances (manufacturing dimension, pick and place, etc.).

DTS® parts that do not pass the screening in quality control will be inked either with an ink-jetter or laser. A non-fully populated wafer can be received due to parts being removed for random quality checks (pick-up) or the upside-down-test. For the upside-down-test, the wafer is turned upside-down to ensure that all loose parts fall off before packing.



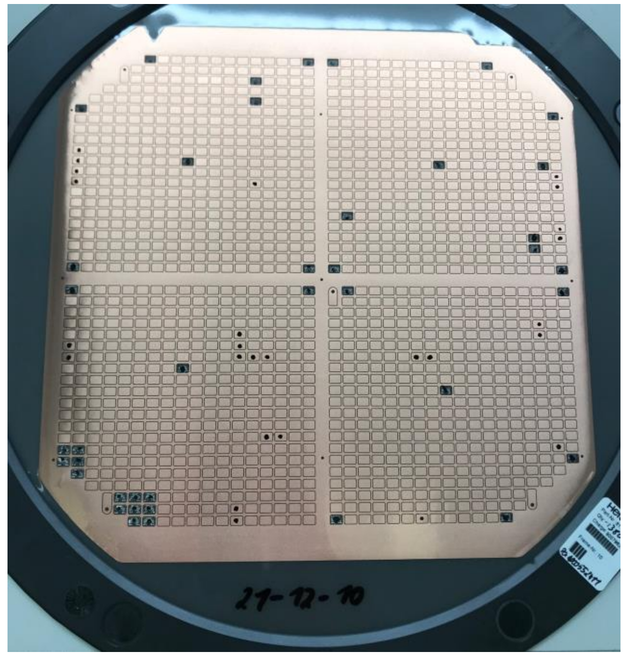


Figure 14: Left image: Semifinished wafer with printed sinter paste.
Right: Finished DTS® wafer after quality check before packing.

3.2 PAA

The pre-applied adhesive (PAA) is applied in dot-form and dried during production. On the delivered wafer it is solid and not sticky. The activation temperature (the temperature at which the PAA becomes sticky), is approximately 80 °C. Once activated, the PAA fulfills its main function by fixing the DTS® to the top side of the chip during the pick and place step and keeping it in position until it is fully sintered. When heated to 250 °C in the sinter process, a small amount of solvent evaporates. The PAA dot becomes soft but not liquid, so it will stay in position. When sinter pressure is also applied on the PAA position, it will usually spread along the copper edge. For customized DTS® designs, it is possible to design in so called "PAA-slits" which form cavities that absorb most of the mushy PAA during the sinter process.

The PAA residues are electrically isolating and inert, and pass H3TRB tests even when located on the guard ring. Power cycling tests do not show any significant difference for DTS® with or without PAA.

Advantages of DTS® with PAA:

- Faster placing time in pick and place process (app. 0.1 s compared to 1 – 10 s without PAA)
- No tacking pressure needed because PAA fixes the DTS® until it is sintered
- Lower tacking temperature needed: 80 °C for PAA activation

Considerations to be made with PAA:

- No sinter paste is placed on the PAA dot position: there is no thermal or electrical connection from DTS® to chip where there is PAA

- No wire bonding on PAA dot position: same with wire bonding on DTS® over gate finger, PAA positioning on gate runner means minimum reduction of bond surface
- PAA residues to be avoided on wire bond areas

4. QUALITY ASSURANCE

4.1 WIRE BOND PULL TEST/ PEEL TEST

When wire bonding, the bonding direction should be from DTS® (= first bond) to DCB (=second bond). All wires must have a minimum distance of 0.2 mm to copper edge. Wire pulling proves all interfaces from DTS® to the die:

1. Bondwedge → DTS® copper
2. DTS® Copper → DTS® sinter layer
3. DTS® sinter layer → Die metallization

The passing criteria is to have a pull-force > 10 N plus the correct failure mode (codes shown in Figure 18). Results with 400 µm wire diameter usually show metal-lifts on first bond (= DTS®). When using 300 µm wire diameter, the majority will show wire breaks.

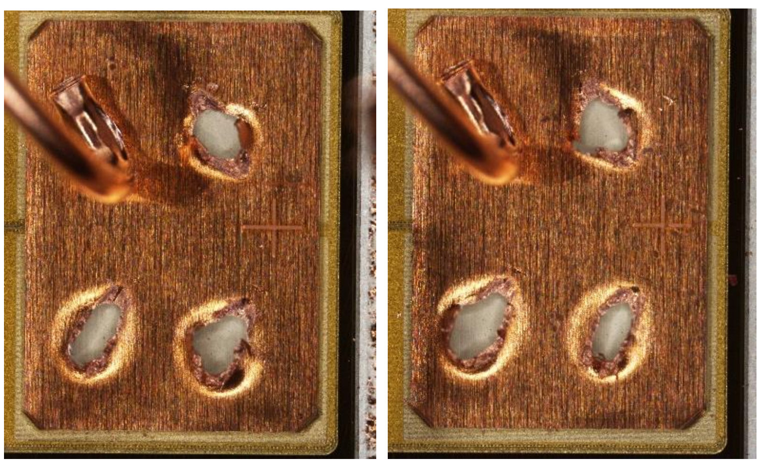


Figure 15: Good result after pull test of 400 µm PowerCu Soft an DTS® Open Tool: Metal-lift.

The Heraeus Standard Operating Procedure (SOP) describes the process, the arrangement and the failure criteria for the wire bond pull test. Figure 18 shows the main details of the SOP using a Heraeus test substrate, with 6 DTS®, and wire bonds.

4.2 FAILURE MODES

The Scanning Acoustic Microscopy (SAM) check after sintering/wire bonding and before pulling indicates sinter quality. An insufficient sinter connection can cause pre-damage with wire bonding. During loop pulling (yellow arrow in Figure 16) a delamination between the DTS® silver and connecting partner can occur (blue arrow). The early beginning delamination is mostly not visible but can grow to a pull-out of a piece of DTS® and can continue until the whole DTS® lifts off (red arrow).

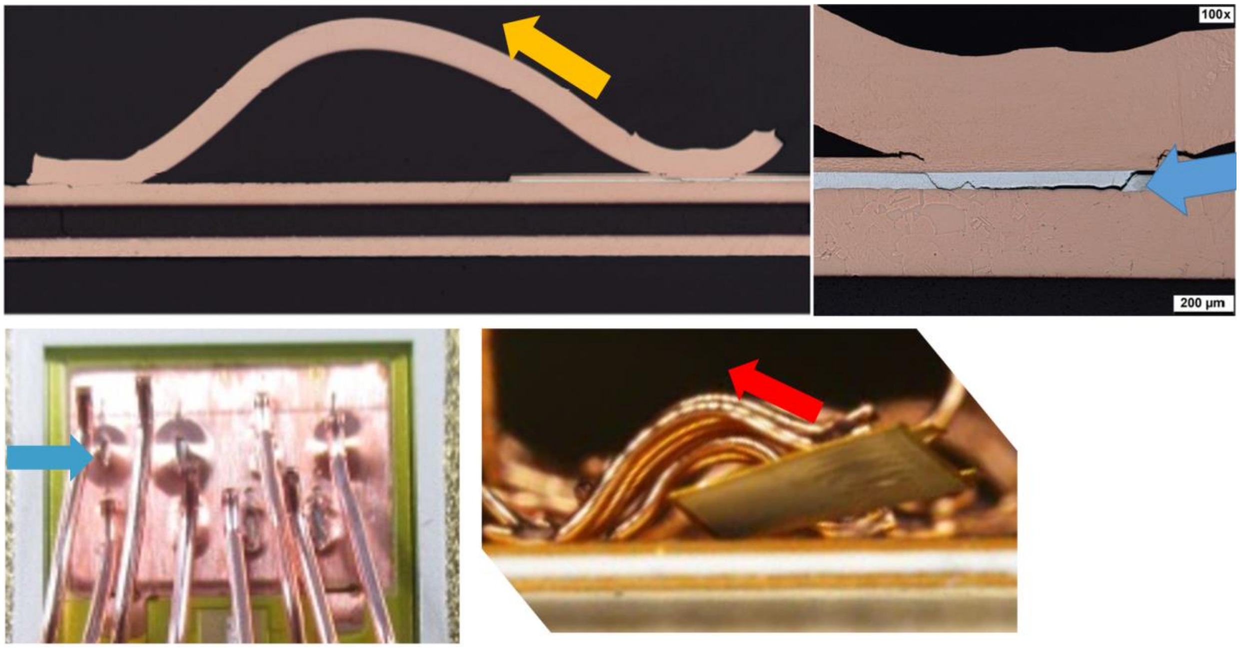


Figure 16: Different appearances of error pattern during wire loop forming.

The SAM checks show the beginning of delamination with round circles under the bond foots (yellow arrow in Figure 17). The example cross section image in Figure 17 shows an adhesion break since no silver residues are visible on the metallization.

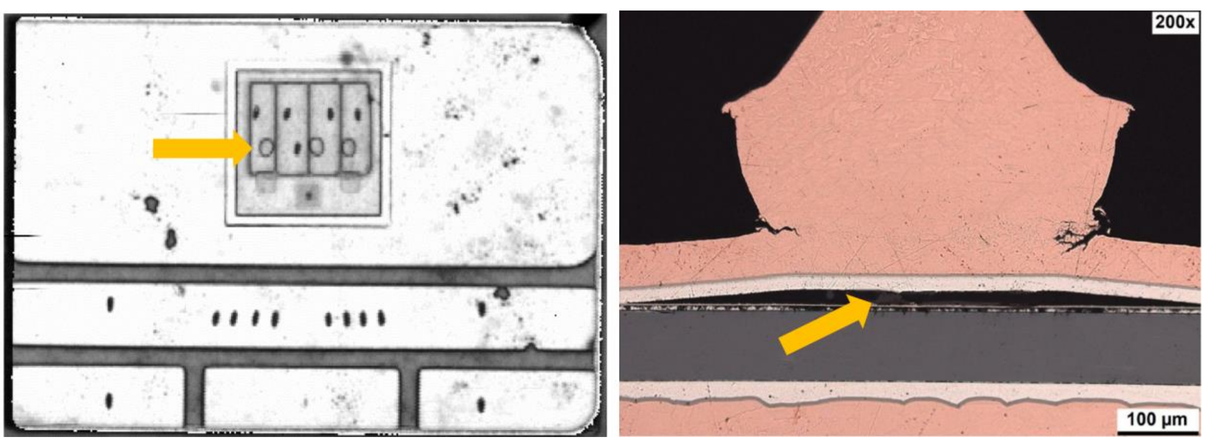


Figure 17: SAM picture with (left) and cross-section (right).
Failures marked with yellow arrow after loop forming before pull test.

Root causes:

1. If defects occur in the precious metal layer on top of the semiconductor, or if that layer is applied too thin, oxidation of the underlying nickel layer disrupts sinter adhesion
2. Impurities on the upper side of the chip such as carbon residues (countermeasure: E.g. Ar-plasma treatment)

3. Sinter pressure too low: a sintering pressure of at least 20 MPa is required to bond a 50 µm thick DTS® sufficiently to the semiconductor

If the SAM check is passed, the pull test can be carried out. The following Table 5 indicates the failure modes during pull test:

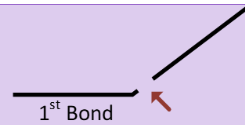
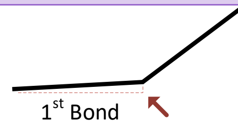
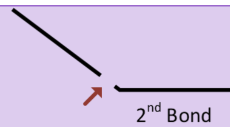
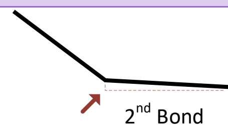
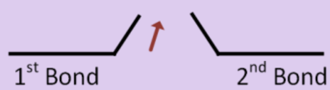
No.	Failure Type	Example	Acceptable?
0	Pull Error		
1	Heel break 1st bond		Ok
2	Lift-off 1st bond		Fail
3	Heel break 2nd bond		Ok
4	Lift-off 2nd bond		Ok
5	Wire break		Ok
6	DTS tear-off		Ok
7	-		
8	DTS lift-off		Fail

Table 5: Pull test fail modes.

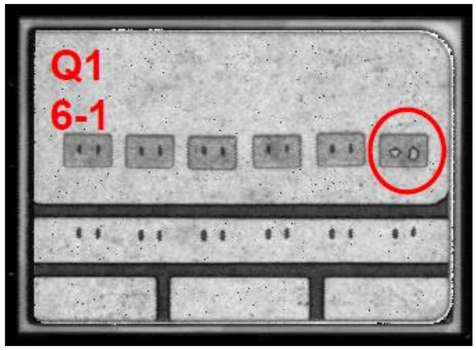


Figure 18: Left: Pull-test failure modes. No. 2 and 8 are not acceptable failure modes.
Right: SAM picture after sintering and wire bonding before pulling with two failures in red circle.

4.3 BACKSIDE CONTROL OF PICKING (DTS® PICK AND FLIP)

Heraeus introduced a quality test to check the sinter paste after picking from the wafer. The process involves the DTS® being automatically picked in a Datacon, flipped upside-down, and transferred to a second pick tool, where it is placed on a blue tape for further 3D-AOI inspection.

For a complete wafer check, every second row is picked up with a vacuum-assisted silicone tool at room temperature. The DTS® wafer is supported from below with the modified needle ejector (described in chapter 2.3). The pick tool turns 180° so that the sinter paste side is upward facing and hands the single DTS® part over to a second pick tool made of steel, which finally places the part on a blue tape, with almost no pressure and at room temperature. During the transfer and place process, the sinter paste is not harmed. Any defect in the sinter paste caused by picking (paste chipping) can be checked by putting the blue tape wafer in a 3D-AOI.

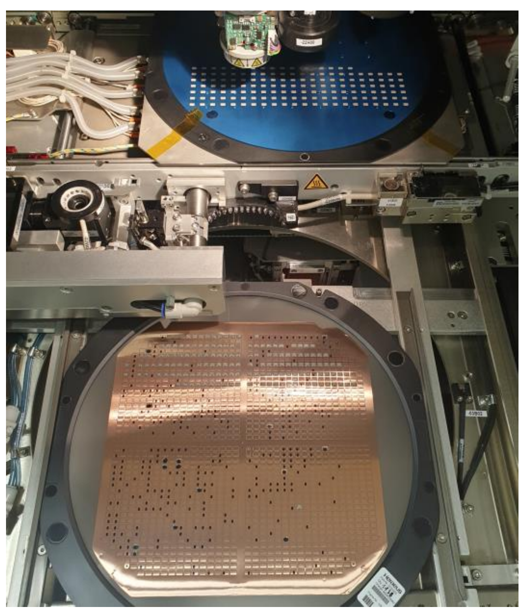


Figure 19: DTS® pick and flip process.

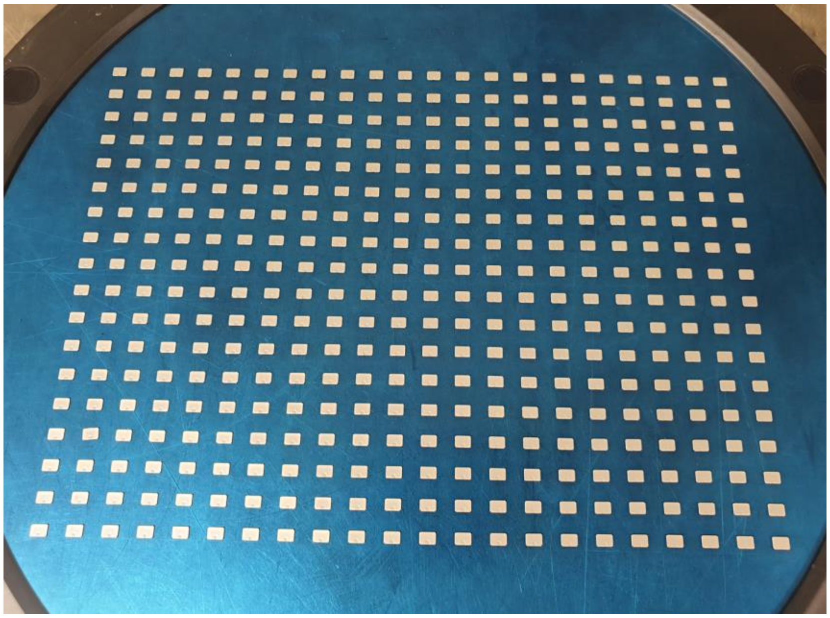


Figure 20: Picked DTS® parts on blue tape wafer to be checked with 3D-AOI.

5. DTS® PACKING

Up to 17 vacuum-sealed DTS® wafers are packed in an EPS box (560 mm x 360 mm x 180 mm). The box consists of many foam layers to protect against mechanical damage and high temperature swings.

Figure 21: Standard DTS® packing in wafer box.

As an alternative and for high-volume delivery, the use of packing into wafer boxes is under evaluation. Standard plastic boxes for up to 25 wafers are used. Foam layers between each wafer are intended to provide enough stabilization to avoid damaging movement. The box can be nitrogen flooded using a bag:

Figure 22: DTS® packing in wafer box (under evaluation).

6. COMMON ISSUES/FAQ

The sinter layer is not adhering to the top of the die, is there a process step that should be changed/reviewed?

- Please see Chapter 4.2 Failure modes

PAA is getting on the copper (bonding side) and obstructing wire bonding, is there a way to avoid this?

- Consider the correct PAA dot position on the layout (e.g. opposite to the gate). The sintering method might influence the spreading behavior, see Chapter 3.2 PAA.

Is it recommended to leave out sinter paste where the gate runner is on the DTS?

- Usually this is not necessary when using a soft tool. The sinter paste does not stick to the PI-layer on the gate runner. Wire bonding on top of the gate runner is not recommended. It is possible to leave out the paste where the gate runner is for a customized layout, but the copper will be pressed down during the sinter process.

7. FURTHER INFORMATION

For more information about Wolfspeed's sinterable die selection, please reach out to Wolfspeed.
For more information about sinter paste, and the Die Top System, please contact Heraeus at electronics.emea@heraeus.com.

8. REFERENCES

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