# Advanced Non-Pressure Silver Sinter Process by Infrared

Wolfgang Schmitt, Daniel Schnee
Heraeus Deutschland GmbH & Co. KG,
Hanau, Germany

**Abstract**
In Power Electronics, increasing attention are drawn to silver sinter materials as an attractive interconnect material for its properties and also as a lead replacement solution. New property demands are longer lifetime, better performance, higher efficiency, lower manufacturing cost and crucially non-lead containing. Specifically, for T0220 application, non-pressure sinter pastes are dispensed on the lead frame followed by die placement. Sintering process is performed in a programmable oven under nitrogen or air atmosphere. Typical non-pressure sintering profile takes approximately 4hrs long to complete, which if shortened, increases attractiveness to adopt non-pressure sintering. In this study, the objective was to investigate using IR radiation to reduce the total sintering profile. A 2-step profile was to reduce sintering defects and encourage maximum diffusion properties. Larger dies would be recommended to hold longer than 30mins to achieve homogenous drying. From our investigations using IR radiation, comparable non-pressure sintered results were achieved with 25% of the standard convection oven profile. In the convection oven, non-pressure sintering is achievable up to typically 25mm² die dimension. Above this, risk of sinter defects increases. With IR radiation, cross section of die sizes above 25mm² did not detect channeling nor voids. From our temperature profiling analysis, the uniform heat distribution within the specimen was a critical improvement, which encourages homogeneous densification of the sintered layer. For dies above 25mm$^2$, young modulus difference between the die's center and edge reduces to improve reliability. Our analysis also reported increases in die shear strength and higher thermal conductivity. The paper will show the detailed results with this new sintering process.

**Introduction**

Silver sinter materials have attracted increasing attention to use as interconnect materials in the power electronic devices mainly due to the requirement for devices with longer lifetime, higher efficiency, lower manufacturing cost and the most important is devices that do not contain lead.


**Figure 1. Typical applications for silver sintering**

**State of the art**

Silver sintering processes are generally classified as pressure and non-pressure sintering process based on the presence or absence of applied pressure during the sintering. A convection oven is used to dry the printed sinter paste before the pressure sintering process or to perform the complete non-pressure sintering process. Figure 2 shows the process flow for both methods.

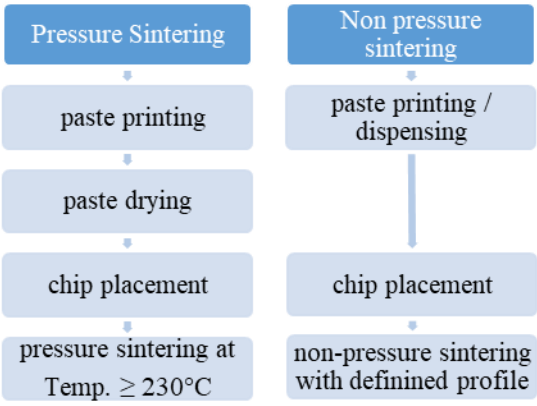



**Figure 2. Different sintering processes**

A long process time of approximately 4 hours is needed for non-pressure sintering process carried out using the typical temperature profile as shown in Figure 3. As can be seen in Figure 3, it is necessary to heat up from room temperature to approximately 160°C with a low heating rate to remove the solvents in the sinter paste and to prevent the generation of voids and drying channel. A longer time is needed for this section of the sintering profile when a larger chip is used. Additionally, it is essential to perform the non-pressure sintering process under nitrogen atmosphere to prevent oxidation of the substrate surfaces or chip metallization as oxidation on the substrate surfaces or chip metallization leads to a bad sintering connection.

At present, the non-pressure sintering process is limited to small die sizes of max. 5mm x5 mm. With die sizes larger than 25 mm², voids will be generated when sintering under the typical non-pressure sintering profile or an unacceptably long process time is needed. The above mentioned issues are the motivation to look for alternative processes.

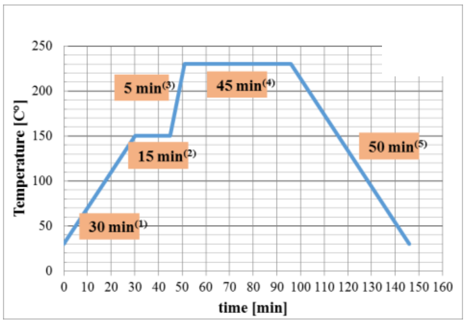



**Figure 3. Typical temperature profile of non-pressure sintering process**

**Background to IR**

Sintering with Infrared Radiation (IR) is already known for printed electronics [1]. For example silver inks on RFID (radio frequency identification), as part of telephone or credit cards (smart cards), as copy protection or as security features in ID cards. However, in these applications the sinter layer is not covered by a component such as a silicon die and has a final layer with a thickness of less than 10 µm.

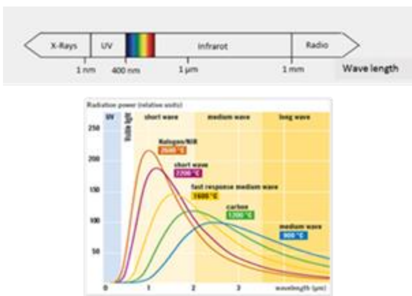



**Figure 4. Details of the electromagnetic spectrum [2]**

Figure 4 shows the electromagnetic spectrum. A further subdivision of the infrared band is shown in Table 1. The short-wave type is mainly used for sintering.

Table 1. Sub-division of IR

| | Wave length [µm] | Type |
|---|---|---|
| IR-A | 0.78 – 1.4 | Short-wave |
| IR-B | 1.4 – 3 | Medium-wave |
| IR-C | 3 - 1000 | Long-wave |

**Potential of IR in different sintering processes**

For both sintering processes, IR has a high potential to shorten the total sintering process.

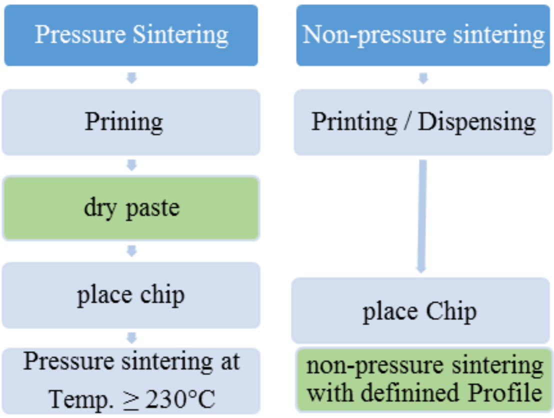
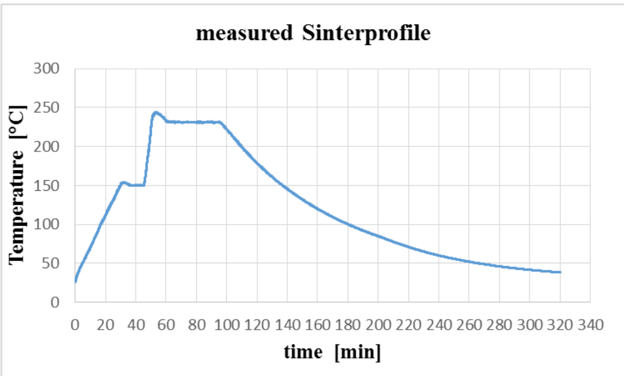



**Figure 5. Potential of IR in different sintering processes in terms of time saving**

The total process time of pressure sintering is about 20 minutes. The most time consuming part of pressure sintering process is the drying process of the printed silver sinter paste.

A theoretical total process time of non-pressure sintering in most applications is about two and half hours. However, the actual profile measurement shows that a much longer process time is required for non-pressure sintering process. The most time consuming step is the cooling phase of a standard convection oven as a low cooling rate was detected. The actual total process time is more than three and half hours for die sizes up to 25 mm² as shown in Figure 6.

**Figure 6. Measured sinter profile according to the profile shown in figure 3**




**Experimental and Results**

Pressure sintering

Different silver sinter pastes were printed on the aluminum oxide ceramic. Half of the prepared samples were dried in a convection oven and the other half were dried using IR. The standard sinter pastes which are optimized for pressure sintering, non-pressure sintering and also new developed sinter pastes were used in this study. For the new developed sinter pastes, 10% of silver particles in the standard sinter paste were replaced by non-silver particles and these pastes labelled as Paste B. The detailed information of sintering pastes used in this study can be found in Table 2.

**Table 2. List of silver sinter pastes used for the investigation**

| Paste | Type | Solids [wt%] | remarks |
|---|---|---|---|
| Paste A | pressure > 10 MPa | 88.0 | |
| Paste B | pressure > 5 MPa | 85.0 | Filler 1 |
| Paste C | pressure > 5 MPa | 85.0 | Filler 2 |
| Paste D | pressure > 5 MPa | 82.0 | |
| Paste E | no pressure | 87.5 | |

The drying in the convection oven (120°C) is about 5 times slower than drying with IR. Figure 7 shows the comparison of drying with convection oven and with IR. It can be seen from Figure 7 that Paste A dried much slower in the convection oven than with IR. Drying with IR, the solvent in the sinter paste was completely removed after 2 to 4 minutes. The same behavior was observed for all the pastes tested in this investigation. Figure 7 only shows the drying behavior up to 5 minutes.

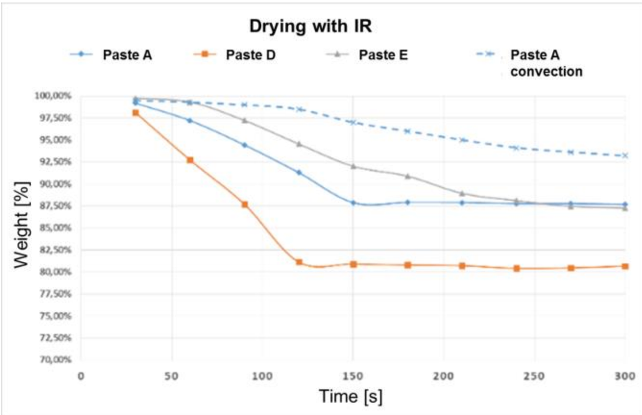



**Figure 7. Comparison of different drying approaches**

After the drying process, silver back side metallization silicon dummy dies with a size of 3 mm x 3 mm were placed on the dried sinter paste and subsequently the pressure sintering process was performed at the temperature of 230°C with the pressure of 10 MPa for 2 minutes. Shear testing was performed for all the sintered samples to evaluate the bonding strength of the sintered layer. All the sinter pastes have a similar trend in which the shear strength obtained by drying in the convection oven is rather similar to the shear strength achieved by drying with IR.

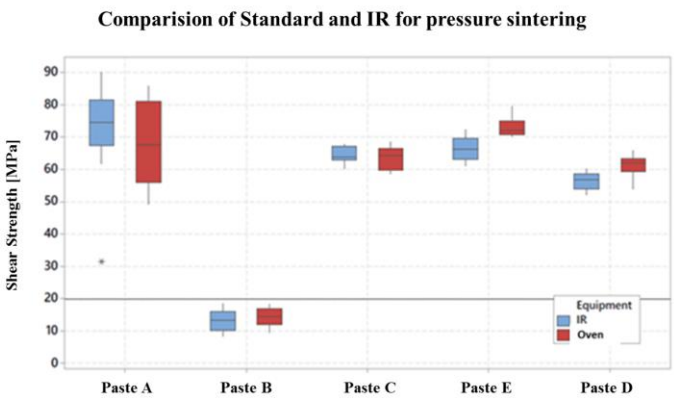



**Figure 8. Shear strength obtained by pressure sintering**

In additional, 10 mm x 10 mm dies were used to attach on the ceramic substrates and followed by the pressure sintering process. It is not possible to evaluate a shear strength for die with sizes larger than 50 mm². Hence, for large dies, a bending test as shown in Figure 9 was used to evaluate the bonding strength of the sintered layer.

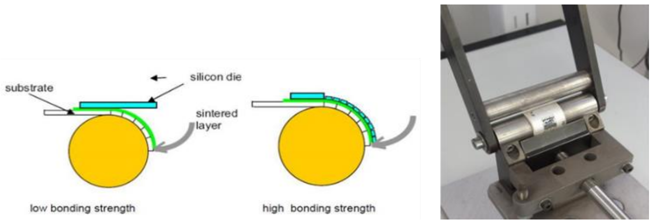



**Figure 9. Principle of the bending test**

All the samples passed the bending test as no delamination from the substrate and multiple cracks of the die were observed as shown in Figure 10. The dies were not peeled off and still were attached to the substrates after the bending test.

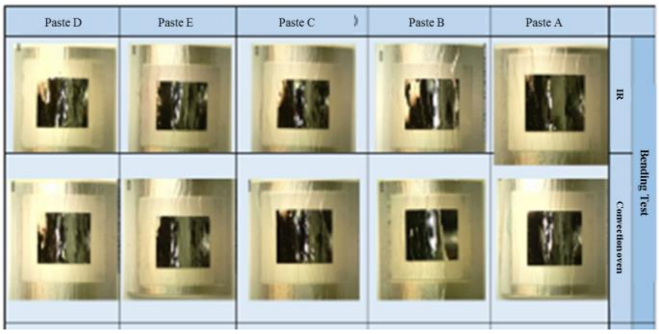



**Figure 10. Results of bending test – comparison of IR and convection oven methods**

Drying the printed sinter paste using IR before die placement can shorten the total process time for the pressure sintering to a minimum of 50 % of the current standard process time. IR equipment can be a part of an inline concept at the production lines.

**Non-pressure sintering**

For this investigation, Paste E sinter paste was used. For sintering without pressure, using Paste E a porosity of about 20 % is obtained, whereas, using a standard pressure sinter paste such as Paste A a porosity of approximately 30 % is achieved. Paste E is specially designed for the non-pressure sintering process.

The sinter paste was printed on 9 squares with an area of 4 mm x 4 mm on a DCB with a silver metallization using a stencil with a thickness of 50 µm as shown in Figure 11.

On every square, 2 mm x 2 mm dies with silver back side metallization were placed and subsequently sintered with IR or in a convection oven.

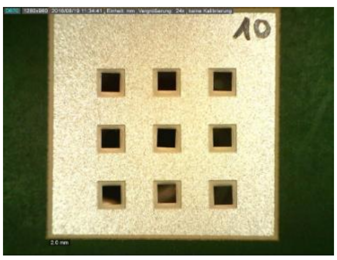



**Figure 11. DCB substrate with dies attached**

The temperature profile shown in Figure 3 was used to perform the non-pressure sinter process in the convection oven. On the other hand, the non-pressure sinter process was carried out with IR using the sinter profile as displayed in Figure

12. The sinter profile (Figure 12) was measured with the sample as shown in Figure 9 by a thin thermocouple element which was placed under the center of the die.

The sinter profile shown in Figure 12 was also used to carry out the non-pressure sinter process with IR for the other sinter pastes.

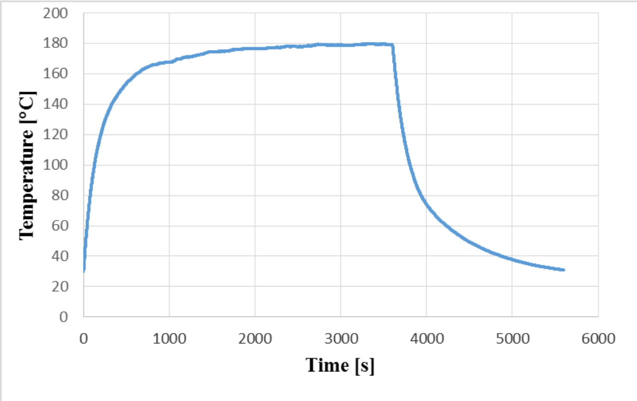



**Figure 12. Measured sinter profile with IR**

Figure13 shows the comparison of temperature behavior under IR sintering for three different sinter pastes; Paste E, Paste A and a newly developed sinter paste which contains 10% of non-silver particles. All three sinter pastes were sintered under the same IR equipment parameters.

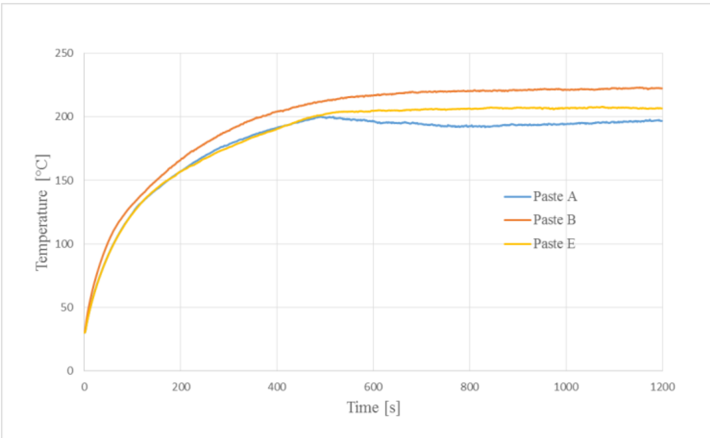



**Figure 13. Comparison of temperature during sintering process with IR**

It was found that the sinter pastes have different maximum temperatures during the sintering process using IR. Figure 13 shows only the values up to 20 minutes. The rest of the profile shows similar characteristics as the profile displayed in Figure 13.

For Paste A, the temperature was increased to 200°C in 500 seconds and followed by a slight decrease in temperature to 190°C then the sintering temperature was kept constant at about 195°C as can be seen from Figure 13. The same behavior was observed for the other pressure sinter pastes.

For Paste E, the temperature was increased in 10 minutes to about 205°C and the temperature stayed constant for about 1 hour until the Infrared radiator was switched off.

The other non-pressure sinter pastes have similar sinter profiles, however, the time to reach the maximum temperature is different.

For Paste B, the temperature was increased to 220°C in about 700 seconds and the temperature stayed constant until the IR was switched off.

More investigations are needed to be carried out in order to gain a better understanding of this phenomena.

After sintering with IR, the shear strength was measured at room temperature.

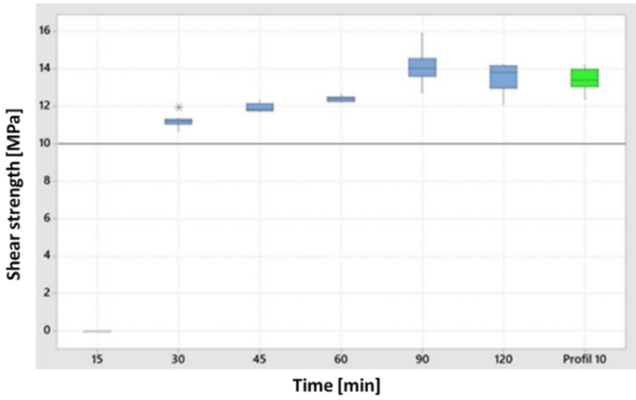



**Figure 14. Comparison of the shear strength after different sintering time by IR and conventional non-pressure sintering**

Figure 14 shows the shear strength obtained at different sintering times by IR. In addition, comparison of the shear strength was obtained at different sintering times by IR compared with the shear strength obtained by non-pressure sintering in a convection oven for about 4 hours.

It can be seen from Figure 14 that a shear strength which is higher than 10 MPa was obtained after 30 minutes sintering with IR.

This is the typical minimum shear strength which enables a save/reliable bond between the die and the substrate.

The shear strength obtained after 90 minutes IR sintering is rather similar to the shear strength obtained by about 4 hours sintering in a convection oven which is above 12 MPa.

Beside the shear strength, the void behavior under the die was also measured by SAM (Scanning Acoustic Microscopy) and additionally the porosity of the sinter layer was measured by cross section.

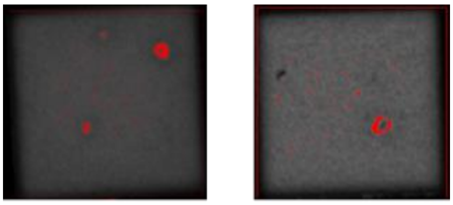



**Figure 15. Void measurement of sintered die 4 mm² by SAM**

Figure 15 shows the void measurements for the sample, 4 mm² dies, sintered with IR and sintered in a convection oven. No huge differences were observed for both samples sintered with IR and in a convection oven. The images show similar void behavior for both samples.

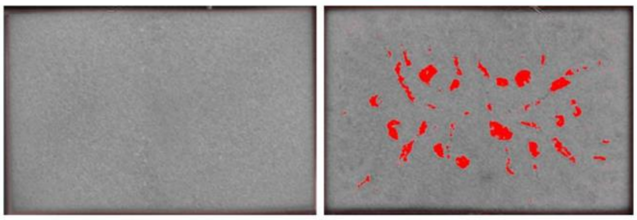



**Figure 16. Void measurement of sintered die 40 mm² by SAM**

For larger dies the results were totally different. The results show that it is possible to performed IR sintering on bigger dies in less than 1 hour with no or less voids, compared to sintering in a convection oven with long sintering times of about 4 hours. Shear testing was also performed on larger dies (40 mm²). Both methods lead to a shear strength above 15

MPa. With IR, the good shear force has already been reached after one hour, while the conventional profile for such large chips is still in the drying phase.

Cross sectioning was performed for both samples sintered with IR and in a convection oven. The cross sectional images are shown in Figure 17. The images show both samples have fairly similar porosity behavior, however, the porosity of the sintered layer obtained by IR sintering is more homogeneously distributed.

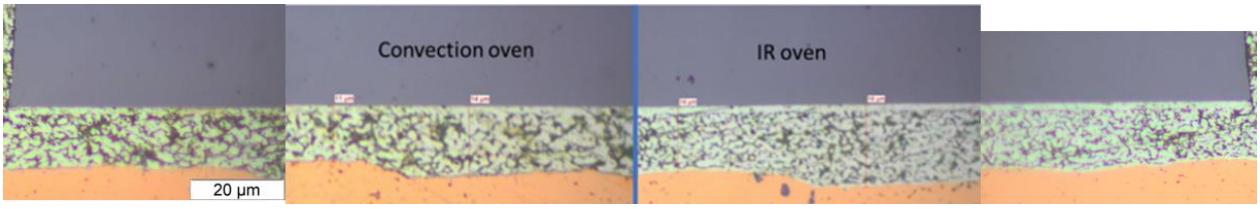



**Figure 17. Cross section images of sintered layer for convection oven (left images) and IR oven (right images)**

**Conclusions and Future Outlook**

The results indicated that sintering using IR is feasible. For pressure sintering, IR is a good method to dry the sinter paste in a short time while keeping a good bonding strength after the pressure sintering process. By implementing an inline concept, a total process time for pressure sintering of about 15 minutes is possible. This is faster than the standard soldering process for power modules.

For non-pressure sintering the feasibility of the IR sintering was shown. The total process time is possible below 60 minutes, which is confirmed for the die sizes of 4 mm². The total process time is reduced by about 75 %.

The sintered structure of the silver layer obtained by IR sintering is more even and it is expected that it will be more reliable than the sintered layers generated in convection ovens. More investigations need to be carried out to verify the hypothesis.

The limitation of die size to create void free sinter layers under the die is still unclear. The first test results show the potential of minimum 25 mm² die size. The goal of IR sintering is to sinter components with minimum 40 mm² die size.

The investigations to find the right parameters for IR sintering is on-going. The investigations provide opportunities to create new paste formulas and new applications for sintering, where the maximum temperature is limited by the substrate material.

**References**

1) Tailored Infrared Tool, Drying and Sintering Processes in Printed Electronics, Jürgen Weber, https://www.heraeus.com/de/hng/industries_and_applications
2) Sinter materials for broad process windows in DCB packages - concepts and results, CIPS 2012, Nuremberg
3) Infrared Basics and Technology, Heraeus Noblelight, Hanau, 2016, https://apps.heraeus.com/IR_Products_D

# Advanced Non-pressure Silver Sinter Process by Infrared


Daniel Schnee

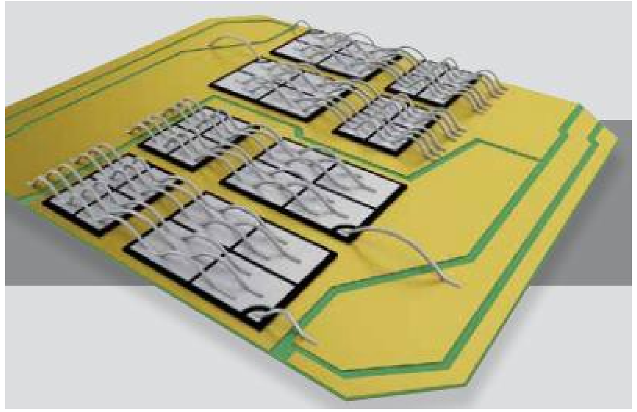
Heraeus Deutschland GmbH & Co. KG

# Topics

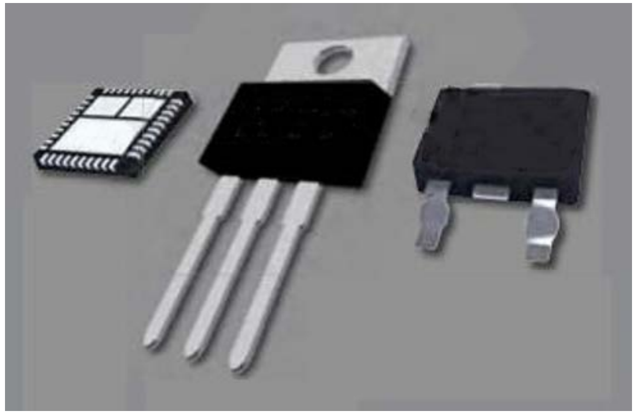
- *State of the art*
- *Why IR?*
- *Feasibility study*
  - Pressure sintering
  - Non pressure sintering
- *Conclusion*
- *Outlook*

# Indroduction

- Power devices
  - *Power modules*
  - *Power discrete*



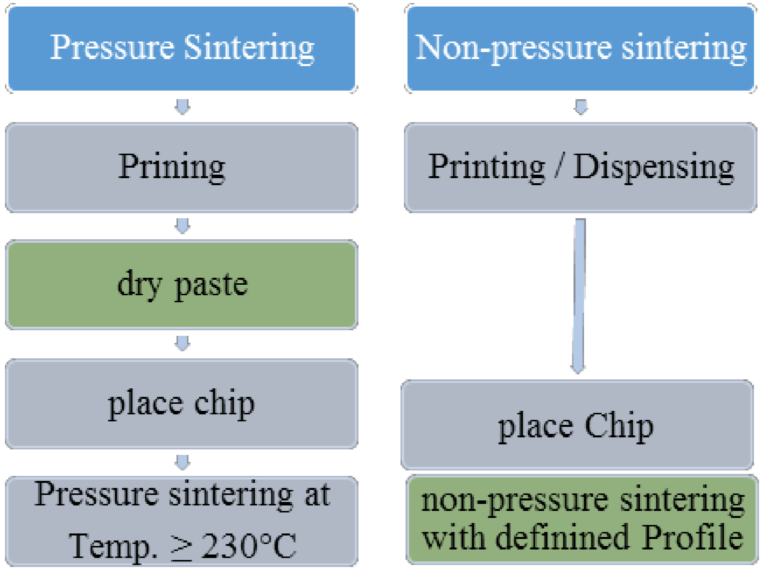
Power Modules
•Highest Life Time
•High Operation Temperature

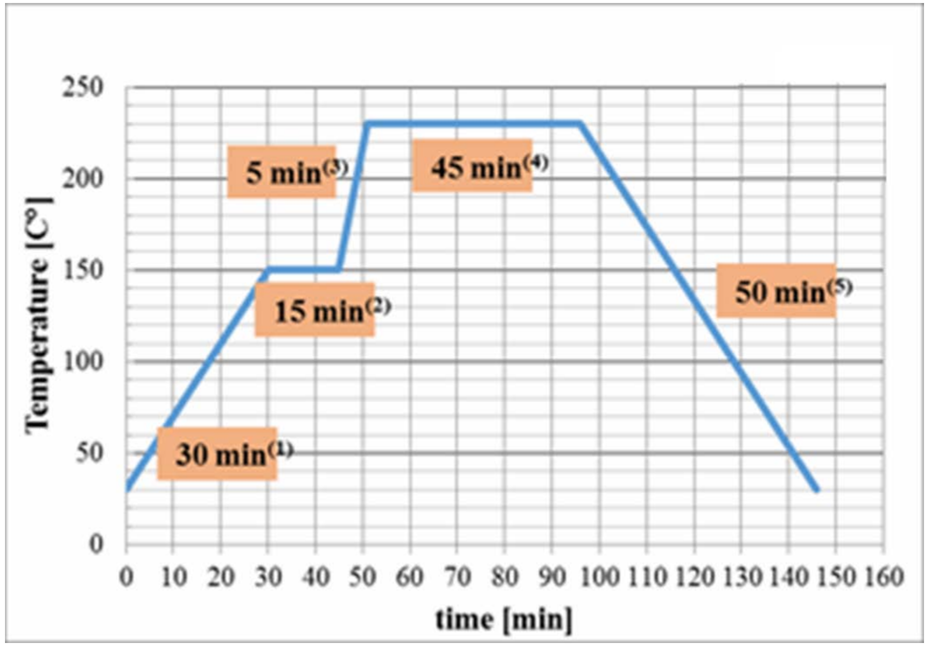


Discretes
•Lead Free
•Melting Point > 260°C
•MSL 1 Proven

# State of the art

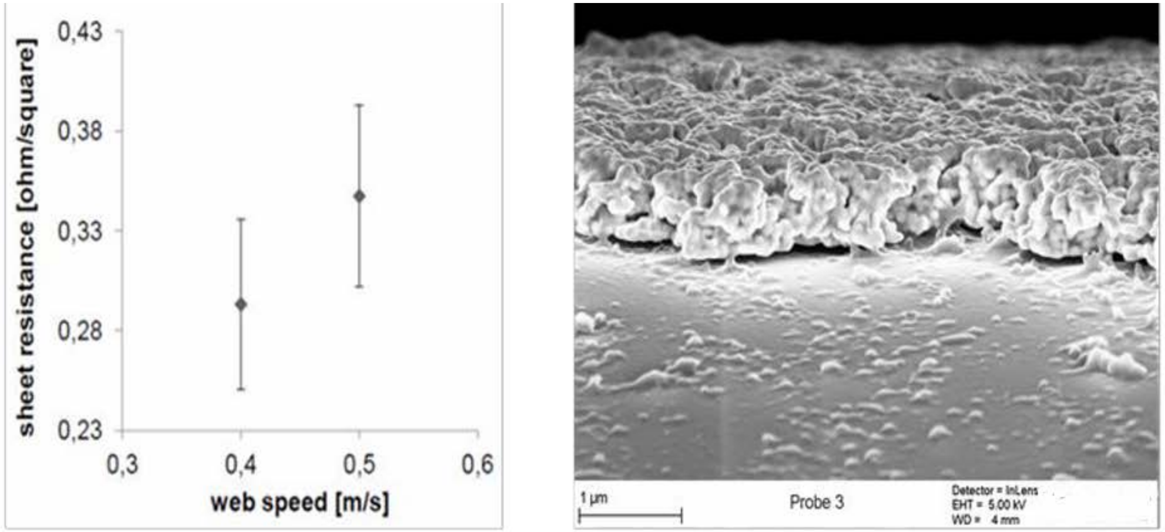
- Pressure sintering
- Non pressure sintering
    - *Long process times*



# Background to IR

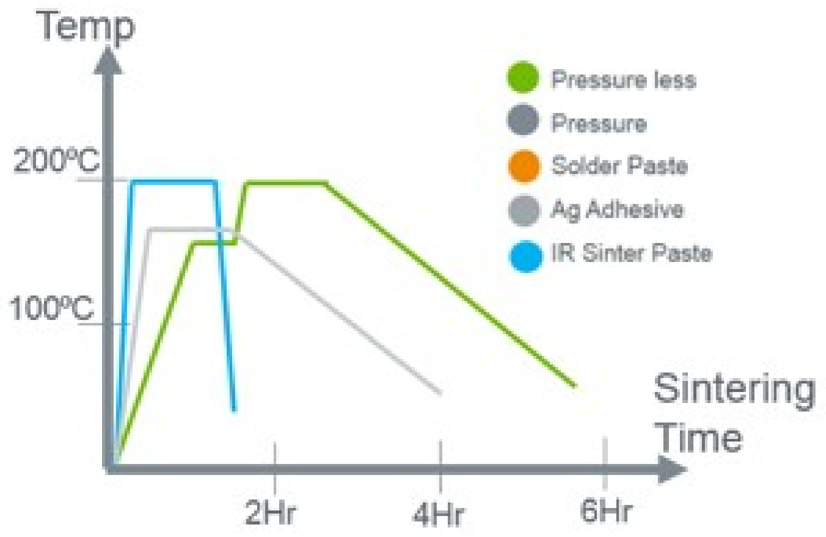
- Dry and sintering with Infrared Radiation (IR) Sintering with IR is already known for printed electronics
  - *Thin silver layers of 1 µm*

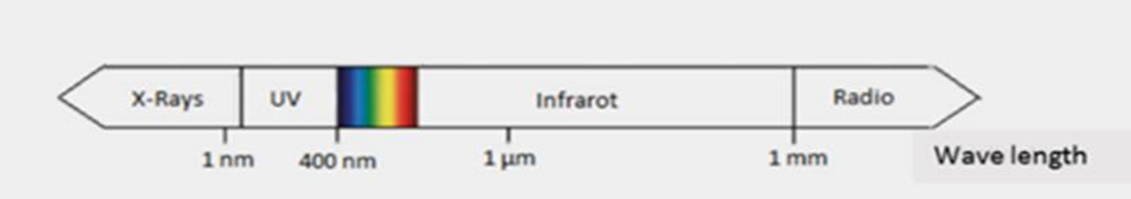


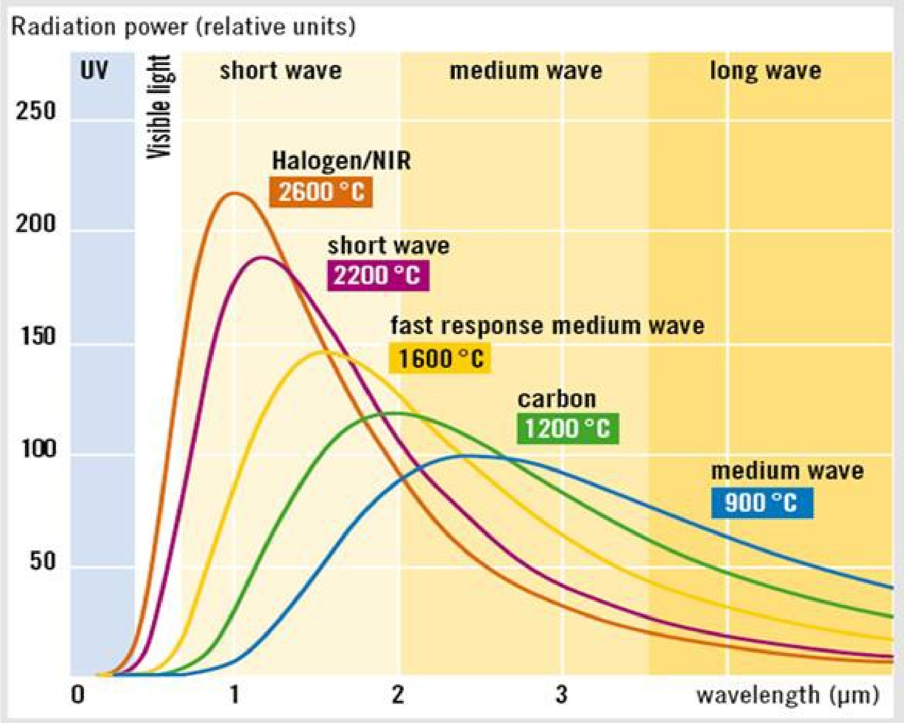

E. Sowade, H. Kang, K. Y. Mitra, O. J. Weiß, J. Weber, R. R. Baumann, *submitted to* Applied Materials & Interfaces (2014)

# Background to IR

- Using short wave length of 700 to 1400 nm
- Potential for shorter process time

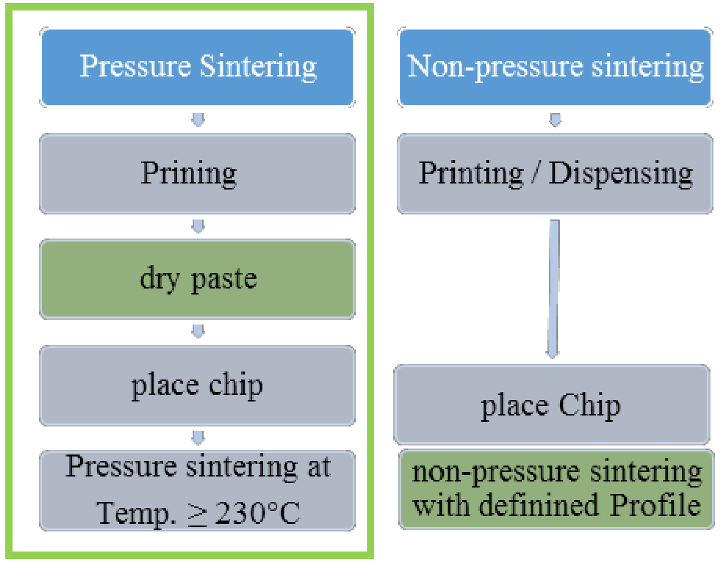


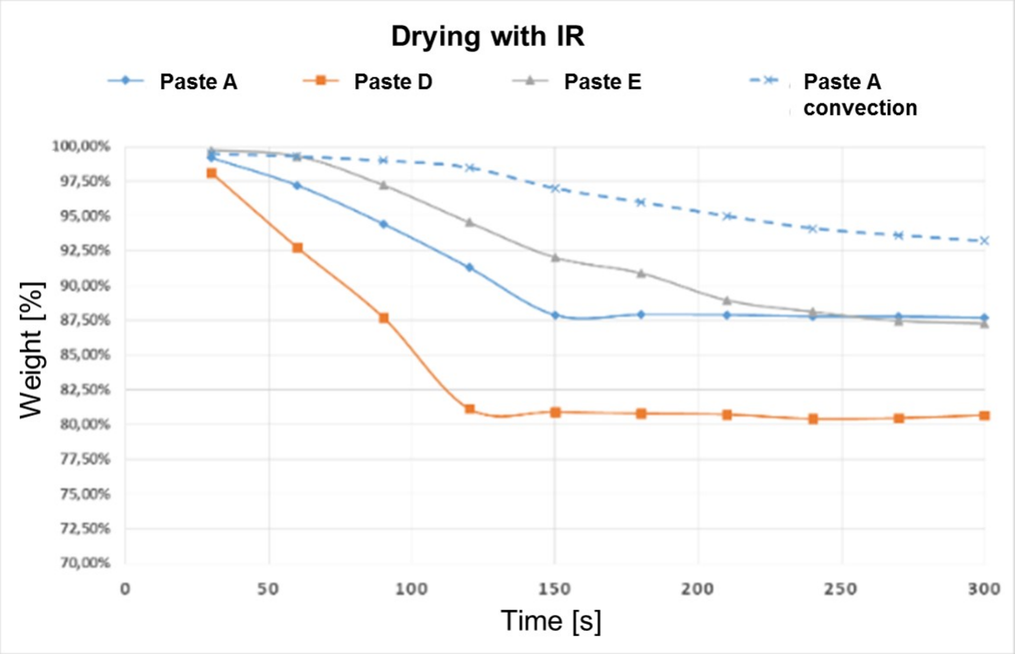
# Pressure Sintering

- Focus is drying the paste
- Different standard paste tested
- Save 20 min drying time
- Total process time reduced from 30 -45 min to max 10 min
- Same shear strength compared to standard process



# Pressure Sintering

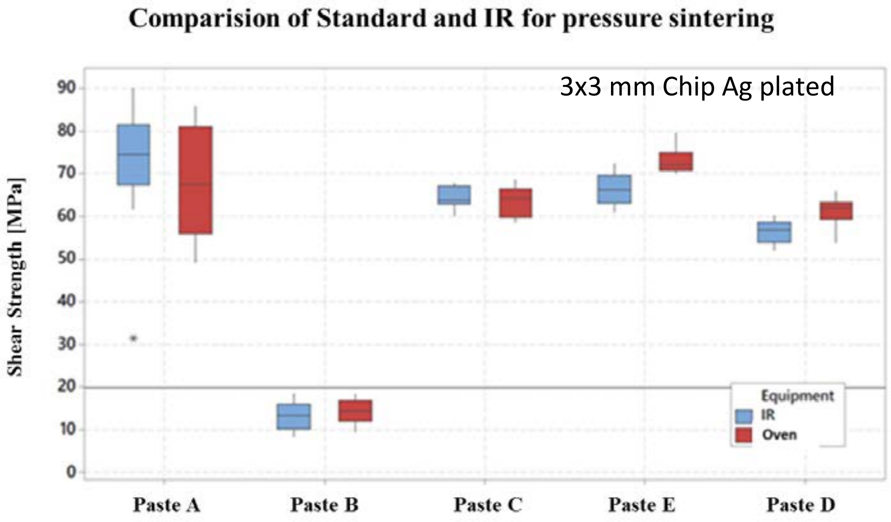
- Test procedure
  - *Print paste on ceramic substrate*
  - *Pattern 20 x 20 mm x 100 µm*
- Test result
  - *Drying time*

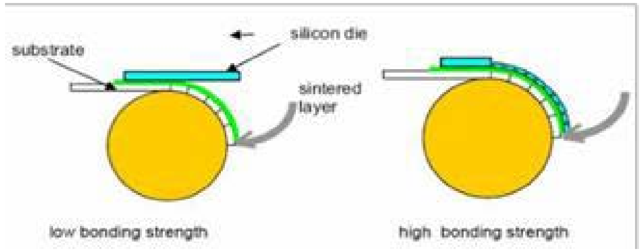


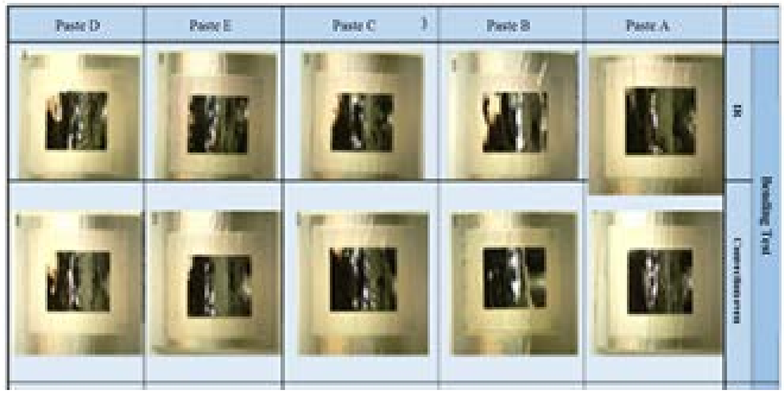

| Paste A (IR) | Paste A (convection) | Paste D (IR) | Paste E (IR) | Paste E (convection) |
|---|---|---|---|---|
| 150 s | 900 s | 120 s | 300 s | 1800 s |

# Pressure Sintering

- Test result
  - *Shear strength*
  - *Bending test*



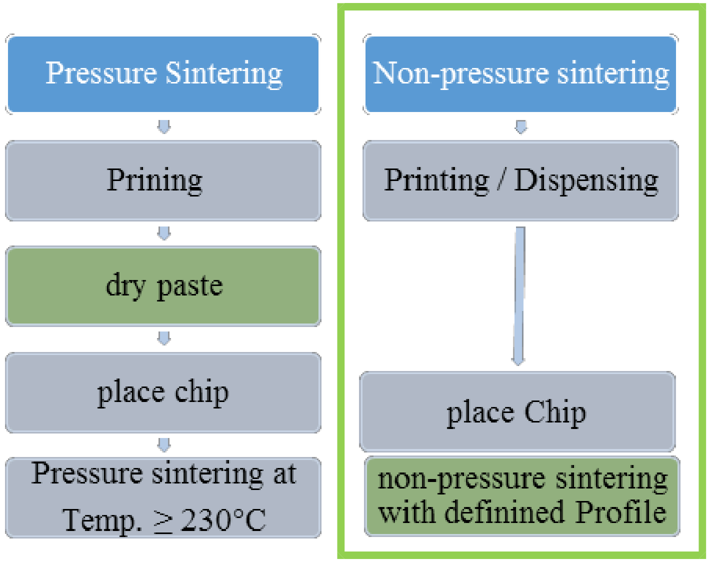




10x10mm Chip Ag plated

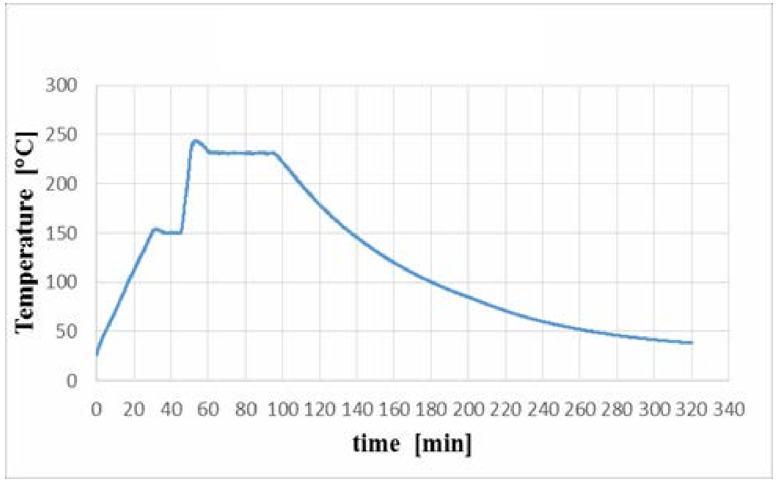
# Non pressure sintering

- Focus is minimizing the total process time from hours to less than 1 hour
- Reduce of voids and drying channels also for larger chips
- Same shear strength like conventional pressure less sintering
- Using of standard non pressure sinter paste

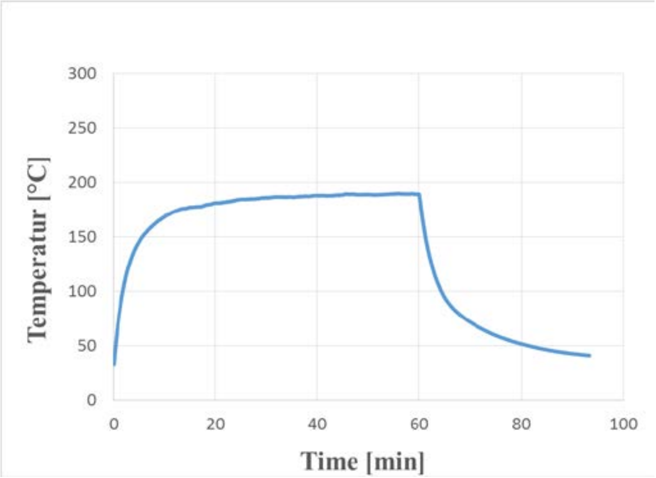


# Non pressure sintering

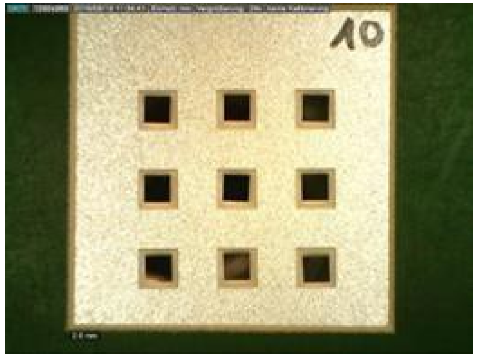
- IR Sinter profile significant shorter than standard profile
- Using 2 x 2 mm dummy Si chips, metallization NiAg




Measured conventional sinter profile

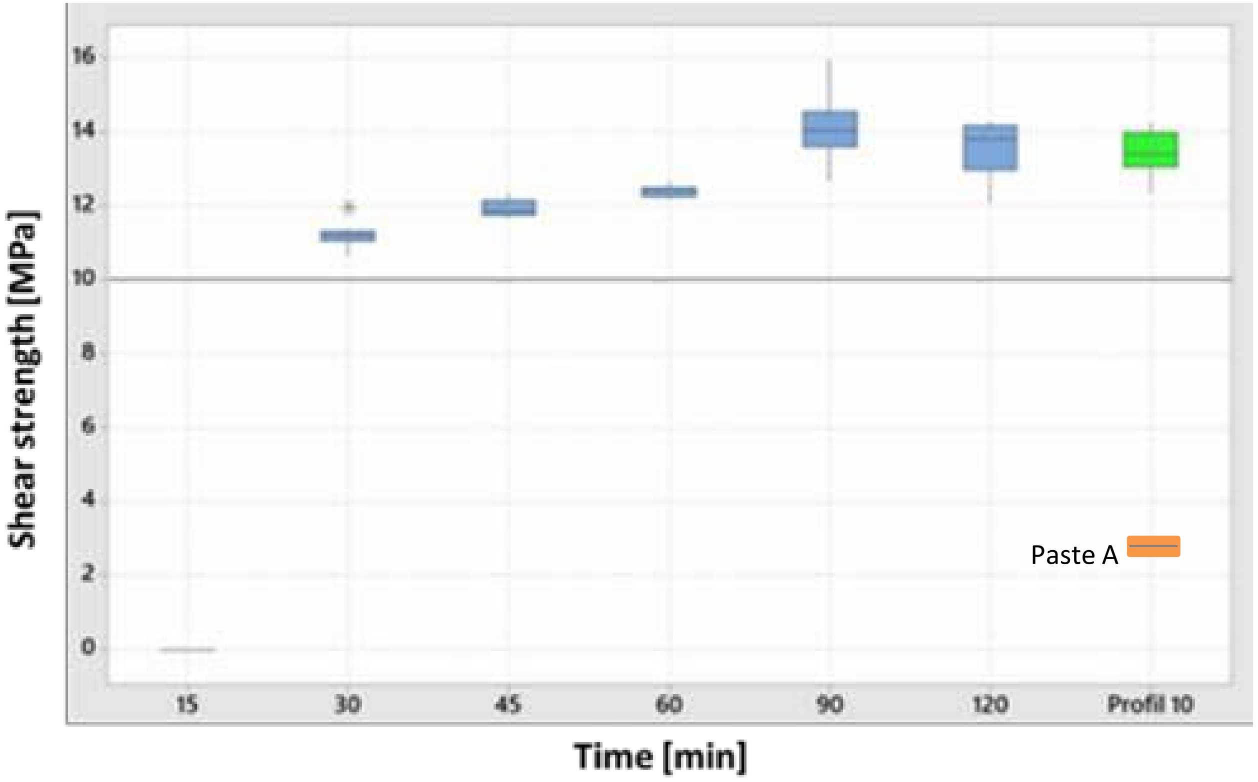



Measured IR sinter profile



# Non pressure sintering - Shear strength study

- IR pass an internal specification of more than 10 MPa already after 30 min. Increased shear strength after longer time.
- After 90 min equal shear strength like sintering with conventional profiles
- Using 2 x 2 mm dummy Si chips, metallization NiAg

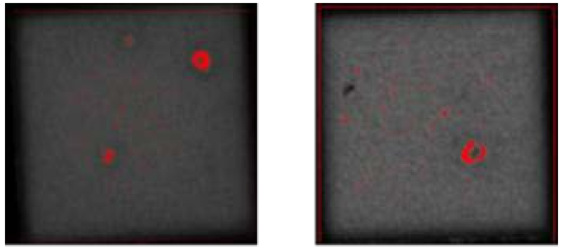



*IR-Sinter results. versus Conventional profile 10 with Paste B.*

# Non pressure sintering

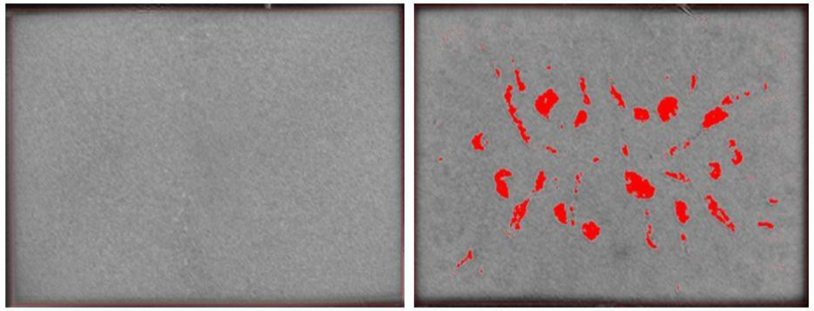
- Void and drying channel study
  - *Same profile like shear strength study*
  - *2 chip size used*
  - *4 and 40 mm²*
- Results
  - *No different with 2 mm²*
  - *4 mm² chips sintered with IR no voids*
  - *Sintered conventional massive drying channels*

*Si-Chips 4 mm², NiAg metallization*



IR Convection oven

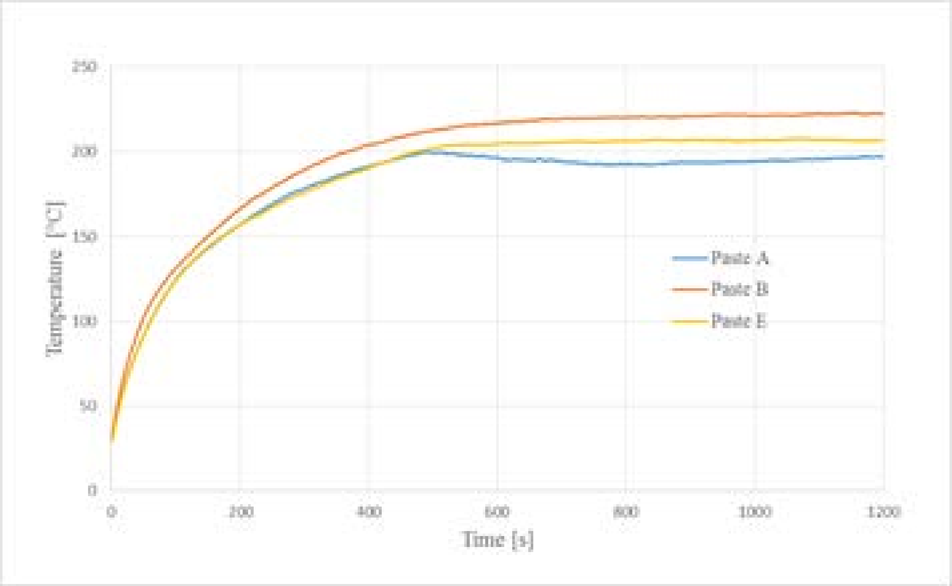
*Si-Chips 40 mm², NiAg metallization*



IR Convection oven

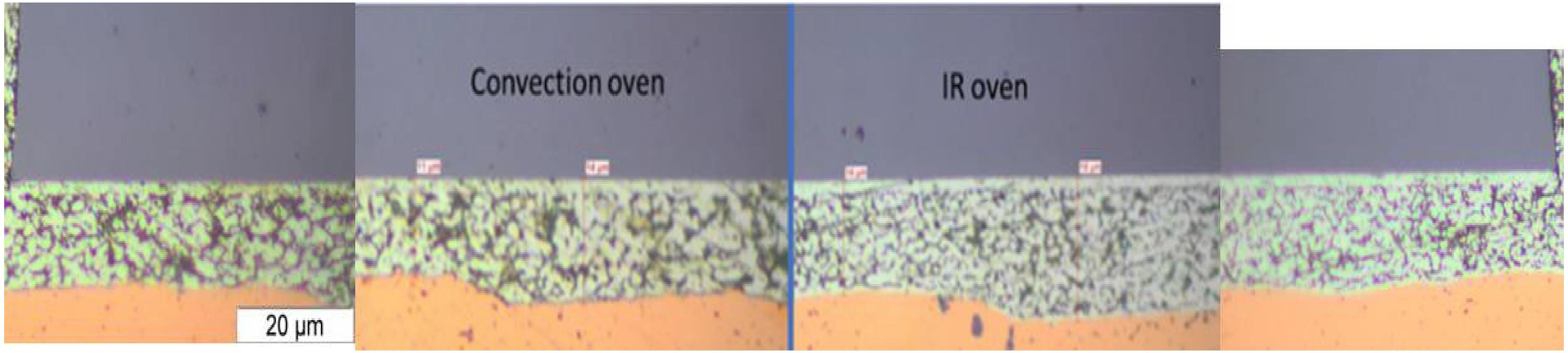
# Non pressure sintering - Sinter paste study

- Different formulations sintered with same conditions
  - *Standard pressure sintering paste*
    - *Paste A*
  - *Standard non pressure sintering paste*
    - *Paste B*
  - *New sinter paste formulation*
    - *Paste E*
- Different behavior
- Different max. temperature
- Formulation influence the sintering in IR



# Non pressure sintering

- Cross section
  - *The images show both samples have fairly similar porosity behavior, however, the porosity of sintered layer obtained by IR sintering is more homogeneously distributed.*



# Conclusions

- *For Pressure sintering total process time could be reduced by* 15 minutes due to faster paste drying.
- IR sintering has a high potential for Non-pressure sintering due to:
  - *Total process time below 60 min possible = reduction approx. 75 %*
  - *Less limitation of die size than conventional process*
  - *Sintered structure of the silver layer being more even*
- Further investigations are needed to evaluate best parameters for IR sintering
- Investigations to create new paste formulas optimized for IR
- New application for sintering, with limited maximum temperature (PCB)