New Technology to Meet Challenging Reflow Requirements

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Abstract
New packaging technologies are making higher demands on components and also jointing techniques. The application of polymer electronics as well as the integration of optical components into the PCB results in a maximum admissible soldering temperature of 150°C on the one hand. The introduction of new lead-free solders raises the soldering temperature up to 260°C on the other hand.

The main objective of developing the soldering methods for electronic devices in recent years was to ensure homogenous distribution of the temperature over the entire board. The introduction of convection soldering therefore showed great advantages compared with the infrared soldering processes which were being used previously. Vapour-phase soldering meets the demands of special components and assemblies which can only withstand slight variations in temperature.

It is no longer sufficient to satisfy the requirements of merely distributing the heat homogeneously nowadays and for future applications. New demands are additionally being made on reflow machinery and processes by the transition to lead-free manufacturing processes. This situation particularly applies to issues such as the parallelism of conveyor rails as well as process gas cleaning.

The current demands made on polymer electronics, electro-optical assemblies and high-temperature electronics require a new technology for making the soldered joints, which allows the solder paste deposit to be heated stronger and faster than the temperature-sensitive components and substrates. This new technology, which is particularly interesting for the production of RF-ID tags or 'Smart' labels, combines a simultaneous soldering process (jointing of all components at the same time) with selective heating (the soldered joints can be heated up more than the substrate and components). Such a process combines convectional reflow soldering and microwave heating. A joint project called 'MICROFLOW', which is being funded by BMBF (the German Federal Ministry of Education and Research), is intended to develop a combined reflow soldering machine.

This paper highlights the first results of practical research from the MICROFLOW project. It also examines in detail all of the issues concerning lead-free soldering techniques in relation to the machine.

********Hinweis vom Übersetzer: ich habe den o.g. geschriebenen Text korrigiert*.***
Initial situation

The general objective of developing various soldering processes for assembly technology in the past was to ensure that the temperature could be distributed as homogeneously as possible over the soldered assemblies. Whereas infra-red radiation that impinged on components with large thermal capacities only caused them to warm up very slowly, small components were overheated far beyond the requisite soldering temperature. 'Forced convection' had therefore become the dominant reflow soldering process during the 1980s. This process had also reached its limits occasionally in the case of particularly demanding components such as large BGAs for example, where the soldering connections are located underneath the components. The surfaces of printed circuit boards and components reach temperatures that are often more than 15°C to 30°C above the temperature of solder balls which have to be soldered. Multi-layered printed circuit boards with at least 20 layers require very long soldering times until the entire assembly has been warmed up and the soldering deposit has reached the soldering temperature too. Nowadays, it is possible to reduce the differences of temperature further by using the vapour-phase soldering process. Differences of temperatures that are virtually nothing can be achieved by means of the condensing vapour's high coefficiency of thermal transmission, even for demanding assemblies.

The aforementioned demands made by polymeric electronics, electro-optical assemblies and high-temperature electronics necessitate further development of the soldering technique, so that only the actual soldered connections will be warmed up in the process if possible: this can only be achieved nowadays with selective soldering processes like stirrup soldering or laser soldering. However, the matter in this case always concerns sequentially working, selective, soldering processes which considerably limit the number of components for treatment to one assembly. Nevertheless, a simultaneous soldering process that has a selective effect at the same time is required for a cheap industrial process which meets the aforementioned objectives, but such a process is certainly not available for electronic assemblies yet. The conceptual solution that is described below has been derived from generally developing the manufacture of assemblies in a study which was commissioned by the firm of SEHO [1].

Objective

It is basically possible by means of electro-magnetic fields to achieve the selective warming-up in a productively simultaneous process that one is seeking, during which the energy penetrates the work piece which has to be warmed up and stimulates the material's properties in specific areas by relying on it. The well-known process of inductive warming-up in the low, medium and high frequency ranges is able to accomplish that in principle, but it requires the inductor to be geometrically adapted to the soldered assembly's shape as well as possible

On the other hand, the use of electro-magnetic fields – which is well-known in the area of household microwave ovens – offers an essentially more flexible possibility to warm up tools of various sizes in a large volume and with high throughput. Specific prerequisites must certainly be fulfilled in order to be able to transfer this effective warming-up method to the manufacture of electronic assemblies.

- The system's reliability must be ensured, even with an open throughput system.
- No damage is allowed to occur in the assemblies and components because of thermal or electrical stress.
- The volume (solder and soldered connections) that has to be warmed up effectively must be able to be warmed up noticeably quicker and more intensively than all of the remaining components.

Reliability can also be ensured for modern micowave systems, even in an open throughput operation under manufacturing conditions. Appropriate systems can be made nowadays – which are ready for serial production and can typically be used for drying wood and other materials – by means of suitable screening measures in the internal and external areas, even for large quantities with high throughput. It is more difficult to answer the question about adversely affecting the electronic components and assemblies. Examples from adhesive technology have already shown that it is possible to apply microwaves reliably in micro-electronics too [3]. Care has to be taken while doing so – as with every other form of energy too – that specific limiting values will not be exceeded. A conventional household microwave oven has a very inhomogeneous distribution of the field – not only chronologically but also locally – because of the source's simple phase, which will only be compensated for by rotating the article to be warmed up. However, such a compensation is much too sluggish and it would inevitably lead to the article's destruction: this is why it is vital to ensure that the field's distribution is as extensive and homogeneous as possible, without local and chronological peaks occurring. This problem is also solvable with the present state of technological development in the construction of modern microwave systems.

The question remains about selectivity of the achievable warming-up regarding the utilized soldering materials. Initial preliminary tests have shown that the remaining solder paste can only be warmed up very slowly and with a high power density. Examples taken from recent literature [4, 5], prove that solders only melt in the microwaves after very long processing times and normally indirectly via the heated-up surrounding assembly.

This is why another approach for using microwaves is being pursued by the research project [2] that was derived from the study [1]. The applied power density can be increased substantially by adding a defined quantity of an extremely well coupled material, which can be coupled to the solder paste, i.e., a so-called susceptor. Such susceptors must have appropriate polar or di-electric properties and they can be added to the solder paste in solid or liquid form, as shown in Figure 1. The solder can be warmed up considerably more quickly than the other assemblies in this way, whereby the requisite energy will be further reduced too.

Hinweis vom Übersetzer: "liquid emulsions" (kein "s" in "liquid")

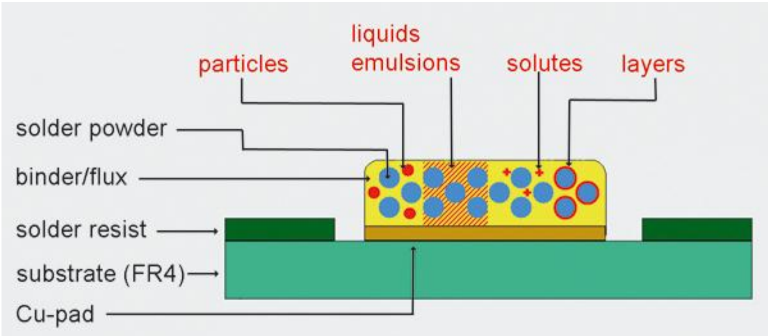

Figure 1 Possibilities for introducing susceptors which are suitable for microwaves into a solder paste.

Basic tests with microwaves

Initial basic tests were carried out with BiSn solder pastes having low melting points and possible susceptors at a melting temperature of 139°C, in order to check the proposed concept's feasibility. It has been clearly proved already in the test results, which are shown in Figure 2, that the requisite temperatures can be transferred to the solder with suitable susceptors, even if the non-molten solder paste's appearance still does not correspond to the soldering technique's requirements.

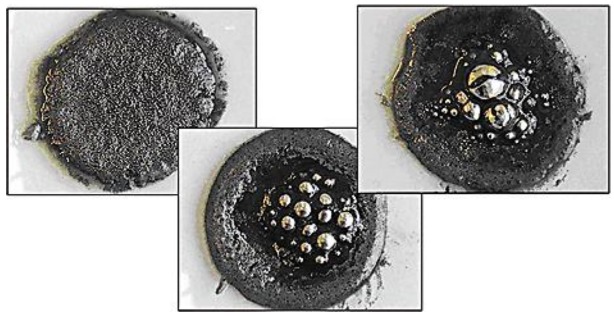

Figure 2 Basic test on microwave soldering with a BiSn solder paste with or without susceptors.

The further test and selection of susceptors identified some versions with which noticeably higher temperatures were able to be achieved and conventional soft solders could be melted around too. The most effective possibility for thermal transmission in the microwaves resulted from using liquid susceptors (Figure 3). An even quicker rise in temperatures resulted from better contact of the liquid with a solid surface: the requisite soldering temperature of 245°C for lead-free solders was safely reached in this case too. A further advantage of utilizing liquid susceptors is a smaller quantity of residues which remain around the soldering points after the soldering process has been completed. The process materials (e.g., fluxing agents) can thus be completely vaporized at an optimally chosen boiling point and soldering temperature.

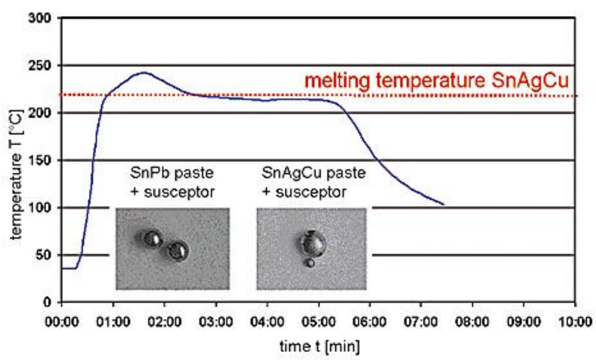

Figure 3 Temperature curves for a solder paste's solvent with liquid susceptors.

Nevertheless, it is insufficient to bring the solder paste up to melting point by means of the microwaves: the effect of microwaves on the components as well as the changing effect of the assembly's individual components among themselves are decisively significant too. Appropriate tests on the effect of incompletely vaporized liquid residues on the printed circuit board led to the finding that the susceptors cannot be expected to damage the base material or metallization. In addition, it has been ascertained by adjusting the frequency and the highest homogenously possible distribution of the field, that it is possible to maintain a production of soldered connections without damaging the components. A reliable processing time without any damaging effect on the printed circuit board to be processed was able to be defined because of this (Figure 4).

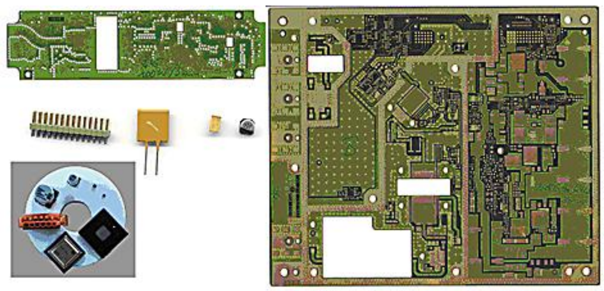

Figure 4 Compatibility of the components and printed circuit boards with microwaves.

<u>Combined microwaves: reflow</u>

The use of hybrid warming-up is a further important aspect of the concept which is being pursued by the research. The basic warmth can be generated with a pre-warming process in the conventional way by means of convection because it is required to keep the differences of temperature on the assembly as low as possible anyway for minimizing the thermal stresses on the assemblies. The soldered connections must only be heated up by the microwaves to an extra 30°C at a pre-warming temperature of typically 200°C in the lead-free solder process in order to enable reliable melting around them. The combination of selective input via the susceptors and hybrid warming-up ensures that the reflow soldering process is conserving and effective. Figure 5 shows the arrangement for integrating a microwave module into a convectional soldering system, in order to ensure that the hybrid warming-up principle functions.

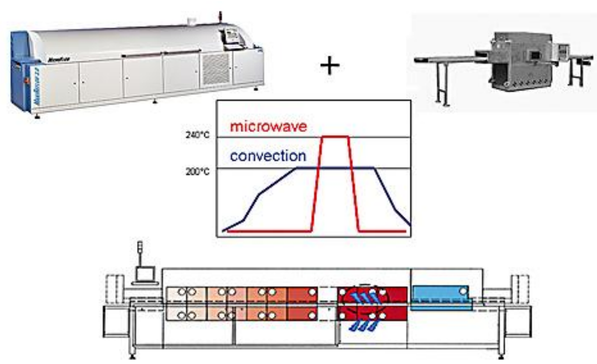

Figure 5 Integration of a microwave module in a convectional soldering system.

A further advantage of such a hybrid conceptual system is that conventional solder pastes without susceptors can continue to be processed as well and the microwave energy will be ‘added in doses’ as needed and to suit the assembly which has to be processed.

<u>The most important results</u>

Laboratory samples have adequately proved that this project idea can be implemented successfully. Figure 6 shows a printed circuit board where the soldering deposits have been completely melted around the components, as well as some soldered components on the printed circuit board without further detectable faults. The following photographs in Figure 7 document the well-known appearance of the lead-free soldering technique, not only in the macroscopic condition but also by means of the metallographic analysis.

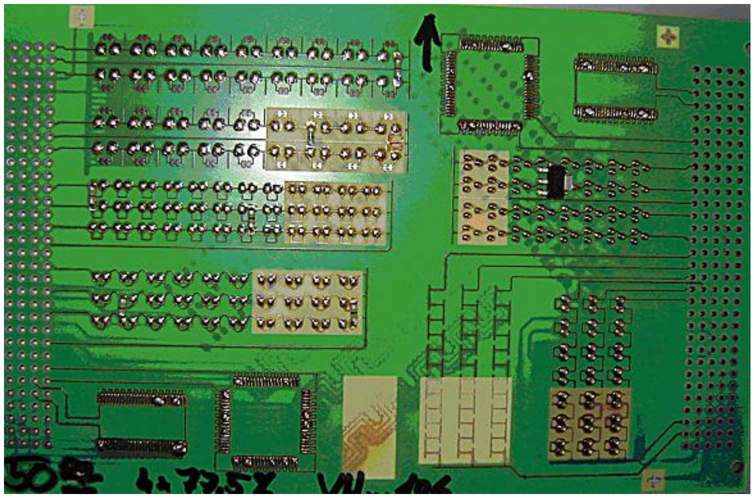

Figure 6 A test assembly which has been soldered in the combined convectional and microwave system.

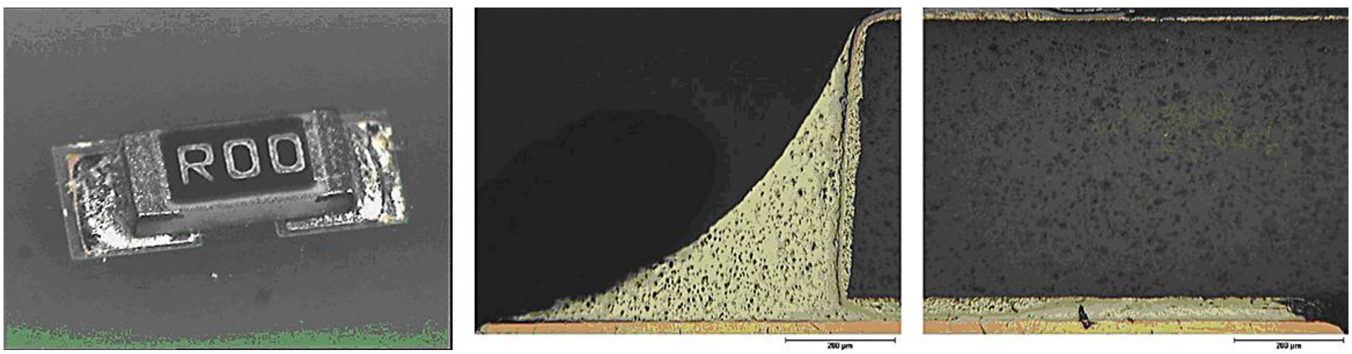

Figure 7 Macroscopic and microscopic representation of a connection which has been soldered by microwaves.

A detailed representation of the results will be given in the final report about the project, which will probably appear in February 2008. In addition, a session will be held about the project's results within the framework of the 'Electronic assemblies and printed circuit boards: EBL 2008' conference, which will also be jointly organized by the FED.

<u>Summary and outlook</u>

All of the described results from this contribution are based on the joint work by the project's consortium, which comprises the firms of Seho Systems, Fricke and Mallah, Heraeus, Daimler-Chrysler, Peters Research and Inboard, as well as Fraunhofer IZM. The 'MICROFLOW' combined project is being sponsored by the Federal Ministry of Research.. We would like to take this opportunity of thanking all the participating partners as well as the project's organizer – Karlsruhe Research Centre, which is in charge of this project – for their good cooperation and support.

The results which were gained from the current 'MICROFLOW' combined research project confirm the hypothesis that it is possible to induce selective warming-up in the simultaneous process through coupling the hybrid warming-up and thermal input into the solder paste by means of susceptors. Adaptation of the materials has meanwhile led to the development of solder pastes on the basis of lead-free SnAgCu solders with a melting point of 217°C. The object of the final work to be done before the project finishes consists of optimizing the hybrid systems engineering and defining the processing time with sufficient reliability.

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New Technology to Meet Challenging Reflow Requirements

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Technical Requirement for New Solutions: MICROFLOW

RoHS & WEEE

↓

Pb

↓

soldering temperature ⇑⇑ & soldering time ⇓
or
soldering temperatue ⇓ & soldering time ⇑⇑

↓

increased thermal stress for the various components of an assembly

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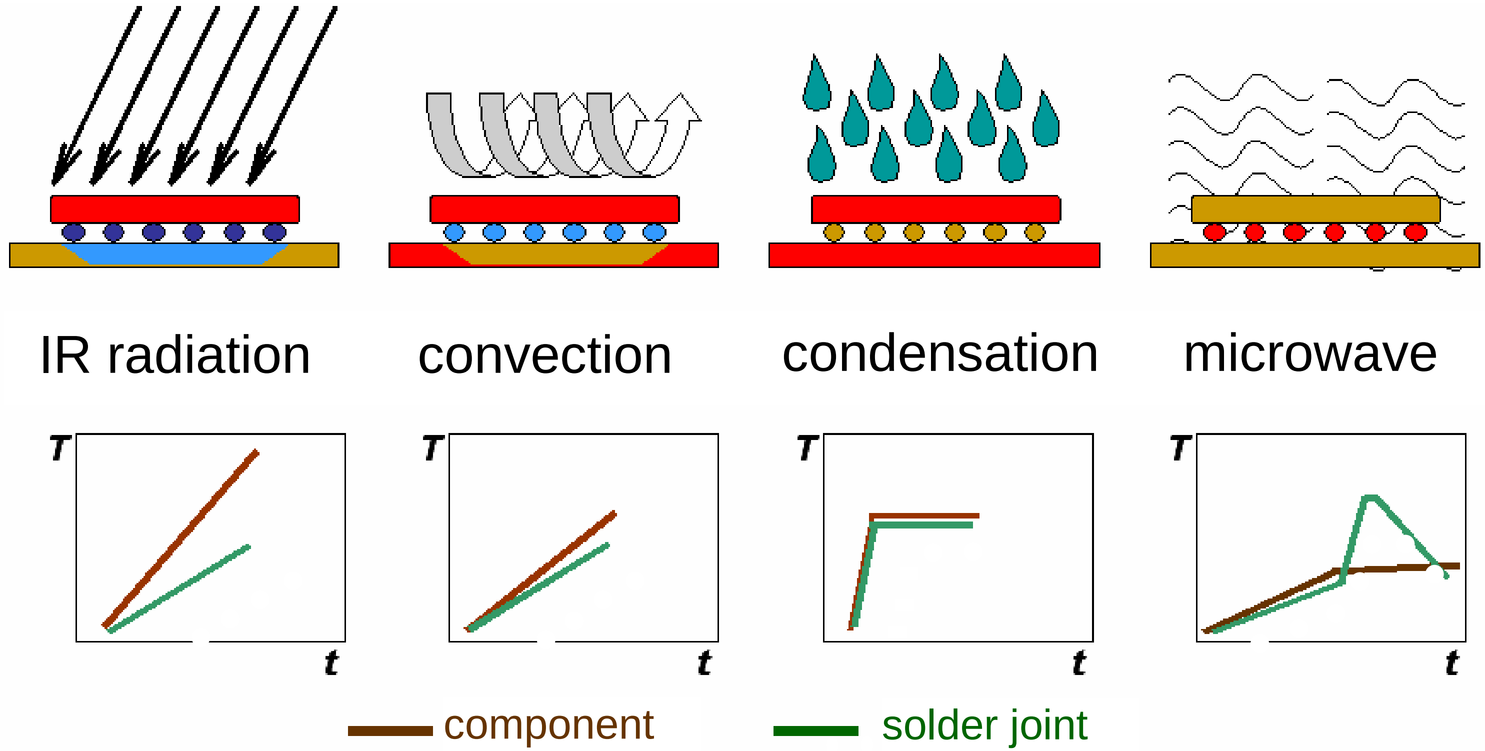
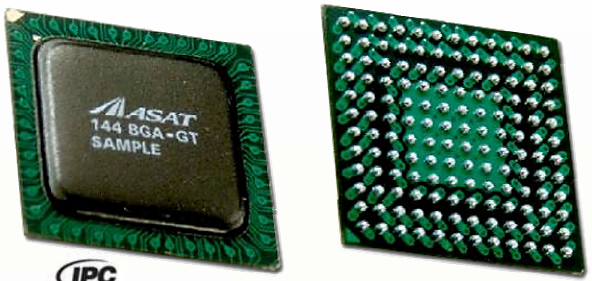
thermal release of the assembly
due to selective heating
with electromagnetic waves

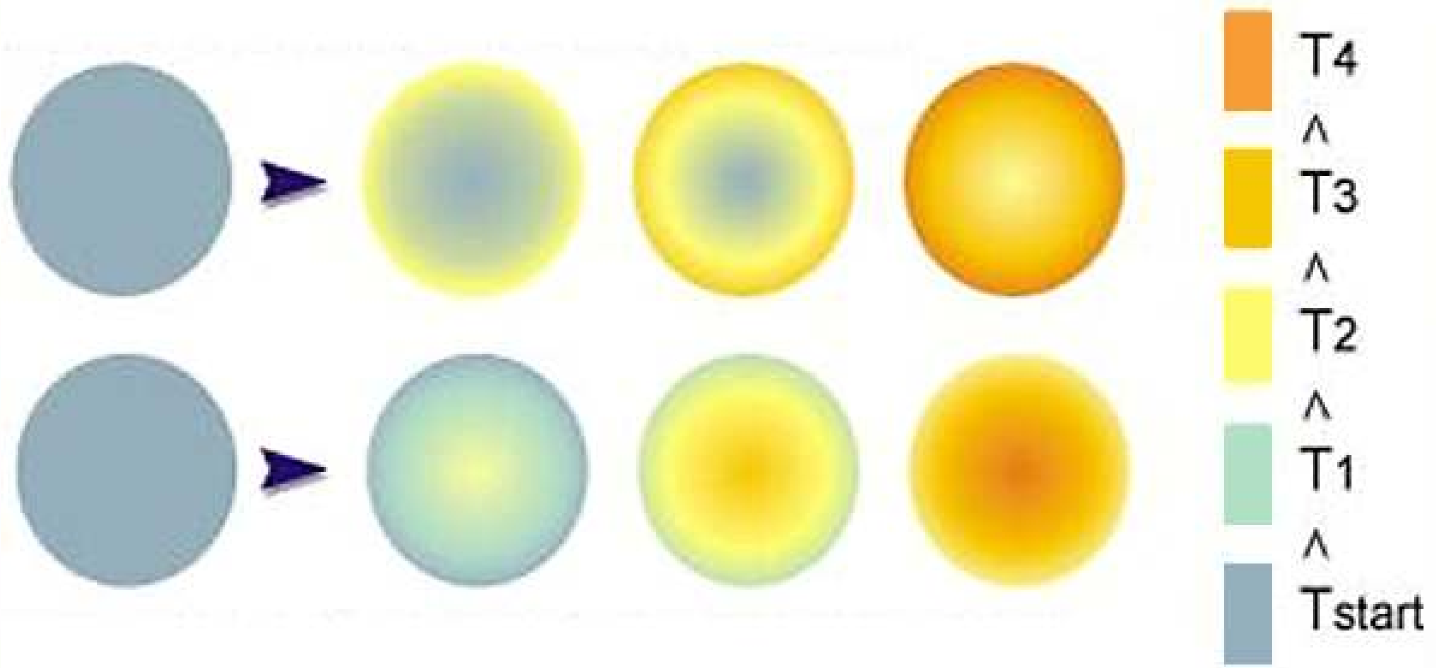
Reflow Technologies and Heating Behaviour





Thermal Effect and Advantages of Electromagnetic Waves

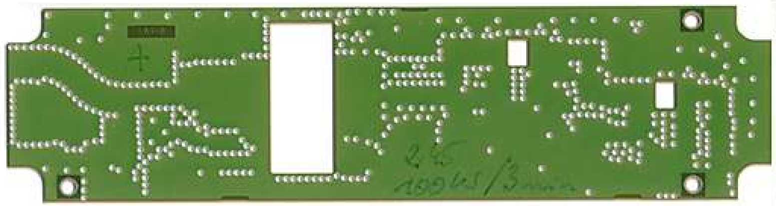
heating with thermal convection

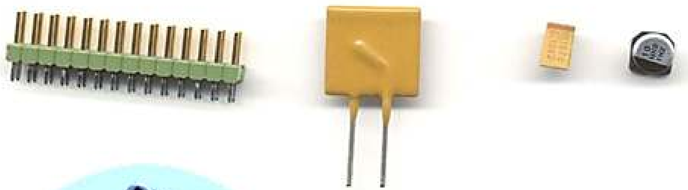


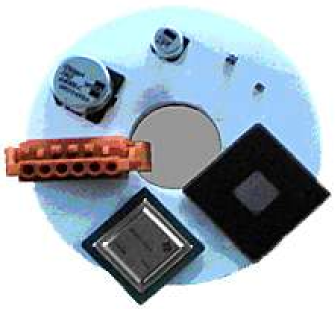
volumetric heating with microwaves

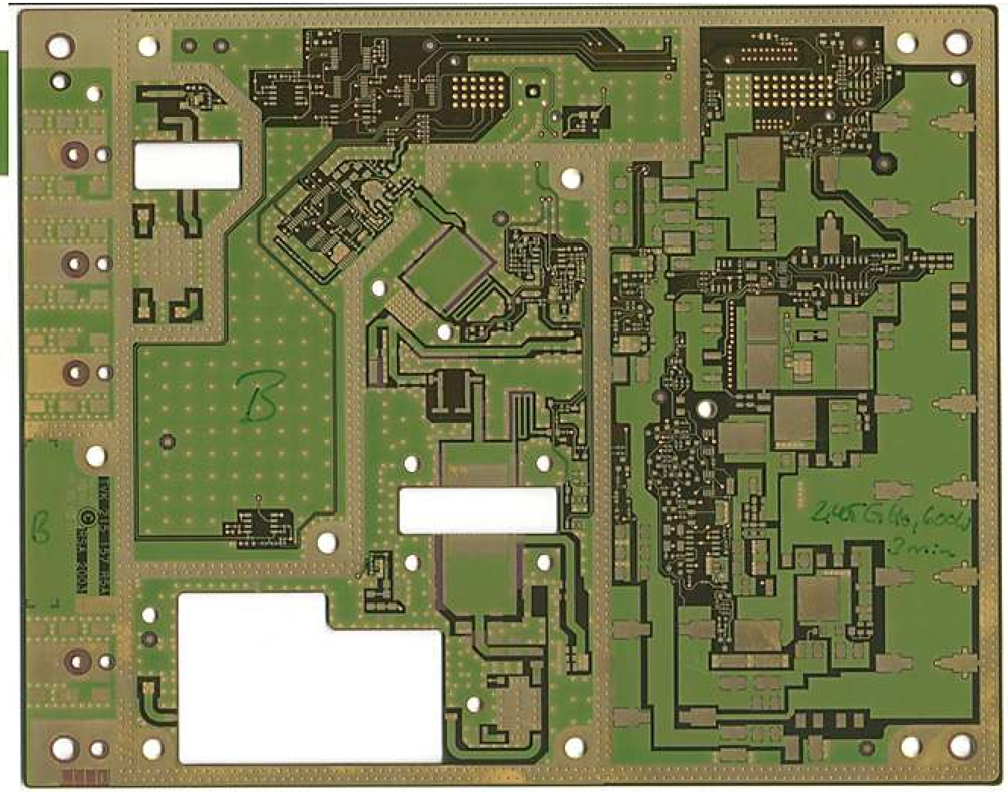
- selective
- volumetric
- low energy consumption
- short process times

Verification of Microwave Compatibility for Components and Boards with Adapted Power and Frequency

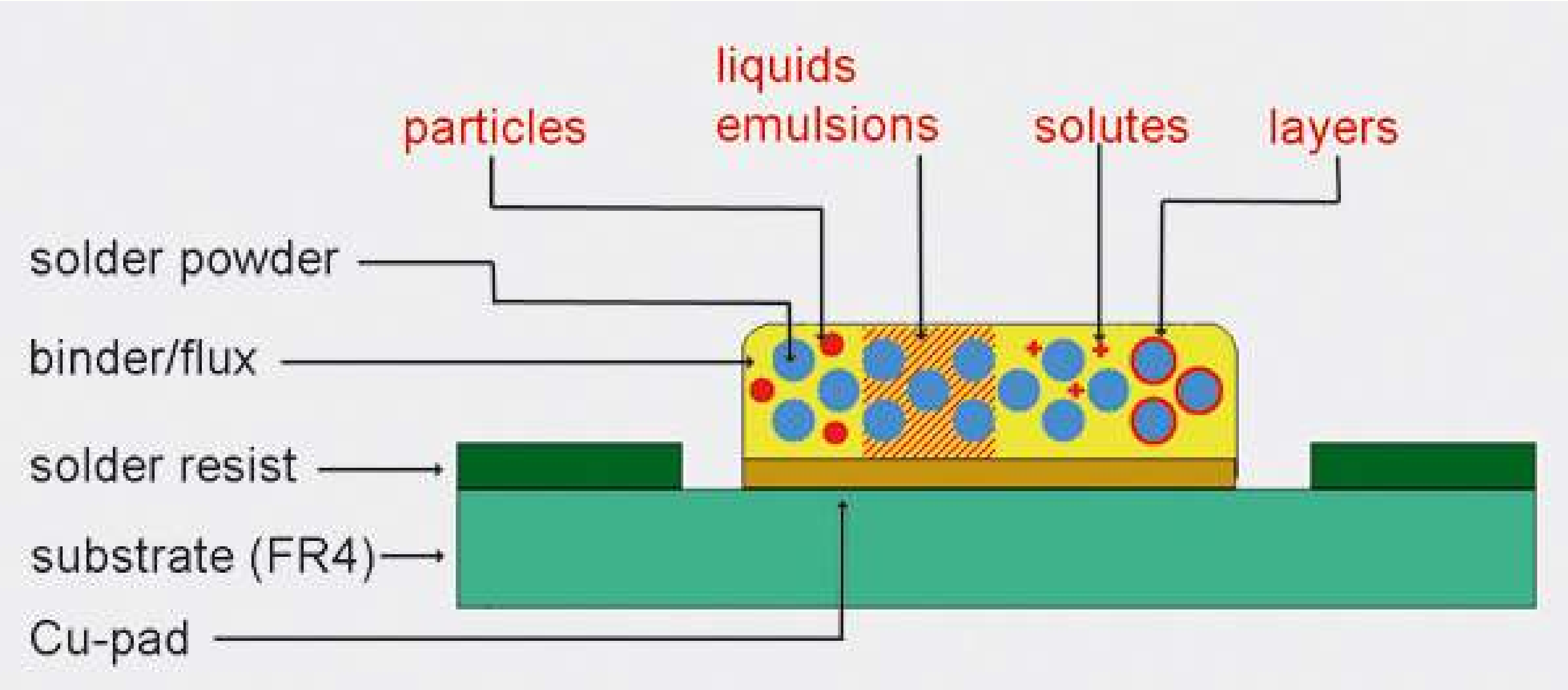




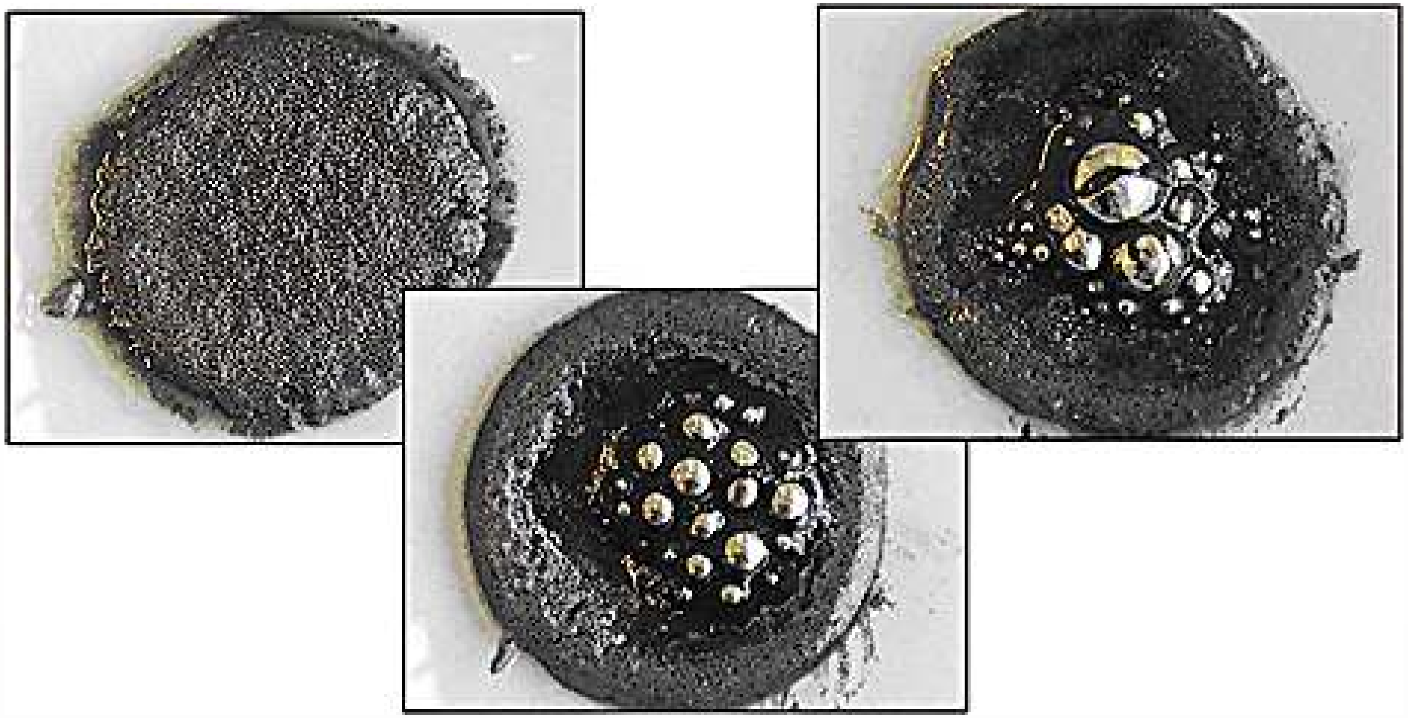




Different Possibilities to Add Microwave Adapted Susceptors to the Solder Paste



Selection of an Appropriate Susceptor – Basic Tests

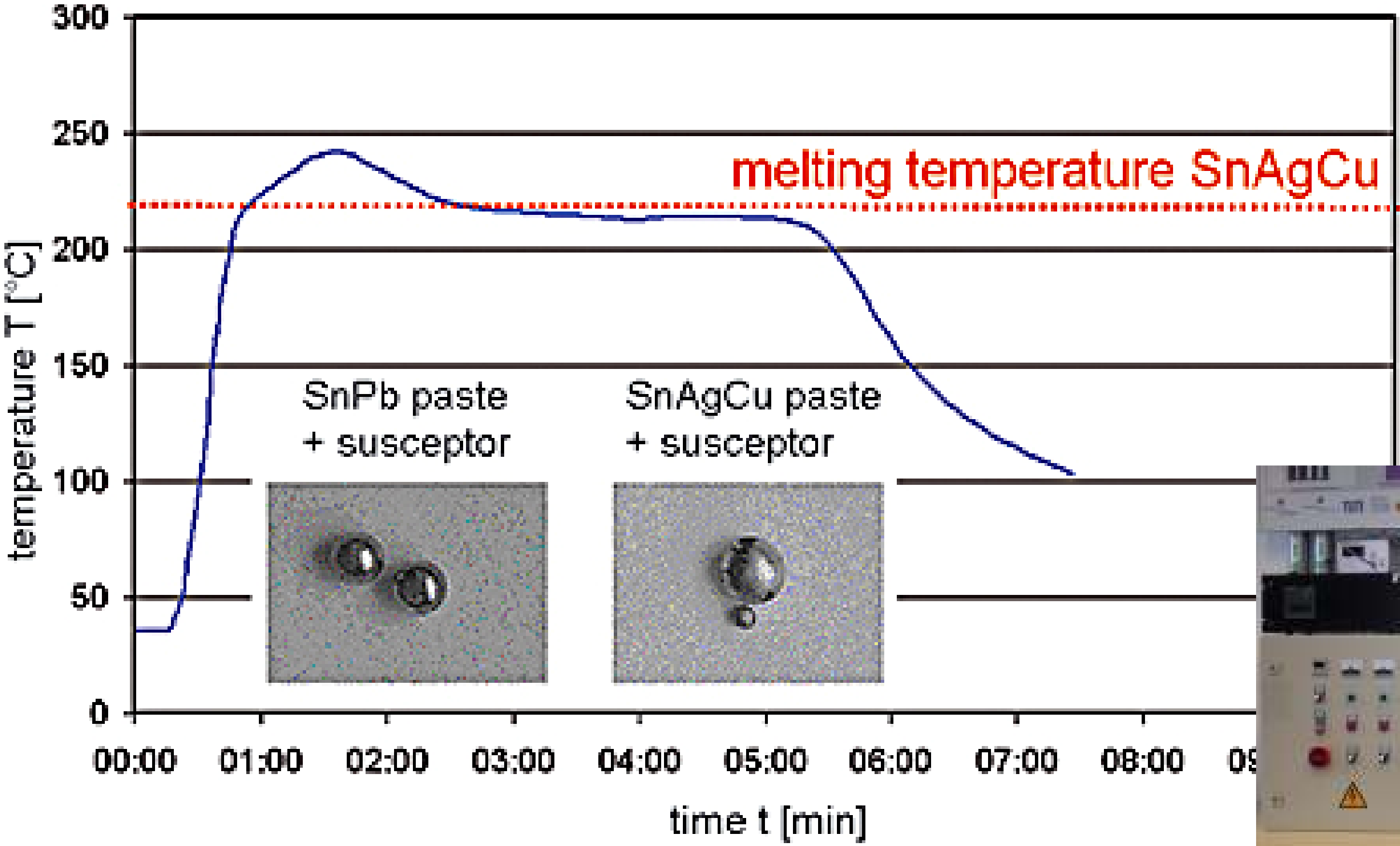


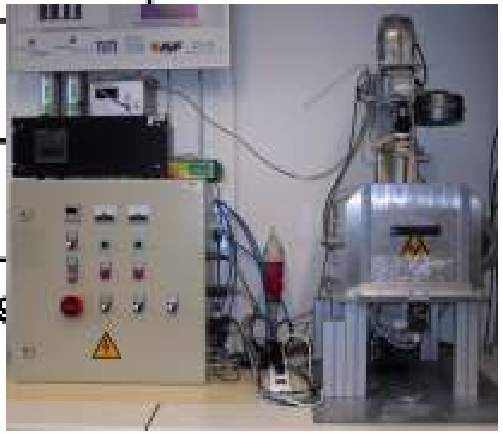
Selection of an Appropriate Susceptor – Ionic Liquids

Characteristics

- thermal stability, non-inflammable
- very low vapour pressure
- very good solubility
- good electrical coductivity
- high electrochemical stability

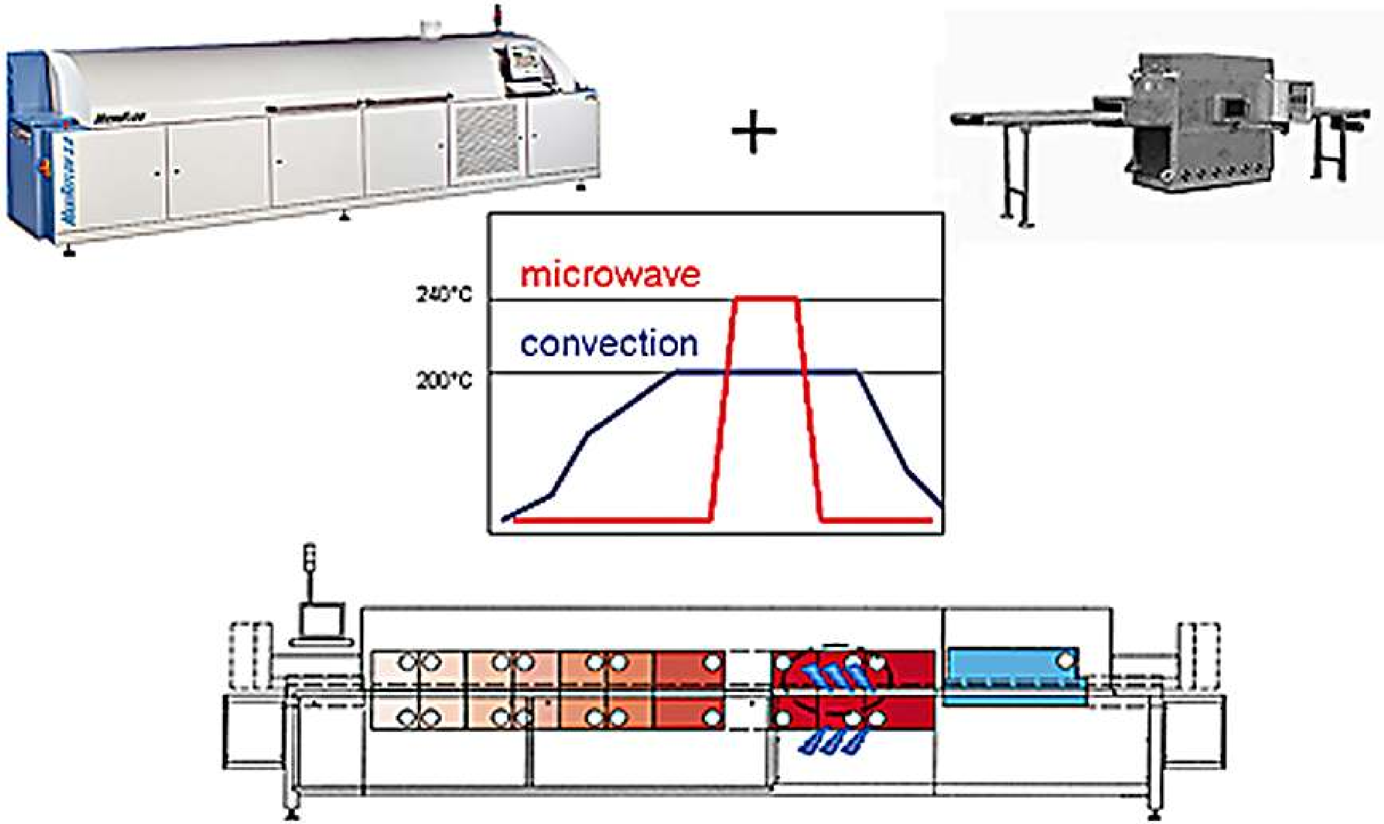
Selection of an Appropriate Susceptor – Ionic Liquids





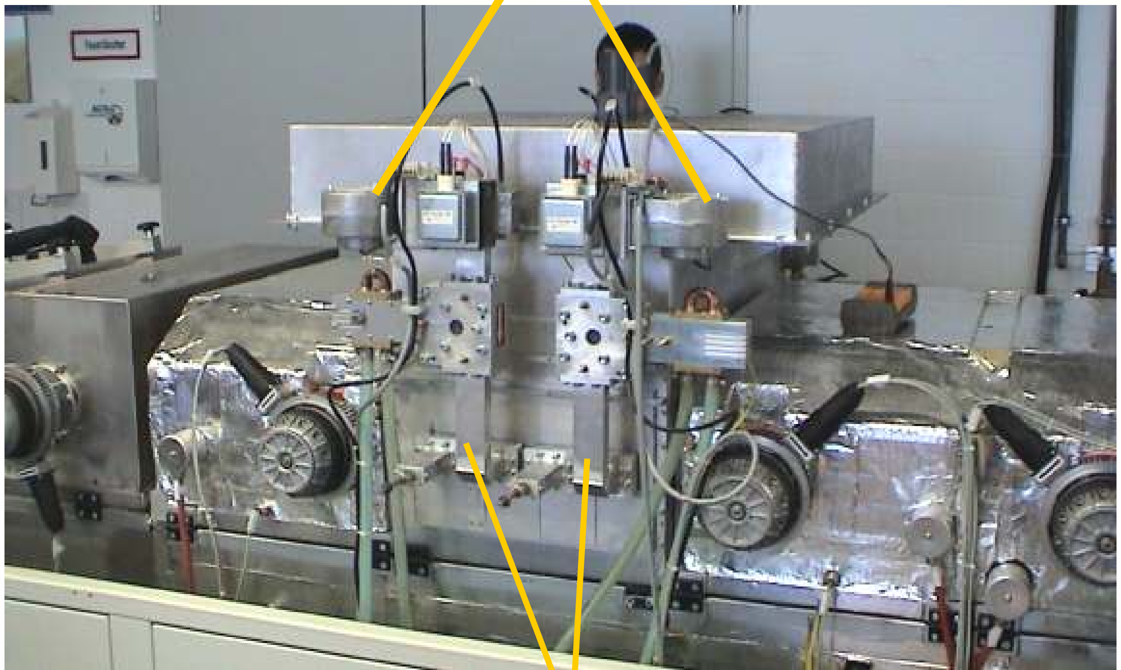
Transfer of the Basic Findings into Maschine Technology

Hybrid Heating Concept



Hybrid Heating Concept – Selection of the Microwave Module

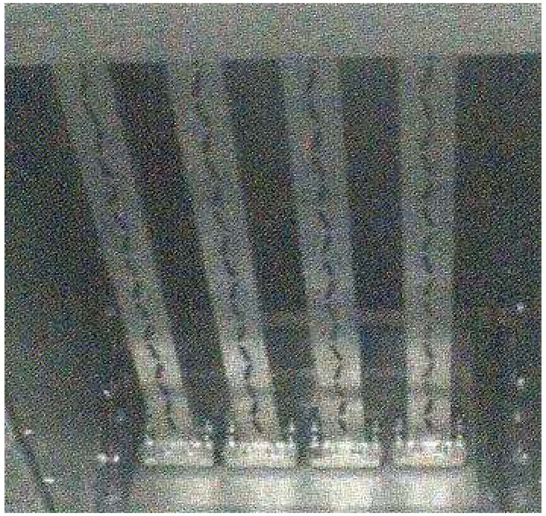
microwave modules
(2 on each side)



waveguides with deflection

Hybrid Heating Concept – Transfer of the Microwaves

Transfer of the microwaves via waveguides into the process chamber

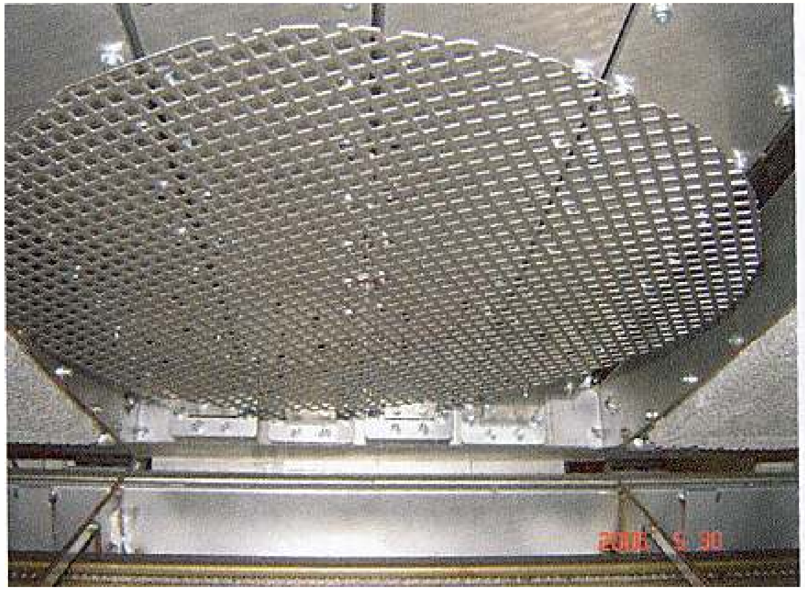


first design

new design

Hybrid Heating Concept – Distribution of the Microwaves

Distribution of the microwaves using stirrers



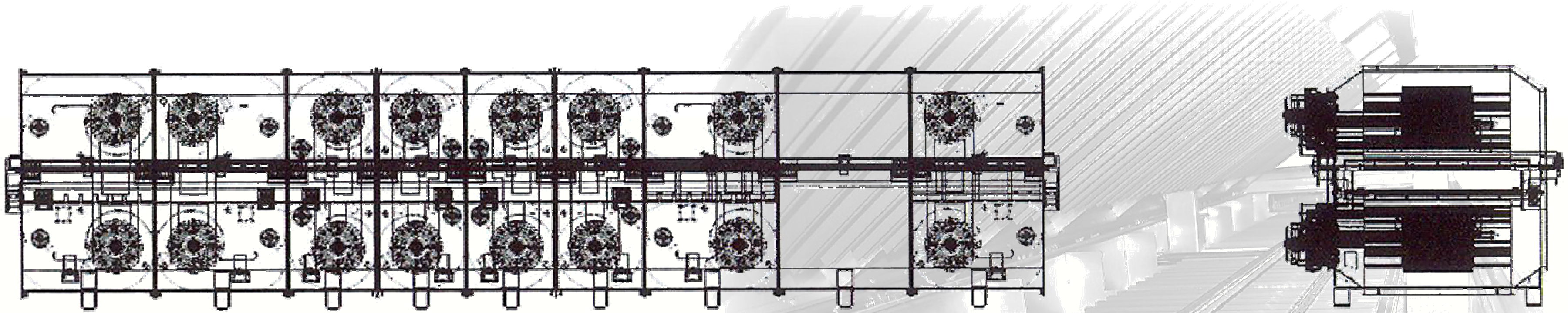
top side stirrers

bottom side stirrers

Hybrid Heating Concept – Safety

Absorber stones

Hybrid Heating Concept – Adaption to an Existing Reflow System

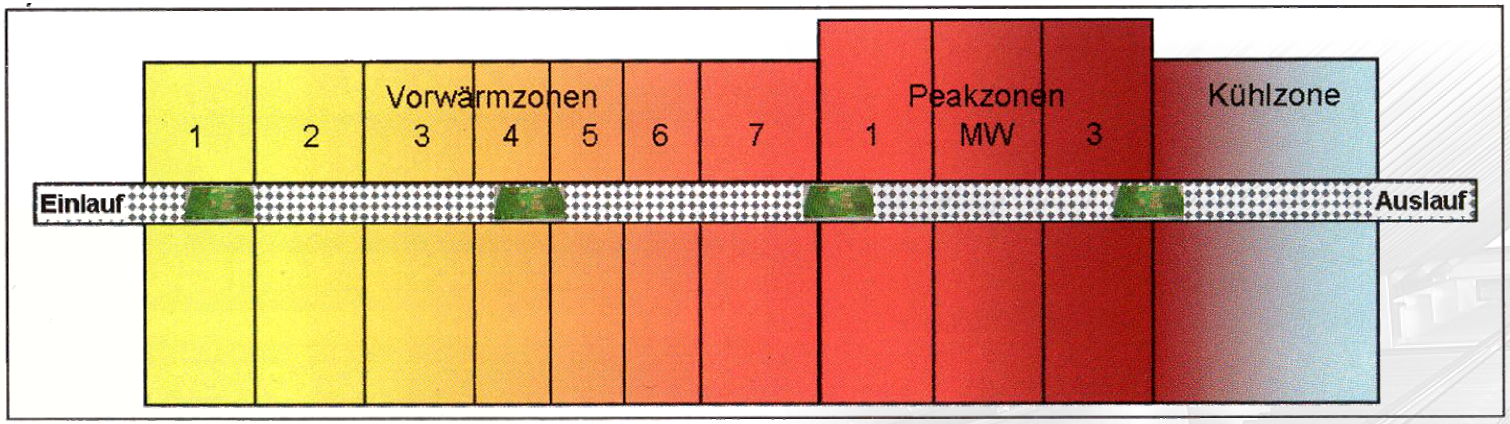


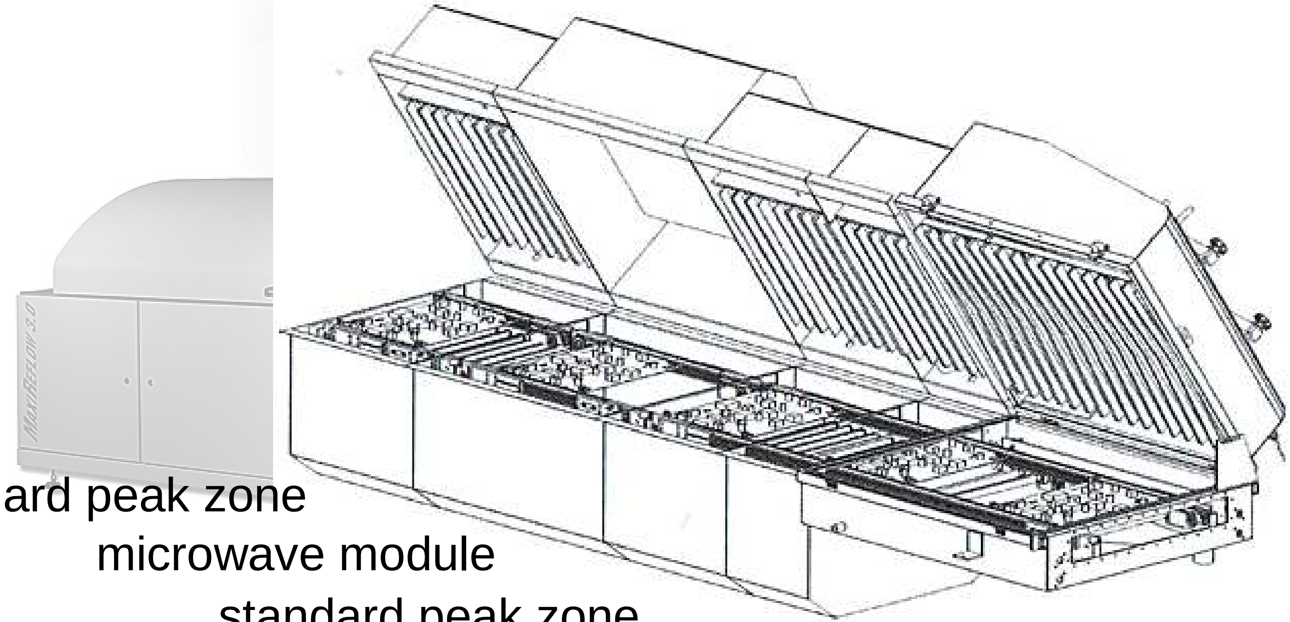
basic system used for hybrid heating concept:

SEHO MaxiReflow 3.0

- 10 top and bottom zones
- tangential fans

Hybrid Heating Concept – Integration of the Microwave Module



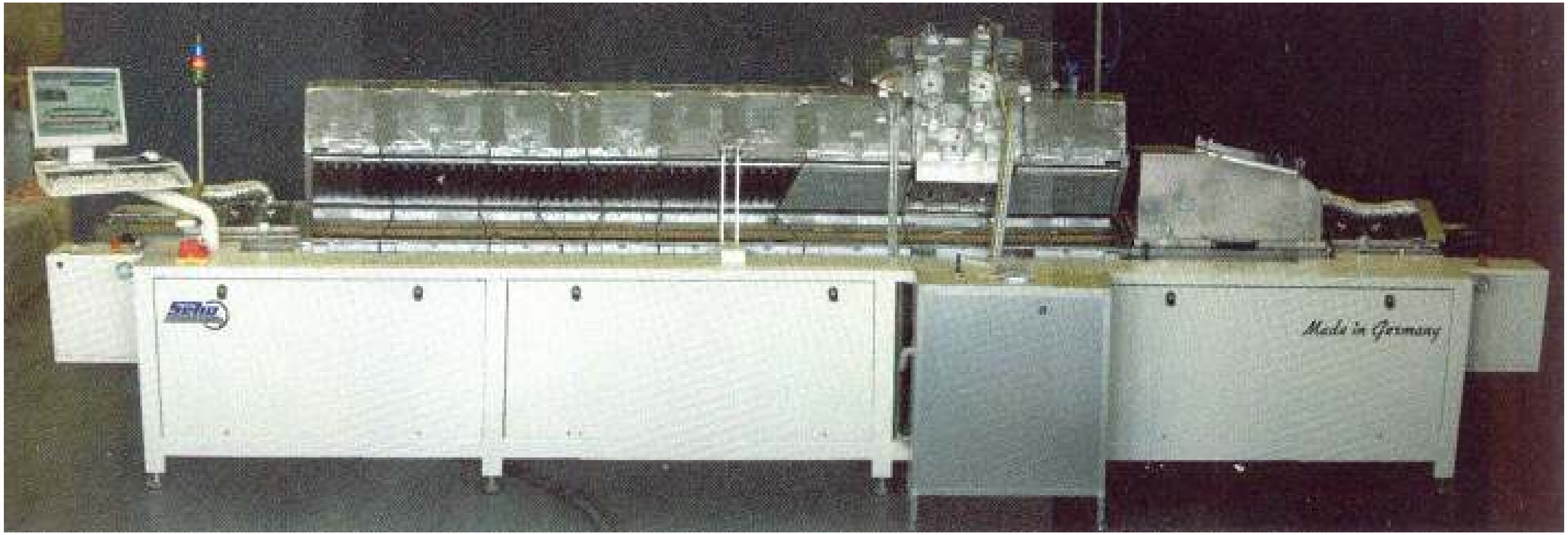


standard peak zone

microwave module

standard peak zone

Hybrid Heating Concept – MicroFlow



preheat area

peak

microwave module

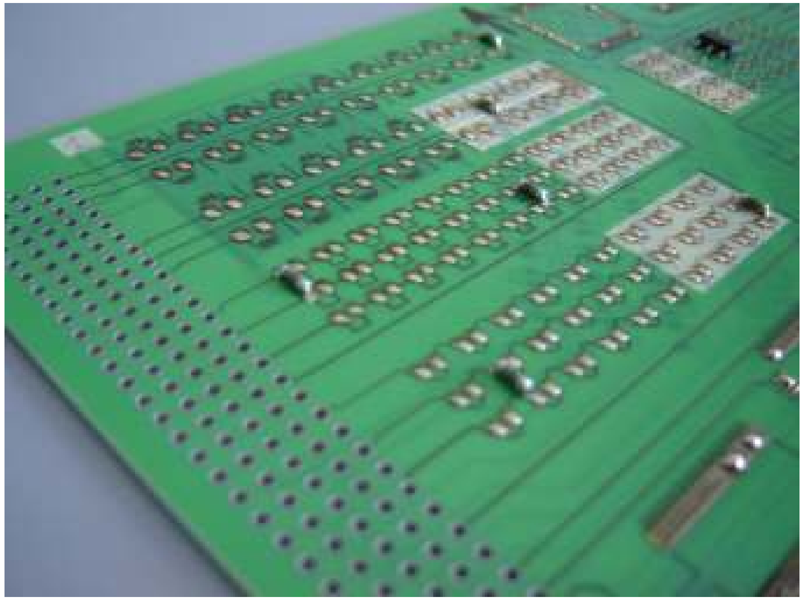
peak

cooling

Variation of Parameter Settings

- form and alignment of the waveguides
- power density in the microwave zone
- preheating
- conveyor speed

Search Criterion: optimum microwave setting at constant preheat power



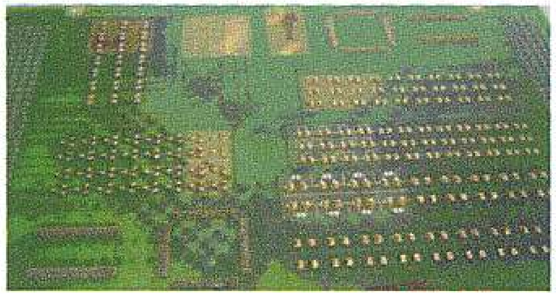
- no delamination of the board material
- no discoloration of the PCB surface
- solder paste completely molten at all depots !!
- first components soldered

Hybrid Heating Concept – Selected Test Results

Search Criterion: optimum microwave setting at 180°C preheat temperature

50 %

partial melting < 50 %
no damages



75 %

complete melting 100 %
no damages

100 %

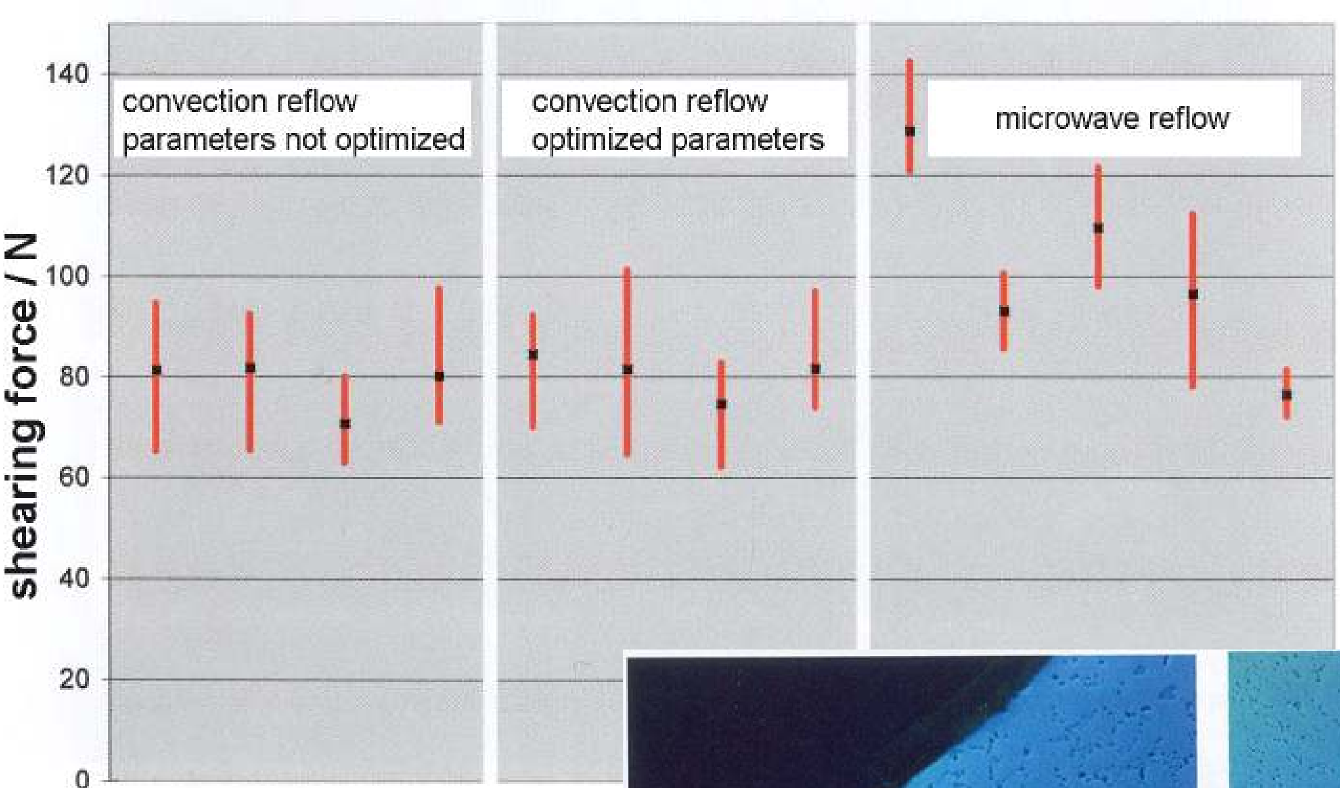
complete melting 100 %
strong delamination

Concept

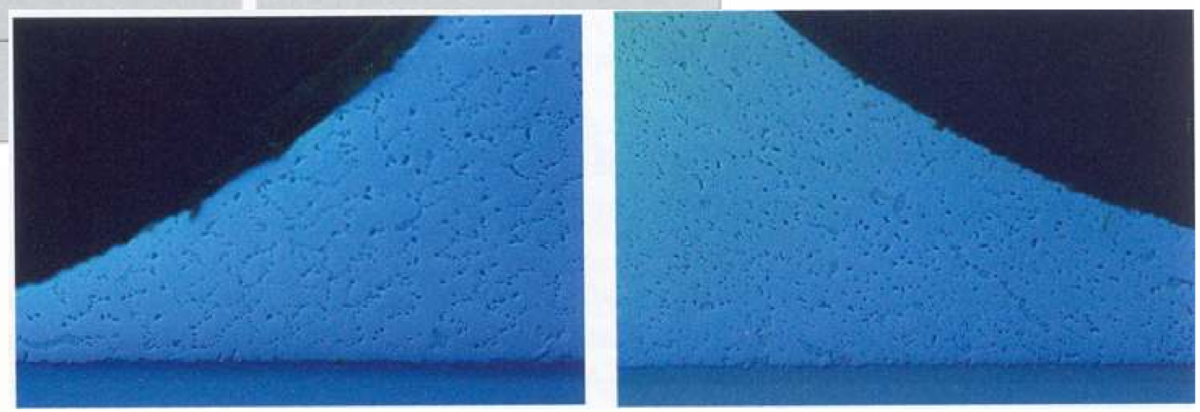
25 samples
storage 168 h / 125°C

mechanical test	lifetime test	climatic test
vibration test 20 Hz – 2000 Hz 5 samples	temperature shock -40°C / +125°C 10 samples	moisture 85°C / 85% r.F. 10 samples

Hybrid Heating Concept – Reliability of Microwave Soldered Assemblies



measurement of shearing force at components 1206



metallographic micro section

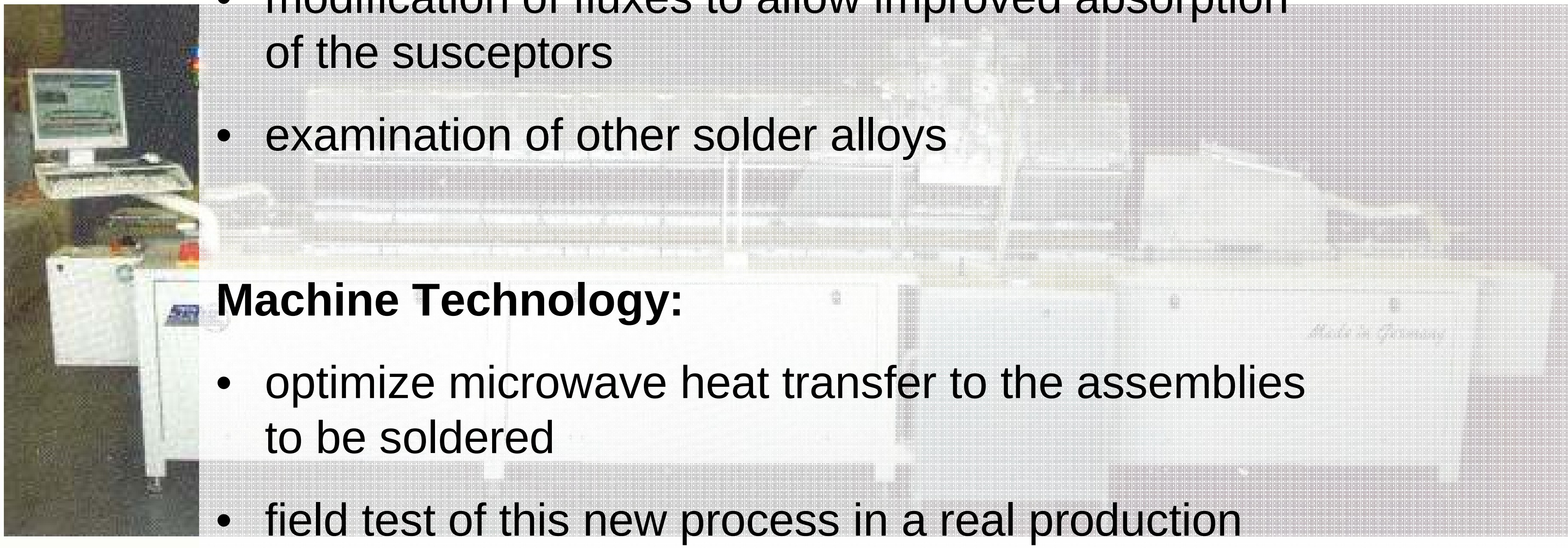
Hybrid Heating Concept – Conclusion

- a selective and simultaneous heating with microwave is possible with a systematic material selection
- susceptors enable the complete melting of solder paste depots and the formation of homogeneous solder joints
- susceptors can be mixed and dosed very good into the solder paste, without noticeable residues after soldering
- the melting point of lead free solders can be achieved without a problem
- components and PCB material are exposed to considerably lower temperatures
- by optimizing the frequency and field distribution, as well as a hybrid oven concept, a very gentle heating of assemblies is possible

Hybrid Heating Concept – Additional Need for Action

Materials:

- further development of susceptors with no residues
- modification of fluxes to allow improved absorption of the susceptors
- examination of other solder alloys



Machine Technology:

- optimize microwave heat transfer to the assemblies to be soldered
- field test of this new process in a real production environment