A SIMULTANEOUS AND SELECTIVE MICROWAVE SUPPORTED SOLDERING TECHNOLOGY

Mathias Nowottnick
University Rostock, Germany
mathias.nowottnick@uni-rostock.de
Wolfgang Scheel, Uwe Pape
Fraunhofer IZM, Berlin, Germany
Rolf Diehm
Seho GmbH, Kreuzwertheim, Germany
Joachim Wiese
W.C. Heraeus GmbH, Hanau, Germany
Wolfgang Kempe
DaimlerChrysler AG, Sindelfingen, Germany
Marcel Mallah
Fricke & Mallah GmbH, Peine, Germany
Manfred Suppa
Peters Research GmbH, Kempen, Germany
Peter Fink
Inboard GmbH, Karlsruhe, Germany

ABSTRACT
This paper is showing results from a joint research project "MICROFLOW", funded by the German Department for Education and Research (BMBF). Usual simultaneous reflow soldering processes like convection soldering or vapor phase soldering were optimized in the past for a minimum of temperature difference between small and large or heavy components on electronic assemblies. Especially the increasing demands for polymer electronics, for electrical-optical assemblies or high temperature electronics require are further development of soldering processes. Such a process should allow a direct heating of the solder joints up to soldering temperature and have to save all other components at the same time. Today this is possible only by application of sequential working selective soldering processes like hot bar soldering or laser soldering. But for a cost effective industrial application it is necessary to realize a selective and as well simultaneous soldering process, which is indeed not available at present.

The wanted selective heating method for an effective simultaneous process is possible in principle by using of electromagnetic fields, when the energy is penetrating the assembly and is launching heat in certain regions, depending on specific material characteristics. Electromagnetic fields in the microwave frequency region are able to treat various sizes and shapes of assemblies with large capacity and with a high throughput. Indeed it is possible to heat conventional solder pastes only with very slowly and with a high microwave power density. It is possible to increase the launched heat considerable by mixing of additional materials, so called suszeptors, into the solder paste, which are absorbing microwave power with a high efficiency. A fundamental task for a save microwave application was the to guarantee the operators safety and to ensure the electromagnetic compatibility of printed circuit boards, integrated circuits and other components as well. This was possible b means of minimizing of volumetric microwave power, optimizing microwave frequency and above all the ensuring of field homogeneity.

Key words: soldering, microwave heating, flux

INTRODUCTION
The principle diagram of soldering temperature profiles for electronic assemblies in figure 1 shows, that the previous developments of soldering processes were driven by the intention to realize a homogeneous temperature distribution as possible on the assembly. Sketched graphs should demonstrate the temperature difference between large components and solder joints. As the infrared radiation is heating large and heavy components very slowly, small and light components will be overheated inevitably much more than demanded soldering temperature. Therefore the forced convection was introduced as the dominating reflow soldering process already in the eighties, which is able to realize comparatively small temperature differences for the electronic assemblies. Especially for demanding

components, e.g. for large BGAs with solder joints below the components body, conditions are crossing sometimes the limits of forced convection. The PCB and component surfaces are heated up to temperatures, 15 … 30 K higher than solder balls, which have to be soldered. It takes a very long soldering time for processing of multilayer boards with 20 layers and more layers, till the whole assembly is heated through and the soldering temperature finally attains the solder deposits.

A further minimization of temperature differences is possible by vapor phase soldering. Because of the high heat transfer of condensing vapor, a temperature difference near zero is achievable also for demanding components.

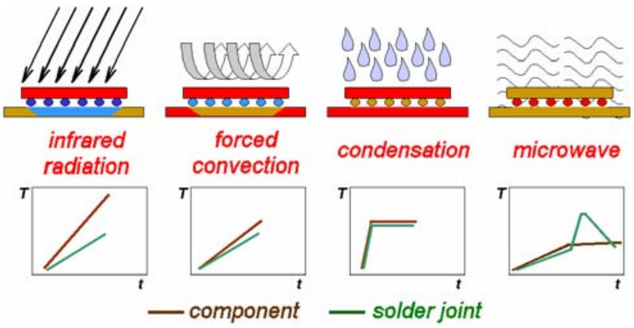

Figure 1. The principle development of reflow soldering technologies

Especially the demands of new technologies, like polymer electronics, electrical-optical assemblies or high temperature electronics, on assembling technology, require a further development of soldering technique. If possible only the actual solder joints should be heated up to soldering temperature. This is possible by selective heating methods like laser soldering or hot bar soldering. Today these selective heating methods are always sequential processes, which are limiting the throughput and the number of processed components considerably. For a cost effective industrial process with the above illustrated characteristics is a selective and also simultaneous soldering process needed, which is indeed not available for electronic assemblies today. A study about technological trends of electronic assembling on behalf of company Seho [1] was leading to a new solution concept, described in the following.

PRINCIPLES OF MICROWAVE HEATING

The wanted selective heating in an industrial simultaneous process is basically possible by electromagnetic fields, whereas the field energy is penetrating the work piece and is able to launch heat in specific areas depending from material properties. The usual induction heating in the low, medium and radio frequency range is able for this effect in principle, but demands a close approach and shape adoption of inductors to the soldering assemblies.

The application of electromagnetic fields in the microwave range, well known form household, is offering much more flexible possibilities in comparison, for treatment of components with different sizes and shapes and also with a high throughput. To transfer this very effect selective heating method to the manufacturing of electronic assemblies it is necessary to achieve following basic requirements:

- the machine safety must be guaranteed also for an open inline microwave process;
- no damages or impairments of printed circuit boards and components by electrical or thermal stress are permitted;
- the appropriated amounts for heating (solder deposits /solder joints) must show a considerable faster and more intensive temperature increase than all other assembly components.

The safety of open inline processes can be ensured with modern microwave equipment also for production conditions. By using of suitable shielding measures especially at run-in and run-out is the use of such open microwave machines e.g. for drying of wood and other materials for high volume and throughput already a common process. More difficult is the issue of influencing electronic components and assemblies. Examples from gluing technology already have shown that a safe application of microwaves for electronic components is possible [3]. Because of the simple chopping of power a common kitchen microwave oven has very inhomogeneous field distribution, as well temporal as spatial. Only the rotation of goods is compensating this. But this compensation is for sensitive electronic components to slow, the power peaks would destroy it inevitably. A large area field distribution as homogeneous as possible without temporal or spatial peaks is required. This challenge is also soluble with the present state of the art in microwave technology.

The remaining question is for the achievable selectivity of solder paste heating. Already preliminary tests have shown that all common solder pastes are suited only for very slow heating with a demand of high power density. Examples from literature in recent years have also shown [4, 5], that melting of solders with microwave needs a lot of time and occurs in particular by indirect heating from surrounding parts.

Therefore it was chosen a different way in using the microwave power for melting for the derived research work [2], based on the feasibility study [1]. By adding of a defined amount of an extreme efficient microwave launching material, the so called suszeptor, it is possible to increase the heat in the solder paste considerably. Such a suszeptor must have corresponding polar or dielectric properties, and can be mixed into the solder paste as a solid or liquid, shown in figure 2. By this means it is possible to increase the heating of solder paste in comparison of the other parts of the assembly substantial and the demanded microwave power can be reduced.

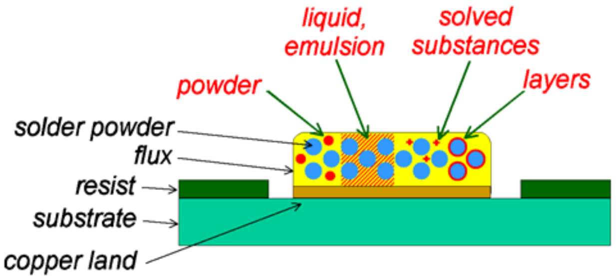

Figure 2. Different possibilities, to add microwave adapted suszeptors into the solder paste

An important aspect of the technological conception is the use of a hybrid heating. Because of the need for minimizing of thermal stress in electronic assemblies it is already necessary to limit the temperature differences as low as possible. Therefore a hybrid combination of basic convection heating and a selective peak heating by microwave power seems to be beneficial. For a preheating temperature of roughly 200°C for lead free soldering processes, the remaining temperature need for the solder joints amounts only 30 K to ensure the solder melting. This can be induced by additional selective microwave heating and realizes a very gentle reflow soldering process. The scheme for a hybrid conception with an integrated microwave module in a common convection soldering machine is presented in figure 3 below.

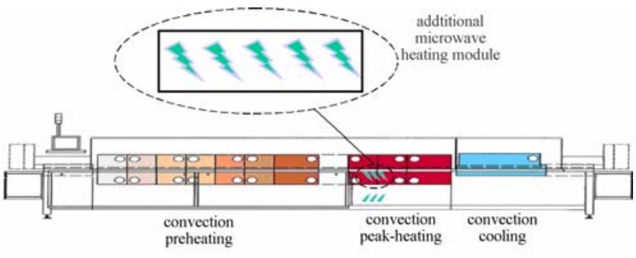

Figure 3. Integration of a microwave module in a conventional forced convection soldering machine (schematic)

An additional advantage of such a hybrid conception is the possibility to process furthermore common solder pastes without suszeptors with the same equipment. The microwave energy can be switched on according to requirements and the specific assemblies.

SOLDERING TESTS

For verifying feasibility of the new selective soldering concept, first trials with a low melting BiSn solder paste and a melting point of 139°C were carried out. Some of the possible suszeptor material candidates were tested with this solder paste. Already these first tests with the low melting BiSn solder paste have clearly shown that suitable suszeptors are able to transfer the demanded heat for melting into the solder paste. Figure 4 shows examples of first test results, even though the appearance of molten solder paste doesn't meet the requirements of electronic assembly technology.

Figure 4. Preliminary test for microwave soldering with a BiSn solder paste with (right) and without (left) suszeptor additions

The further investigation and selection of suszeptor materials has resulted some variants with considerably higher temperatures, which are able to melt also usual solder alloys. Temperature charts in figure 5 are resulting from suszeptor powders with different concentrations in flux solvents. A maximum temperature of 250°C after three minutes of microwave treatment without additional external heat source is sufficient to melt also current lead free solders like SnAg3.5, SnCu1 or SnAg3.8Cu0.5.

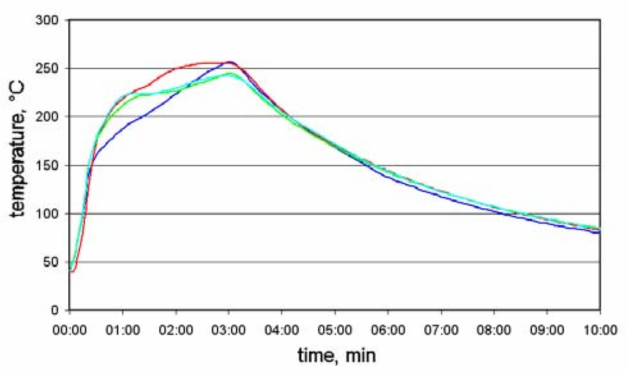

Figure 5. Temperature graphs of a solder flux with suszeptor powder, which is heated by microwave

Another effective possibility of heat transfer is the application of liquid suszeptor materials, results are shown in figure 6. Due to the better contact between liquid and solid solder powder is the resulting temperature rise definitely higher. This mixture is also obtaining the required temperature for processing of lead free solder alloys, in this case 245°C. An additional advantage of using liquid suszeptors is the lower amount of residues remaining on the printed circuit board after soldering. A suitable selection of boiling points presumed it would be possible to evaporate the liquid suszeptor completely. The described mixtures of suszeptors and flux solvents were converted firstly with

Sn63Pb37 alloy and also with SnAg3.8Cu0.5b solder powder to laboratory solder pastes.

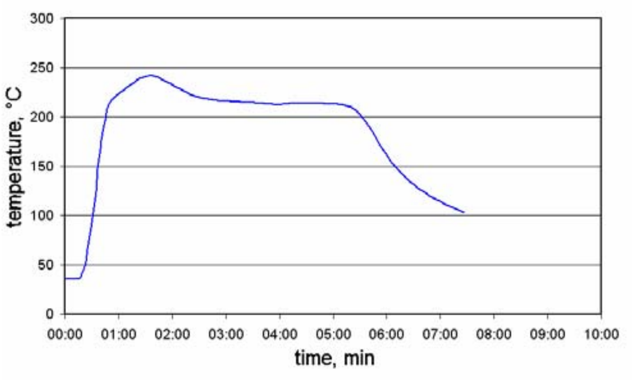

Figure 6. Temperature graphs of a solder flux with liquid suszeptor, which is heated by microwave

Solder pastes were successful tested by remelting and improved for suszeptor amount and viscosity. Figure 7 shows results of the first melting and solder balling tests with microwave processed solder pastes.

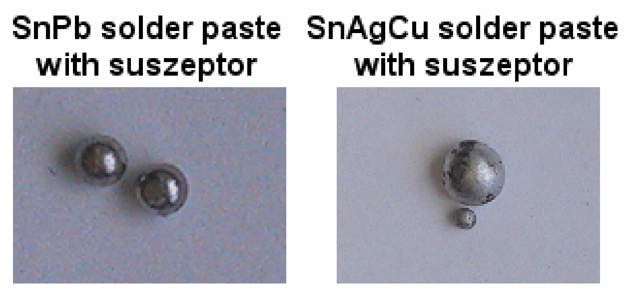

Figure 7. Results of solder melting trials with suszeptor solder pastes, heated by microwave

ASSEMBLY INTERACTION

In comparison with solder pastes the printed circuit board materials are featuring only a minor warming with sub critical temperatures for the same power of microwave treatment. Figure 8 shows the heating characteristics for an usual FR4 material with a maximum of 85°C, where the temperature rise is flatten also for longer process time.

It was surprising, that conventionally preheated printed circuit boards (preheating temperature 150°C) are cooling down in the microwave oven to a level about 90°C. It seems that the maximum of microwave launching is between 85°C and 90°C, therefore the temperature is self controlling in the microwave for this material. A special advantage of microwave heating is that an overheating would be impossible, because with further increasing temperature the launching of power will decrease and the heating is reducing too. Theoretical it would be possible to heat each component of an assembly individually up to a different given temperature in the same microwave oven.

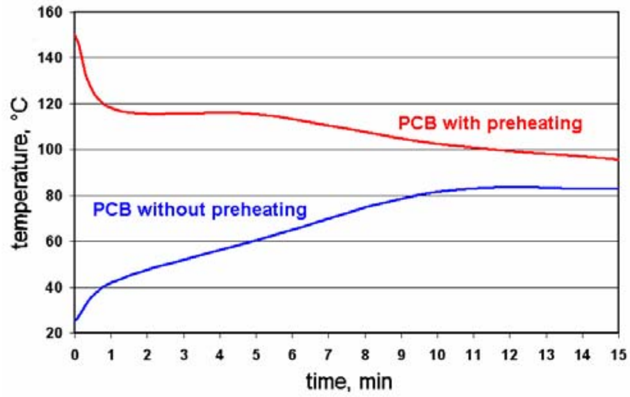

Figure 8. Heating of standard PCB substrate material (FR4) with and without preheating by microwave

Right from the start with the first feasibility tests a representative selection of electronic components and wiring structures on printed circuit boards were checked for microwave compatibility. That includes microprocessors, ROM components, ceramic and electrolyte capacitors, resistors and coils as well as printed circuit boards of different types like rf, microvia, multilayer and power (thick copper) structures. Whereas all electronic components are featuring no damages or parameter drift at all, especially wiring structures with high structure density and multiple layers are offering a cognizably critical limit of power density. Exceeding of this power limit can cause electrical breakdowns or delamination of boards, recognizable e.g. in the X-ray image in figure 9 (right photo). By frequency adaptation and a homogenization of field it was possible to find a safe process window for further tests without any harmful effects to printed circuit boards.

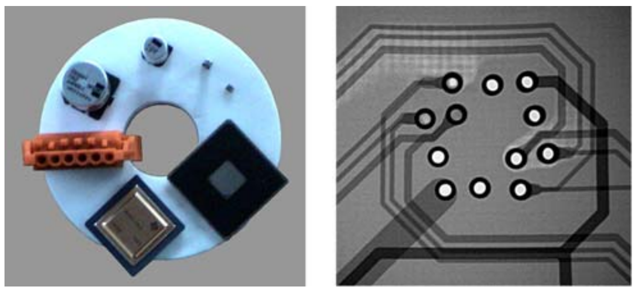

Figure 9. Selected electronic and electrical components (left) and PCB patterns (right) were tested in view of microwave compatibility with different microwave power and frequencies

Investigation of electromagnetic compatibility of different components depending on frequency and power density is representing a special focus of work in the joint research project for its total duration. A tendency of better heating efficiency for higher microwave frequencies and a lower need of total power were emerged. The usual standard frequency for microwave power sources is 2.45 GHz. Such

sources are available for low cost. Sources with a double frequency are increasing expense tenfold. Since costs for the microwave equipment are increasing rapidly for higher frequencies too, a compromise between technical possibilities and economical limits has to be found.
A further question of reliability is the long term stability of possible flux residues considering the additional suszeptor materials. Especially for the liquid suszeptor additives no impairment or visible effect is occurs until now. Samples were tested for 1000 hours, elevated humidity and temperature up to 150°C.

TEST BOARD MANUFACTURING

After optimizing of solder paste and suszeptor composition and after selection of suitable microwave parameters regarding microwave power and frequency, first test boards were assembled with the prototype of an hybrid microwave – convection soldering machine. Beside of the special adopted solder paste with a common SnAgCu solder alloy, only standard components and materials were used. The FR4 printed circuit board was finished only with an OSP surface on copper. A visual inspection shows for a start the molten solder deposits without anomalies, shown in figure 10.

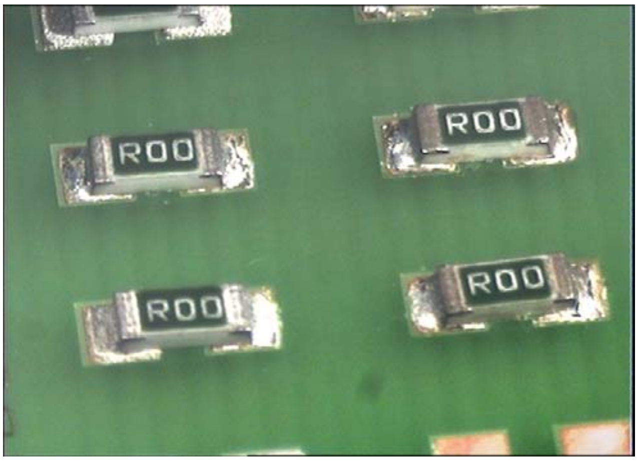

Figure 10. Examples for soldered components, processed in a microwave soldering oven with SnAgCu solder on a FR4 printed circuit board

The temperature profile was optimized for hybrid heating with a usual throughput time about seven minutes. A contrasting test with the same settings but without microwave support shows clearly, that no melting of solder paste happens. A special difficulty of optimizing temperature profiles with microwave support is the electrical interaction of microwave power with thermocouples, which is falsifying the measured results. For an accurate temperature measurement were sheath thermocouples or better glass fibers for temperature measurement needed. Non-contact measuring methods with infrared photo cells or pyrometers are also possible, but is delivering only integral values for a large spot. Therefore all temperature diagrams above were measured with such an optical fiber.

Beside of the outside appearance the quality of solder joints was also evaluated by microsection analysis. Figure 11 shows the cross section of a soldered chip resistor with a good bonding of solder to the metallization of the component and the copper of printed circuit board.

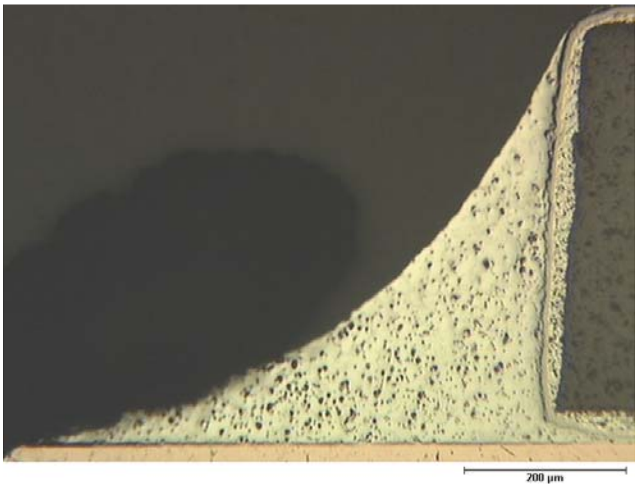

Figure 11. Cross section of a solder joint, chip resistor soldered with microwave power and a suszeptors modified SnAgCu solder paste

SUMMARY AND CONCLUSION

The results of the joint research project have shown, that selective and simultaneous soldering with microwave heating is possible. Most critical is the processing of wiring structures, especially for high density structures. A suitable process window with a maximum power density and first of all with a very homogeneous field distribution was found. The selective heating of solder paste demands the support of special microwave launching materials, so called suszeptors. Selected liquids are able to heat solder paste in the microwave up to the demanded soldering temperature region for lead free solders. Best launching was reached with highest microwave frequencies, a compromise between heat efficiency and equipment expenses was found for 5.8 GHz microwave sources.

The reliability of process was also proven, as well for the electrical function of applied components as for the quality of processed solder joints. Also the flux system with the added liquid suszeptors and its residues has passed all standard tests concerning corrosion and electro migration. A special demand for processing with microwave is the measuring of temperature. Because standard thermocouples are unsuitable, sheath thermocouples are required at least.

The safety of prototype machine was permanently checked as a matter of course. Measuring of escaping microwave radiation doesn't achieve critical values, nor at the open run-in and out. A great potential of this selective and simultaneous soldering process is the manufacturing of heat-sensitive assemblies like polymer electronic, e.g. with OLED displays.

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