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Thermocouple Attachment Methods for PCB Profiling During Vapour Phase Soldering

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***Abstract*—Vapour Phase Soldering (VPS) is an alternative reflow soldering method, which had a comeback after the introduction of Galden fluid. The heat transfer in a VPS oven is totally different than in the case of conventional soldering methods, such as convectional and IR radiation soldering. Most of the energy (which is required to melt the solder alloy) is transferred to the board during the condensation of the Galden vapour. Printed Circuit Board (PCB) temperature profiling is usually done with thermocouples attached to the board itself with different attachment methods. An unprocessed laminate PCB was prepared for temperature profiling. Standard K-Type thermocouples were attached to it with the standard methods, such as thermocouple fixing with Polyimide tape, SMD adhesive and High-Temperature Solder (HTS) alloy. The paper highlights the importance of condensate film layer, which have an effect on attachments and the thermocouples themselves. The results of the measurements are investigated in the paper.**

***Index Terms*— Vapour Phase Soldering, PCB, Profiling, Temperature**

I. Introduction and Motivation

Vapour Phase Soldering (VPS) [1] is becoming a more significant alternative reflow method [2]. The available literature of Vapour Phase Soldering lacks the focus on specific aspects of the technology. The "condensation soldering" method raises some new questions from the aspect of practical and theoretical approach. Temperature profiling with PCB samples is a common practice during the optimization and supervision of soldering processes. However the effect of different standard thermocouple attachments are not yet characterized for VPS, where the condensate film layer affect the attaching medium, the thermocouples and thermocouple wires. The goal is to achieve a reliable temperature profile, where the different effects of the different attachment methods are minimized during condensation heating.

The common VPS oven (Fig. 1) consists of a sealed chamber, which can be considered as the processing zone. In the bottom of the processing zone a fluid is filled into a reservoir. This fluid is the heat transfer material. The boiling fluid forms a vapour blanket, in which the temperature is limited to the actual boiling point of the fluid. The PCB is not in direct contact with the heated fluid, but it is immersed into the vapour of it. The mass transport induces energy transport, so the energy coupled to the boiling fluid via the heater element is used for phase change. The mass and energy transport reverses when the ambient temperature board is immersed into the vapour. The latent heat of condensation is transferred into the PCB via the condensed film layer. The amount of available vapour for condensation, the properties of the heat transfer fluid, the mounted PCB structure (and its material properties) all affect the process and the heat transfer, which is ultimately used for melting the solder alloy.

The heat transfer fluid is usually one of the Galden (perfluoropolyether) types; the Galden products are available for many application fields, such as semiconductor cleaning, heat transfer in special appliances, sealing tests, and for different soldering processes. Conventional lead-free soldering is available due to the LS-type Galden fluids.

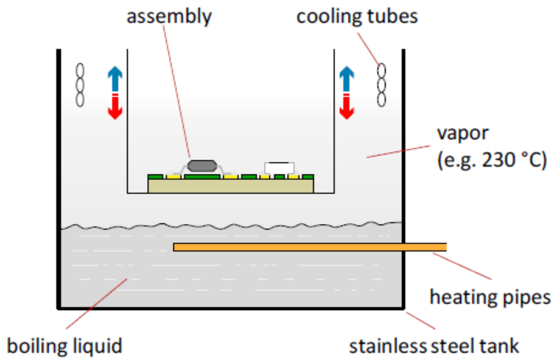

Fig. 1: Basic schematic of a Vapour Phase Soldering oven [3,4]

The construction of a process zone is expanded with cooler tubes on the top, to prevent overflow of any exceeding vapour. It is possible to monitor the vapour and the process zone with sole temperature measurements; however it is also possible to get information about the volume and the concentration of the vapour with pressure probes. [5] The control of the vapour may be solved with control of the heater, collapsing the vapour blanket with additional circular cooler at a given height, or the positioning of the PCB with a controlled lift across the Z axis. The VPS ovens may be constructed for mass production (inline machines), and for smaller scale manufacturing or technology experiments (batch type machines). The technology may be extended with an additional vacuum chamber, where any voids are removed during the liquidus state of the alloy. Condensation heating is considered to have an even heat distribution effect along a PCB. According to research results, solder joints produced with VPS have been found to have near equivalent quality like the ones created with conventional reflow technologies [3-9].

During the immersion of the PCB into the vapour, filmwise condensation occurs and the generated film covers the whole assembly (Fig. 2). The condensate film has a ~0.25 mm thickness, and in the first moment, the outer boundary of the film has the temperature of the vapour, the inner boundary (the boundary of the SMD component and the film) still has ambient temperature.

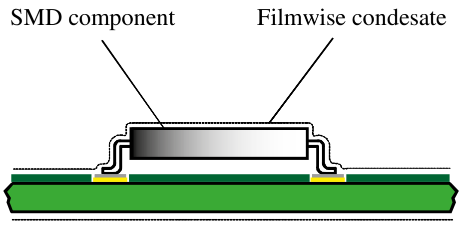

Fig. 2: Filmwise condensation on the sample PCB after immersion into the vapour

According to Asscon technology reports, if a thermocouple has a stripped wire near the welded hot spot (Fig. 3), the condensate wets the stripped wire, heats it and eventually heats the hot spot with heat conduction along the wire, adding an additional temperature distortion to the output signal of the thermocouple. This must be avoided during the measurements. The experiments discussed in this paper also focus on this possibility.

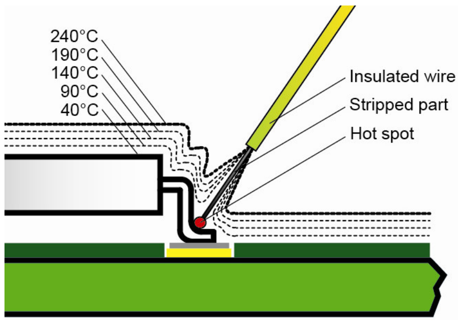

Fig. 3: Isothermal lines in the condensate at the first moment; a thermocouple with a stripped wire near the welded hot spot (Asscon)

II. Experimental

K-type thermocouples are usually suitable for PCB temperature profiling. For the experiment K-type thermocouples with small diameter (0.5 mm) welded hot spots were chosen, to minimize the additional thermal capacitance. The protective insulator layer (Fig. 2) on the wires is Teflon PFA (perfluoroalkoxy) material with a heat resistance of 250 °C. Therefore the thermocouples are compatible with Galden fluids suited for lead-free applications.

Five K-type thermocouples (Fig. 4) were attached on an unprocessed (1.6 mm thick) PCB sample board. The thermocouples have a tolerance of ± 1 °C, which is acceptable for the measurement purposes. The wires are 2 m long and flexible enough to send them into the process zone of a VPS oven while the hot spots are attached to the PCB. The additional thermal capacitance of the wires is the same for all profile measurements.

Fig. 4: K-type thermocouple with PFA insulation

The measurement setup (Fig. 5) is based on a batched data logging system connected to a PC. The data loggers are Novus MyPClab type devices. The device is able to measure the voltage drop on the end of the thermocouple wires and convert the value to °C values, according to a calibration. The recorded temperature values are registered to an Excel file for further processing.

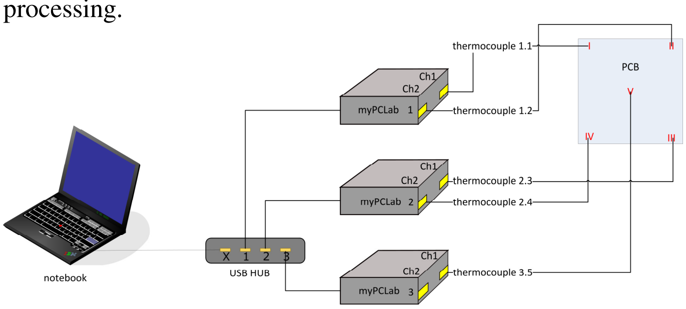

Fig. 5: The measurement setup

The PCB is lowered into the vapour space (process zone) of an Asscon Quicky 450 type VPS station (Fig. 6).

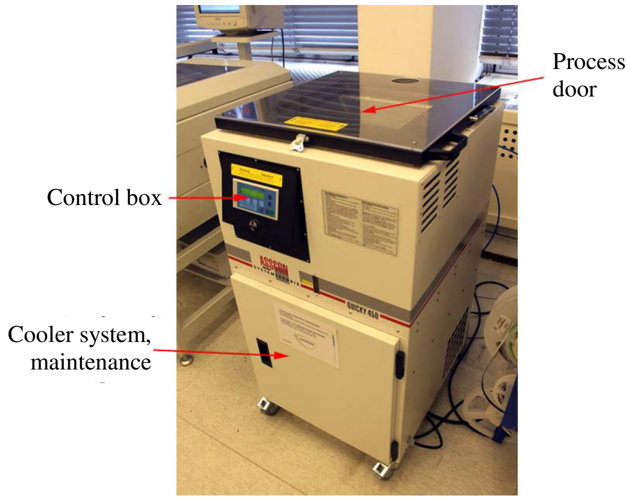

Fig. 6: Asscon Quicky 450

The Quicky 450 is a batch type machine, where the soldered board is moved with a lift vertically to the bottom of the tank. The rubber insulator ring along the edges of the process allows thermocouple wire insertion to the process zone. Galden LS 240 was applied to the fluid reservoir of the system. The nominal boiling point of the applied Galden fluid was 240 °C. Parameter settings of the Asscon station are presented in Table 1.

TABLE I. AQ-450 PROCESS PARAMETERS

Parameter Type	Parameter Setting
Heat Output	75 %
Medium Type	241 °C*
Max Vapour Temp.	150 °C
Heat Delay	10 s

* 1 °C boiling point measurement error

The PCB is an unprocessed laminate sample board, with full copper clad laminate on the top side. Two layouts were designed for the measurements according to Figure 7. Layout A defines five measurement points (four thermocouples in the corners and one in the middle), Layout B defines three measurement points (two thermocouples in the corners and three in the middle). The two additional thermocouples in the middle have stripped wire sections (~2-3 cm) next to the hot spots. The other thermocouples had shorter blank sections (~1-2 mm) all covered with the different attachment methods.

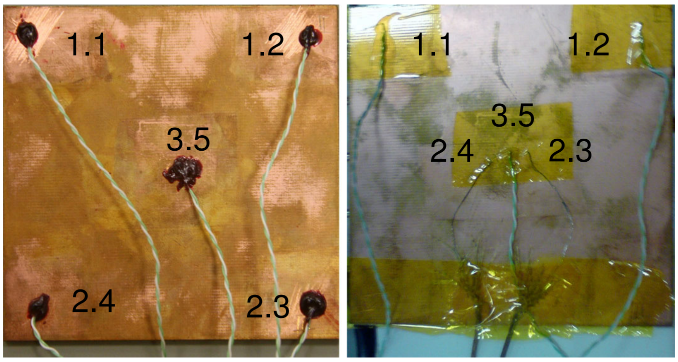

Fig. 7: (Left) Layout A, (Right) Layout B; measurement points: 1.1; 1.2; 2.3; 2.4; 2.5

Three thermocouple attachment methods [10-11] (Fig. 8) were applied to the PCB (I-II-III.). The first type (I.) was a basic attachment with Kapton (polyimide) tape, where the main concern is the weak fixation (the adhesion can be reduced by the wet surface of the Galden soaked PCB), and the non-hermetic sealing, so that the Galden film can leak under the tape wrinkles, due to the capillary forces. Layout B was also prepared with the Kapton tape fixing. The second method (II.) was fixation with SMD chipbonder adhesive (Loctite 3621). The curing was done with hot gas method for ~120 s on 150 °C. The third method (III.) was attachment with high temperature solder (HTS). Sn10Pb90 type alloy was used (302 ºC melting point). The surface of the PCB and the small hot spots of the thermocouples were pre-wetted (and cleaned) with Sn96Ag4 type solder wire (221 °C). The acidic Arax flux content in the wire core helps to clean the surfaces and also helps the high temperature solder to wet the hot spot and the copper surface.

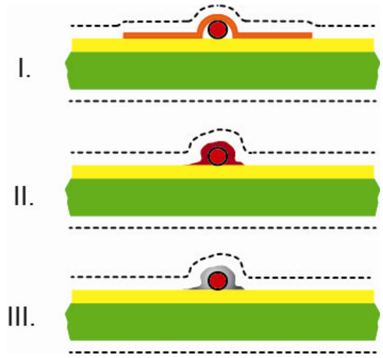

Fig. 8: Three types of thermocouple attachments (I-II-III.)

Aluminum tape attachment method was considered to be very similar to Kapton tape attachments (even the two may be used together in the same time), so the experiments were simplified to use only the latter. According to the literature [10-11] the following is stated of the three different types:

I. Kapton tape is the least expensive method, however its repeatability and the overall reliability is the worst, due to tape lifting.

II. The epoxy adhesives have inconsistent thermal conductivity. Repeatability is still a problem.

III. HTS attachment is a time consuming task. High soldering temperature may damage the board.

III. RESULTS

The data is logged to Excel tables. With each setup (I-II-III) four measurements are recorded and then the data is evaluated. The logged data is processed in OriginPro software. Figure 9 shows a typical profile with the settings of Table 1. (I. method)

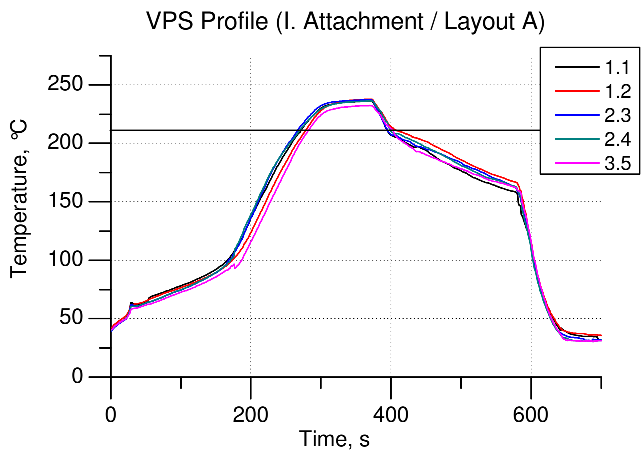

Fig. 9: Linear VPS profile achieved with Table I. settings

This plot already points out imprecision of Kapton tape attachment method (I.), while the plotlines show some slight divergence around the rise period and even at the peak temperature. The melting point of lead-free SAC 305 paste (217 °C) is highlighted on the plot. For more thorough discussion, the following figures discuss the divergences.

Figure 10 shows the recorded maximum temperatures. The tendency shows that overall temperature is the lowest with Kapton attachment. The huge deviations with Kapton tape are due to the unsteady adhesion. The two stripped thermocouples (2.3, 2.4) bring a huge deviation to the measurements with I/B method. The peaks of I/B (2.3, 2.4) show that the hot spot of the thermocouple is indeed heated trough the stripped wires of the couples. HTS (III.) method has the smallest deviation along the PCB (1.1-3.5), also the values almost reach the boiling point temperature. The overall deviation at each measurement point is the smallest in the case of HTS.

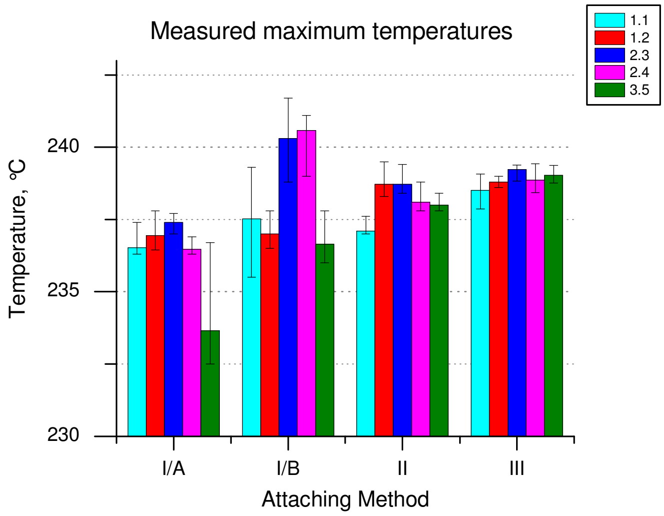

Fig. 10: Temperature maximum values (aggregation of four measurements per attaching method)

According to the previous results and the fact that many thermocouples did not reach the actual maximum temperature, a nominal "peak" was defined when the temperature reached and surpassed 230 °C. Figure 11 shows that the thermocouples stay at the peak for a considerably longer time in the case of HTS (III), compared to the other methods. (Due to additional thermal capacitances.) The overall deviation within the confines of one method is the least in the case of SMD adhesive (II) attachments. Kapton tape is the least reliable from the aspect of peak temperature.

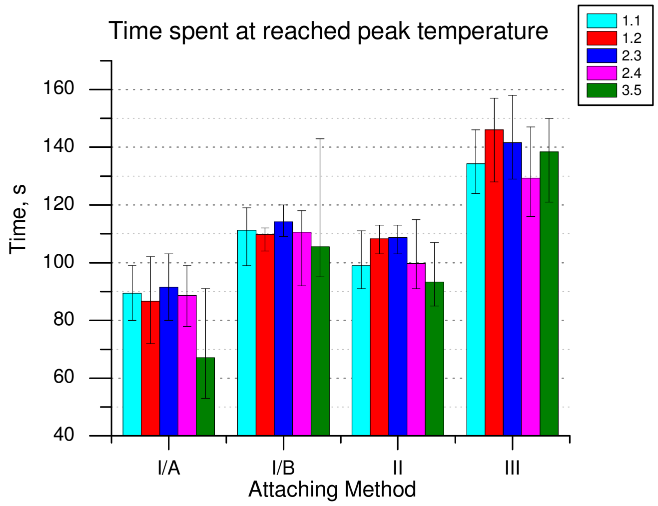

Fig. 11: Time spent at peak temperatures (Peak=230°C; aggregation of four measurements per attaching method)

For repeatability investigations, the Time Above Liquidus (TAL) values were investigated. For each measurement, the recorded values at separate measuring positions along the PCB (1.1, 1.2 … 3.5) are averaged to form one dedicated temperature profile for the whole board. For an attaching method we get four averaged profiles with four measurement cycles this way. The parameters of the scatter plot in Figure 12 are these four separate measurements.

The actual data points in the figure were obtained from the averaged profiles. One data point represents the time spent above the liquidus temperature per each averaged profile.

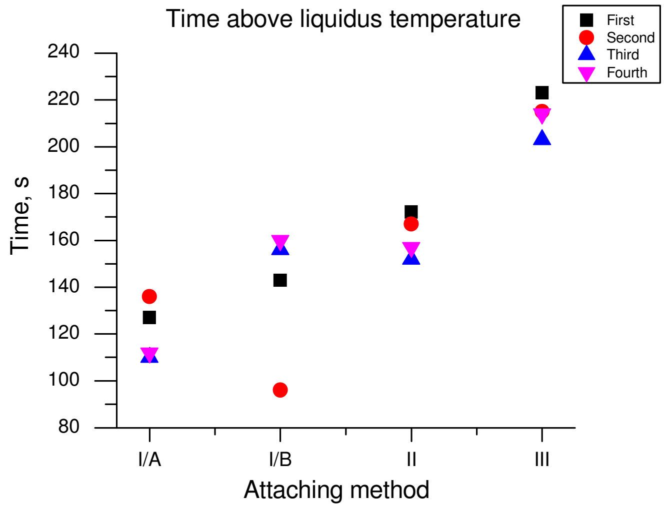

Fig. 12: Time above liquidus temperature (TAL=217°C; aggregation of four measurements per attaching method)

The deviation is the least in the case of methods II and III. The repeatability is almost similar; however it is not too precise (still has a ~20 s deviation). I had a considerably larger deviation (~30 s); I/B had a huge deviation alone (~70 s), highlighting the reliability concerns with Kapton tape attachment and the stripped wires. It is interesting that TAL is consequently rising with each method. It is due to the additional thermal capacitances during the heating and the cooling phases of the thermal profile.

According to the previous plot figures, it can be stated, that in the case of condensation heat transfer, the heating may not be as even, as the literature would suggest, as small differences in the temperature appear along a bare unprocessed PCB. (Pointing beyond the imprecision of the thermocouples.) Also there are considerable time differences in the transients of the heating, even within the confines of one method.

The results point out that the overall best result can be achieved with the HTS (III) method, where the temperature deviations are the least significant among the other attachment methods. The repeatability also excels in the case of HTS. There is however a concern about the application of the solder itself – it can be a complex task to apply the alloy to the non-wetting hot spot of the thermocouple or to a PCB pad. Also a metallic surface is needed for the contact. Using HTS has also a considerable transient effect due to the additional thermal capacitance – this transient effect however may enable to reflect similar values as if a real solder joint is measured. HTS is also the most expensive method.

SMD adhesive attachment method (II) can be considered as a decent substitute method - with similar repeatability as the HTS method. However the attachment requires careful dispensing. Afterwards it is also important that removing the cured adhesive may destroy the hot spot of the thermocouple. The deviations along PCB and within each measurement are also acceptable.

Kapton tape (I/A, I/B) is the least reliable method. The uneven tendencies and high deviation shows that not only the peak temperature of the PCB is not reflected precisely, but the repeatability and the uneven tape adhesion may be a problem as well. The tape adhesion problems and the uneven tendencies are also caused by the wet film which reduces adhesion and overall mechanical stability. It was also shown that if the thermocouple has a stripped wire, the film condensate overheats the hot spot of the wire along the wire line.

The measurement results, where the Kapton tape lifted off (causing the thermocouple to lift off as well) were excluded from our investigations.

IV. Conclusions

Three methods were considered for thermocouple attachments, and the results of different characterization methods are highlighted by this paper. The main goal was to find aspects of temperature reliability during the different methods in the case of Vapour Phase Soldering, also highlighting the repeatability of the methods for continuous, cyclic profiling. The special effect of the condensate film layer was also considered during the investigations. It was pointed out that HTS method and SMD adhesive method yields the best and almost the same results – the recommended application of the different methods depends on the applicability and the present practical circumstances. The Kapton tape method is not recommended for precise application in the case of VPS.

It was also shown that even in the case of an unprocessed PCB, the temperature and heating in time may not be totally evenly distributed during condensation heating.

Future work may involve measurements with aluminum tape attachments to highlight any possible differences between Kapton and aluminum tapes. Also the Heating Factor [3] can be considered as a possible evaluation method for repeatability and reliability characterizations. Special PCBs, such as multi-layered boards, metal-core PCBs, ceramic substrates or flexible circuits can be considered for future investigations.

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