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Multi-physics modelling of a vapour phase soldering (VPS) system

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HIGHLIGHTS

► Multi-physics model of the Vapour Phase Soldering (VPS) process is presented.
► The model calculates the heat, mass and energy transport mechanisms.
► The model was tested by simulations of a batch type vapour phase soldering system.
► Heating time for the saturation of the vapour concentration and temperature was defined.
► The processing volume of the system was modified according to the simulation.

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ABSTRACT

This paper presents a novel multi-physics modelling approach of the Vapour Phase Soldering (VPS) process. The model applies combined transport mechanisms including heat transport by heat conduction; mass transport by diffusion in the fluids and by phase change during the evaporation and condensation of the Galden liquid; and energy transport caused by mass transport. The model can describe the temperature and vapour concentration relations in the oven – which are the main parameters of the vapour phase soldering process – from the start of the Galden evaporation until the saturation of the vapour space (prepared for soldering). The results calculated by the model show proper conformation with the experimental results of temperature and pressure measurements. The model was tested on a batch type VPS system where the position of the processing volume was optimized in the soldering tank. With the information obtained from the model the whole VPS process can be investigated.

1. Introduction

Vapour Phase Soldering (VPS, also Condensation Soldering) is an alternative method of conventional reflow soldering techniques, such as forced convection or infrared (IR) type reflow soldering. During the process of VPS, heat transfer fluid is heated at the bottom of a tank, which is the source material of vapour blanket generation. A cooling appliance condenses any excessive vapour at the top of the construction, thus the vapour blanket stays inside the tank. This blanket of generated vapour is the actual heat transfer medium for soldering; therefore the most important parameters are the temperature and the Galden concentration in the vapour space. In this application vapour concentration means the amount of Galden vapour in a given volume. The assembled board is lowered into the vapour, which condenses on the cooler surface of the board. The latent heat of condensation and the heat transfer of the condensed Galden liquid provide the energy for the solder material to melt. After a specific amount of time, the board is lifted from the vapour to a cooling area.

The VPS technology was invented by Pfahl and Ammann [1] and it was improved later by Wenger who also compared [2] various heat transfer fluids (and their vapours) for the VPS process. However, the VPS technology did not become widespread due to the environmental hazard of Chlorofluorocarbon (CFC) gas by-products, which were released during the process [3]. Vapour phase soldering has come back into focus with the development of “Galden” fluid [4] which is a specific product composed of perfluoropolyether substance (PFPE):

$$CF_3-(OCF(CF_3)CF_2)_n-(OCF_2)_m-OCF_3 \quad (1)$$

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Nomenclature

T	temperature, K
k	ratio of saturation mass transport
E	energy, J
n	indexing of the mesh
t	time, s
v, w	general variables
R	heat conduction resistance, K/W
α	constant parameter
C	thermal capacity, J/K
C_S	specific heat capacity, J/kg K
pc	phase change
ρ	density, kg/m^3
ev	evaporation
φ	concentration of the vapour, kg/m^3
bp	boiling point
V	volume, m^3
co	condensation
A	surface, m^2
diff	diffusion
m	mass, kg
st	saturation
λ	specific thermal cond., W/m K
txp	thermal expansion
h	latent heat, J/kg
vp	vapour
D	diffusion constant, m^2/s
liq	liquid
β	thermal volumetric coef., m^3/m^3 K
sol	solid
Δx, Δy, Δz	resolution of the mesh, mm
ga	galden

where the flexible ether chain structure is closed with strong carbon-fluorine bonds providing excellent stability for VPS [5]. Galden is considered a harmless, inert material, which is noncorrosive, nontoxic, nonflammable, having zero ozone depletion potential (Zero ODP). Galden is used in many other industrial applications for hermetic sealing [6], heat transfer, semiconductor cleaning and testing [7].

The main advantages of the VPS process are the uniform heating (and heat recovery) of the assembled boards where the maximum temperature is limited [8] because the temperature of the vapour is not able to exceed the boiling point temperature of the fluid itself. Further advantages are the inert atmosphere (fluxes with lower activation level can be used [9]) and the presence of a condensed film layer which keeps the oxygen and other gases from coming into direct contact with the solder paste. A disadvantage of VPS may be rapid heating, while the heat transfer coefficient of vapour is ten times higher than forced convection, this parameter can cause soldering failures such as tombstoning [9]; popcorn cracking [10] (also specified for given package types, such as TQFPs [11]), solder void generation [12]; solder beading [13], and delamination [14] of packages; and solder cracking [15].

Basically, linear soldering temperature profiles can be achieved with VPS, where only the heating gradient can be adjusted via the setting of heating power [16]. However, this linearity does not always match the requirements of solder pastes. Therefore, several modifications were applied on the process such as infrared preheating [10] where spluttering of the paste, tombstoning, and damage of the components can be avoided. Also, the dwelling time in the vapour can be reduced for the immersed board. Duck and Zabel of Asscon presented the use of additional cooling around the immersed board to modify the linearity of the profile [16]. They also investigated the application of the vacuum chamber for VPS, where the voids are drawn out from the molten solder [17]. Leicht and Thumm of IBL have investigated the application of the non-saturated vapour space to get non-linear soldering profile [3]. In the non-saturated vapour space the temperature and the concentration of the vapour have a gradient along the Z axis which can be utilized for controlled dipping of the assembled board [3].

Besides the technical innovations mentioned above, there is a very limited amount of examples in the literature for the characterization of vapour space in the soldering tank by measurement or simulation. Therefore, this paper tries to approach VPS from a new perspective and it presents a novel multi-physics model of the vapour phase soldering whereby the vapour concentration and temperature distribution of the vapour space inside the soldering tank can be studied.

2. Description of the VPS system

The investigated batch type VPS system is based on a closed stainless steel tank. An immersion resistor heater heats the Galden fluid at the bottom of the tank. The power of the heater can be adjusted with a toroidal transformer. The current flow and voltage drop of the heater are measured on-the-fly with a digital measurement setup including an ammeter and a multimeter device. The filament inside the immersion heater has a resistance of 25 Ω. A cooling copper tube is positioned on the top of the tank with circulated ambient temperature water inside it. The block diagram of the system [18] is shown on Fig. 1.

The schematic of the VPS tank is presented in Fig. 2. The dimensions of the tank are the following: width (x axis) 180 mm; length (y axis) 280 mm; height (z axis) 170 mm; and wall thickness 0.5 mm. The metal lid of the tank is removable, with a heat-resistant glass window on the top. The glass window can be removed for in situ access of the vapour space. There is an aperture on the metal lid to access the vapour space with probes and wires.

The horizontal plane of the heater element is immersed in the Galden liquid 10 mm from the bottom of the tank. The pipes of the heater are led out vertically via a prepared outlet at the edge of the

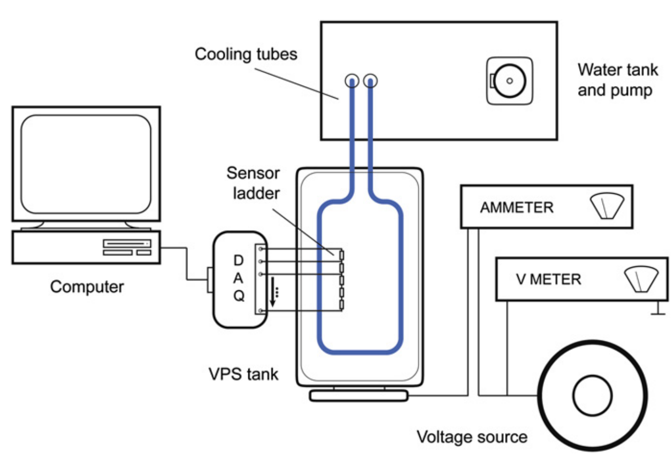

Fig. 1. Block diagram of the VPS system (top view on the VPS tank).