Vacuum Soldering Using Formic Acid: A Stable and Cost-efficient Process.

Overview:

1. Introduction

Application of formic acid (HCOOH) enriched with nitrogen is a stable and economical soldering process for oxide film reduction, tested in the industry for many years. In this process no fluxing agent is necessary. It is used in the vacuum soldering - subgroup of the reflow soldering technology.

Vacuum soldering delivers a good process result regarding the void rate across the surface, due to the surface activation with formic acid. The process is applicable to almost all surfaces and components. Such a high level of tolerance makes it suitable for the soldering of power semiconductors and also, with few restrictions, the Advanced Packaging Area.

2. Process Description

Oxide films inhibit the soldering processes substantially. To guarantee a stable and controllable conduction of the process, they must be removed. The formic acid (HCOOH, max. concentration 1,2%) enriched with nitrogen (N_2) is applied by a so called bubbler. The nitrogen is injected into the bubbler with a lance and is released through the bubbler outlet, enriched with formic acid. The gas piping injects the mixture into the vacuum chamber.

Figure 1: Formic Acid Bubbler

Soldering using formic acid is a two-stage process.

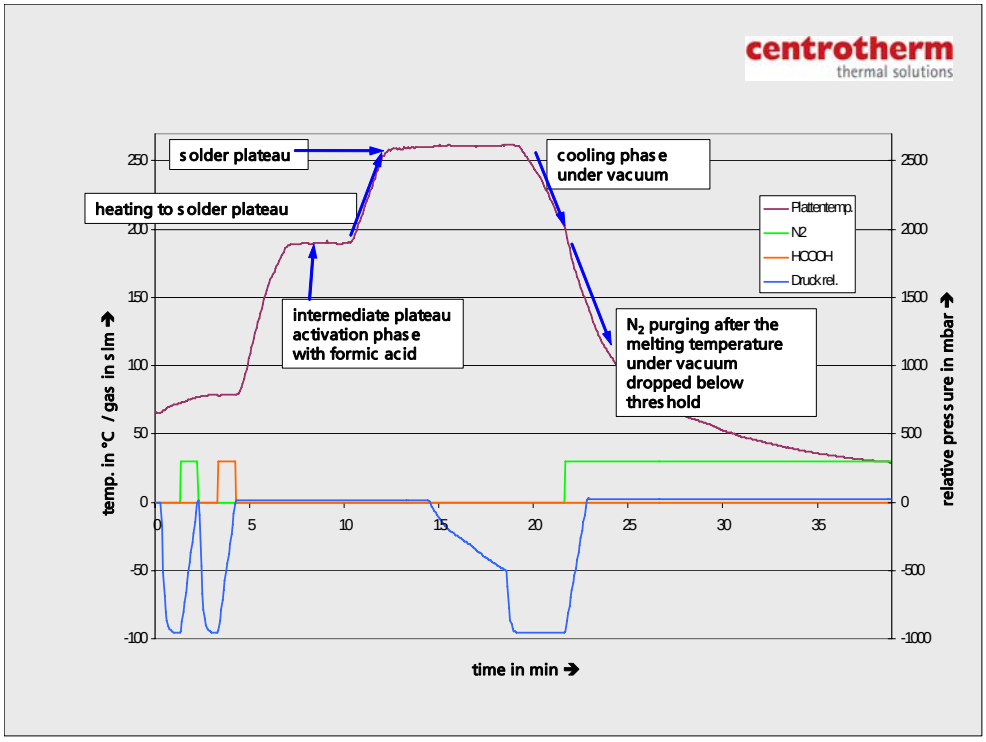

Figure 2: Vacuum Reflow Profile of Formic Acid

a.) First heat-up phase and intermediate activation plateau

With oxygen (O_2) in the molecular form

- $2HCOOH + O_2 \rightarrow 2CO_2 + 2H_2O$

From the process point of view, it is recommended to always insert an intermediate plate into the reflow profile when the temperature is greater than 120° or less than liquidus temperature.

Though the intermediate plate increases the process time in comparison with soldering using forming gas (N_2/H_2 95/5) or hydrogen (H_2), the process result, concerning the void rate and wetting, improves.

b.) Second heat-up phase and soldering plate

At over 200°C hydrogen ions (H+) are produced. Therefore, the soldering plate is used not only to melt the solder but also to reduce the oxide film with H+ ions. The scheme of the simplified chemical process is as follows:

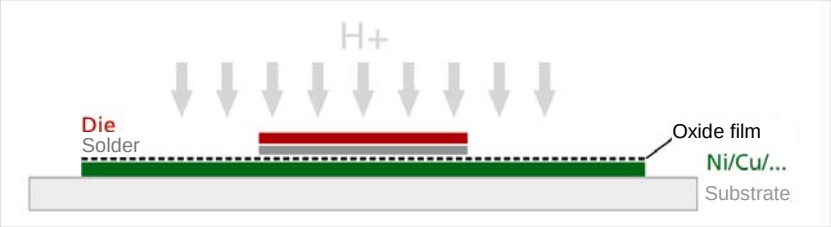

Figure 3: Hydrogen as Reducing Process Gas

$O_2 + 2H_2 \rightarrow O_2 + 4\ H+ \rightarrow 2H_2O$

3. Advantages of the Process

- safety engineering is less complex (centrotherm Safe Guard Level 1) than for soldering using H_2 (centrotherm Safe Guard Level 2)
- the process is cost-efficient
- the process is easy to control
- fluxing agents can be taken entirely out of the equation by the process mentioned above
- great reducing effects with regard to oxidized surfaces

4. Standard Application of Soldering Using Nitrogen and Formic Acid Mixture

In case of Power Semiconductors, the naked dies (Si, SiC, GaAs, at al.) are soldered with the solderable rear side metallization to the DCB (Direct Copper Bonded) substrates. This procedure - also called "die attach" – is used for stacking of the power hybrid. During this process step the soldering temperature of the solder alloys is 250°C and higher. That enables very efficient soldering with a residual oxygen content of much less than 10 ppm. After that, these hybrids (die and substrate) are soldered at low soldering temperature onto so called heat sinks. Also, in this case, the soldering process with nitrogen enriched with formic acid can be applied.

Both soldering applications create good soldered joints in a cost-effcient and high-quality process without fluxing agent. Under production conditions, the vacuum soldering systems of

the VLO series made by centrotherm offer good wetting as well as a void rate far below 2 % across the surface, due to the reduced oxide film.

Tests carried out by the Transferzentrum Mikroelektronik (Technology Center for Microelectronics; TZM) in Göppingen proved that already in 2004 the centrotherm VLO series was able to easily fulfill the requirement of a voiding rate below 2%.

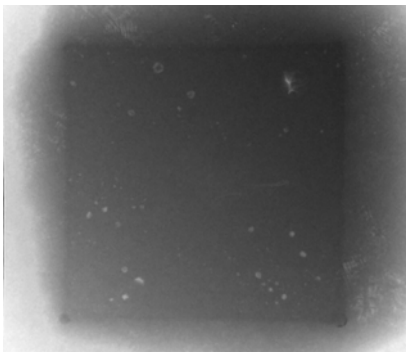

Figure 4: TZM Picture; Vacuum Soldering with Formic Acid Activation

This test of TZM revealed that, in reference to the void rate, soldering using formic acid (HCOOH) delivers worse results than soldering using forming gas (N_2/H_2 95/5). However, in comparison with forming gas, the corners of the soldered area are processed better. The tests were carried out on bare nickel layers. They are in general bad wetting surfaces.

PbSn36Ag2 at a liquidus temperature of 178°C was used as a soldering paste.

In this temperature range, formic acid has an advantage over forming gas because of its two-stage activation mechanism.

At the process temperature of over 120°C, the usage of formic acid positively affects the wetting and the voiding.

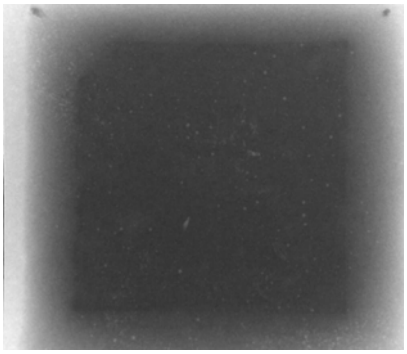

Figure 5: TZM Picture; Vacuum Soldering using Forming Gas 95/5

According to the TZM tests carried out in 2004, at a temperature higher than 200°C and a hydrogen concentration higher than 40%, soldering using formic acid is less effective in respect to voiding and wetting, than soldering with forming gas/hydrogen.

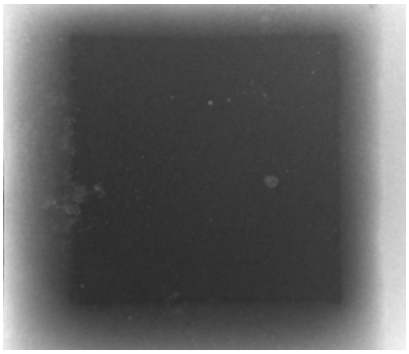

Figure 6: TZM Picture; Vacuum Soldering using Hydrogen 100

According to recent centrotherm findings, the plasma activation integrated into the soldering process using hydrogen significantly increases the performance resp. voiding and wetting (cp. centrotherm report „Blue Plasma – vacuum soldering with hydrogen: clean and better“).

5. Summary

As far as price and performance are concerned, soldering with formic acid is a good and practicable process.

The test carried out by TZM show, that vacuum soldering using forming gas does not reach the full quality of the vacuum soldering with formic acid, in respect to void rate.

It seems that, the best results of the vacuum soldering resp. the void rate are reached at temperatures higher than 200°C and with hydrogen amount of > 40%.

Type of activation	**Costs**	**Soldering result**	**Ability to retrofit**	**Restriction**
gas				
N_2	$	+	standard	no activation by N_2
N_2/H_2 95%/5%	$$	++	+++++	
H_2 100 %	$$$	++++	++++	safe guard level 2 required
RF plasma	$$$$	+++++	++++	open semiconductor → MW plasma
MW plasma	$$$$	+++++	-	not retrofittable
Gas/formic acid				
HCOOH	$$$	+++	+++	formate residuals (salts) possible

Table 1: Vacuum Soldering with Different Types of Activation

6. Prospects

Many years of experience and a wide range of centrotherm products with frontend, photovoltaic and backend solutions, make it possible for centrotherm to quickly develop vacuum soldering system solutions for the industrial market. Thanks to the modular VLO line concept, which covers various process requirements (highly plumbiferous, SAC solders, glass solders, hard solders), centrotherm is able to offer proven vacuum soldering which meet industrial standards witch a temperature range of up to 650°C. centrotherm's new high vacuum (10^-5 mbar) and heating concepts can be combined with various conventional activation agents such as forming gas (N_2/H_2 95/5 %), formic acid (HCOOH), hydrogen (H_2 to 100%) and/or plasma activation agents (RF and/or MW) for fast heating ramps (JEDEC/IPC compliant up to 5K/Sek.) and fast cooling ramps (JEDEC/IPC J-STD-020C up to 3 K/Sek).

As a result, centrotherm solutions are not only used for power semiconductor vacuum soldering but also for other industrial applications such as advanced packaging, optoelectronics and MEMS/MOEMS.

Our VSS development team and the soldering laboratory have combined forces to optimize equipment, processes and applications for tried and approved fields of application and to develop new solutions.

About the Author:

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Since 2006, Ulrich Völler has been the product manager of the Vacuum Soldering Systems at centrotherm thermal solutions GmbH + Co. KG.

Mr. Völler studied at the Technical University of Esslingen and worked many years at TZ Mikroelektronik (TZM) in Göppingen as team leader for Packaging, Manufacturing and Development Services.

About centrotherm thermal solutions:

For more than 30 years, centrotherm thermal solutions has designed, produced and sold high-end equipment as well as components for thermal semiconductor and photovoltaic processes. The range of activities includes horizontal and vertical furnaces, conveyor furnaces, vacuum soldering ovens as well as process technology development.

Picture credits: