Plasma-Supported Soldering Processes

Overview:

1. Low Pressure Plasma

Plasma is the fourth state of matter. If a matter is continuously supplied with energy, it changes from a solid to a liquid to a gas. Supplying further energy breaks the electron shells so that negatively charged electrons, positively charged ions and smaller complete molecules are generated. A low pressure plasma is for example generated when high-frequency electrical fields are applied to pure gas or a gas mixture in a vacuum chamber. The gas/gas mixture is ionized by which process radicals (negatively charged electrons and positively charged ions) are generated. The partial recombination of electrons and ions releases visible UV radiation ranging from yellow to blue shades (depending on the gas and the gas mixture). This excited, highly active gas is specifically used for surface modification by appropriately selecting parameters of the mixture composition, the coupled energy, the gas flow and the excitation frequency.

General Advantages of Low Pressure Plasmas

Low pressure plasmas (LP) are extremely efficient and environment-friendly when used for surface modification and are usually far more cost-effective than conventional chemical solutions. A low pressure plasma treatment can be applied to all substrate materials. Complicated assembly geometries can be activated, cleaned, coated and etched by plasma. The thermal and mechanical load is extremely low during low pressure plasma treatment so that even temperature-sensitive materials can be treated with low pressure plasma.

2. Radio Frequency (RF) as Excitation Frequency

Radio frequency describes radio waves with a frequency range between 10 kHz and 150 MHz.

centrotherm uses a 40 kHz RF generator. From the control aspect, the coupling frequency of 40 kHz offers a cost-efficient variant for RF plasmas as the external matching unit is not required anymore. Furthermore, centrotherm implements uniformly a proven and tested generator solution in accordance with industry standards. RF systems are often described as electrode systems as they require antenna (first electrode) and ground (second electrode).

3. Microwave (MW) as Excitation Frequency

Microwave is used to describe microwaves with a frequency range of 300 MHz to 300 GHz. centrotherm uses a MW frequency of 2.45 GHz. In simple terms, microwaves are electromagnetic waves which can be reflected and refracted like e.g. light and can even interfere.

The coupling frequency of 2.45 GHz and the encapsulated plasma head allow to generate an electrically neutral plasma. Electrically neutral plasmas are suited for the processing of assemblies with open semiconductors (dies). This also comprises power semiconductor assemblies.

centrotherm uses an encapsulated plasma head and corresponding generator in accordance with industry standards; the generators can also be coupled among each other.

MW systems are often designated as systems without electrodes.

4. Technical Implementation at centrotherm

Plasma-supported vacuum soldering in combination with gas mixtures of over 40 % H_2 and up to 100 % H_2 is an ideal process for the reduction of oxide films on substrate, component and solder surfaces.

Soldering temperatures below 250 °C require additional reactive energy insertion via the alternating electrical field of a plasma in order to activate the hydrogen.

In principle, the activation frequency is secondary in the first approach along with the inserted power and the process time. The chemical reactions always take place according to the same chemical equation.

The reaction of the reduction results from the excited H+ ions in the alternating electrical field: $O_2 + 2H_2 \rightarrow O_2 + 4\ H+ \rightarrow 2H_2O$. (cp. Fig. 1)

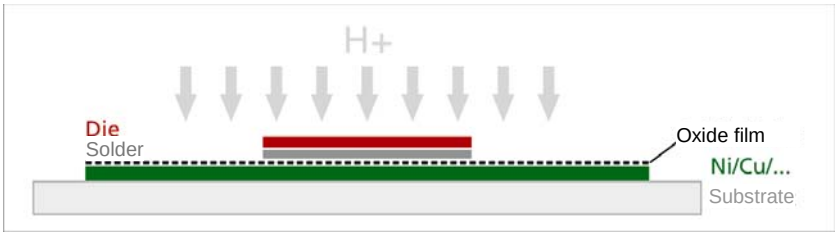

Fig. 1: Schematic Configuration of a Hybrid Stack

The plasma supported soldering process allows to reach void rates over the surface way below 2 %. (cp. Fig. 6)

4.1 Technical Implementation of the RF Plasma Generation

With RF plasma, the excitation frequency of 40 kHz is coupled via a cooled antenna and ground. (cp. Fig. 2)

The long-proven and cost-efficient centrotherm RF plasma excitation system has the advantage of being retrofittable in all centrotherm VLO 20 with control via the centrotherm machine control (CMC) system and can be used in combination with the centrotherm VLO H_2 technology. The RF plasma generator is exclusively controlled by the CMC system.

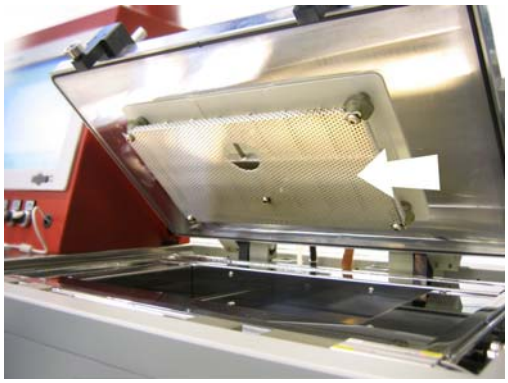

Fig. 2: Cooled RF Plasma Antenna of the VLO 20

The RF excitation frequency is generated by a generator system which has long-proven itself in the fields of semiconductor and solar cell manufacturing at centrotherm. (cp. Fig. 3)

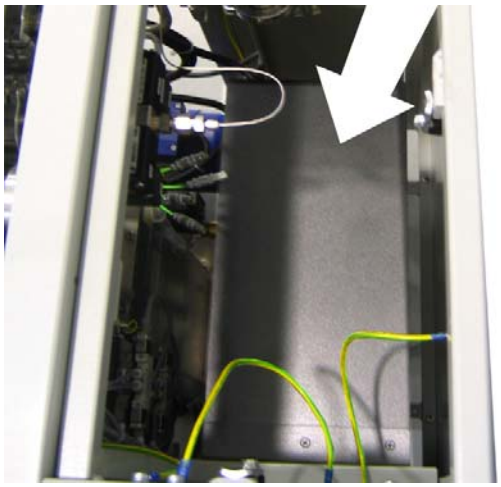

Fig. 3: RF Plasma Generator

4.2 Technical Implementation of the MW Plasma Generation

With MW plasma, the MW excitation frequency of 2.45 GHz is coupled via an encapsulated plasma head. (cp. Fig. 4)

The MW plasma excitation system built by centrotherm offers unrestricted use when soldering with semiconductors (dies). In addition, it can be combined with the centrotherm VLO H_2 technology which has now proven highly successful for many years.

The MW plasma generator is exclusively controlled by the centrotherm machine control system.

Fig. 4: Cooled and Encapsulated MW Plasma Head

At centrotherm, the MW excitation frequency is also generated by a generator system which has proven highly efficient over the years. (cp. Fig. 5)

Fig. 5: MW Plasma Generator

5. Summary

Nowadays, hybrids are decreasingly soldered with highly plumbiferous solders at a temperature range of over 250 °C. Just like with consumer electronics, environmental issues as well as the RoHS directive play a decisive role. As a result, solders with a low lead content or even so-called lead-free SAC solders [stannous (Sn), silver (Ag) and copper (Cu)] are used more and more often for soldering. In this case, the soldering temperatures range from 230 °C to 270 °C. The plasma-supported soldering process from centrotherm allows to achieve soldering results with a void rate way below 2 % when the process is carried out correctly. (cp. Fig. 6)

Internal surveys revealed that the best soldering results are achieved with plasma and 100 % hydrogen. With a H_2 concentration of less than 40 %, the soldering result is comparable with a correctly performed soldering using formic acid (wet chemical activation under HCOOH). Formic acid as wet chemical activation is available at centrotherm for all batch systems of the VLO line and for inline systems of the CVRS line. (cp. Fig. 7)

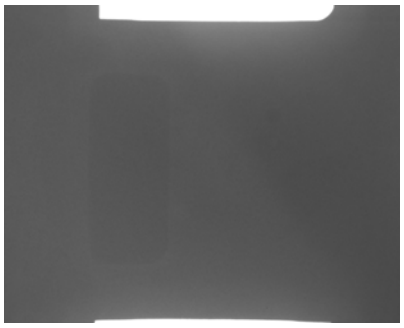

Fig. 6: „Very good“ Soldered Joint under Die and Heatsink with a Void Rate over Surface of approx. 0 %

Type of activation	Costs	Soldering result	Ability to retrofit	Restriction
dry chemical				
N_2	$	+	standard	no activation by N_2
N_2/H_2 95%/5%	$$	++	+++++	
H_2 100 %	$$$	++++	++++	safe guard level 2 required
RF plasma	$$$$	+++++	++++	open semiconductor → MW plasma
MW plasma	$$$$	+++++	-	not retrofittable
wet chemical				
HCOOH	$$$	+++	+++	formate residues (salts)

Fig. 7: Summary - Comparison of the Individual centrotherm Types of Activation for the Vacuum Soldering

6. Prospects

Due to longtime experience and its wide range of products, centrotherm is able to integrate and to launch processes in a very short delay and in accordance with industry standards. In the field of vacuum soldering, centrotherm offers proven solutions in accordance with industry standards thanks to the modular concept of the VLO line for various process requirements (highly plumbiferous, SAC solders, glass solders, hard solders) at a temperature range of up to 650 °C. Fast heating ramps (JEDEC/IPC compliant) and fast cooling ramps (3 K/sec) as well as a transverse homogeneity of +/- 1% at 250°C are achieved by the new centrotherm heating concept in combination with various activations like forming gas (N_2/H_2 95/5 %), formic acid (HCOOH), hydrogen (H_2 up to 100 %) and plasma activations (RF and/or MW).

Hence, thermal solutions from centrotherm are not only used in the field of vacuum soldering for power semiconductors but also in the fields of advanced packaging, optoelectronics and in the field of MEMS/MOEMS.

Our VLO development team with its soldering laboratory strive to update and enhance our tried and approved technology.

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Since 2006 Ulrich Völler has been product manager for 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) as a 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 products includes horizontal and vertical furnaces, conveyor furnaces as well as vacuum soldering systems.