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Key Advances in Void Reduction in the Reflow Process Using Multi-Stage Controlled Vacuum

This paper explores new advances in the reflow soldering process including vacuum technology and warpage mitigation systems.

The first topic for discussion will be the implementation of a vacuum process directly in a conventional inline soldering system. The paper discusses the significant results that have been achieved in reducing voids to < 1%.

Another key area to be discussed is the maximizing of the unit per hour (UPH) of the system while still achieving the void rate reduction < 1%.

Another key capability that will be explored is the elimination of solder splatter during the process of vacuum purge down.

The second topic we will present is the mitigation of warpage on substrates or wafers. This is one of the key technical challenges facing the industry.

We will explore direct warpage mitigation as well as independent substrate/wafer clamping systems as well as inline and recirculating automation solutions.

Key Advances in Void Reduction with Vacuum Technology

One of the challenges facing the industry is the requirement to significantly reduce voids from the process.

The proven method of reducing voids has been through the implementation of vacuum chambers in conventional convection reflow machines.

Why Use A Vacuum In Reflow Soldering?

There are five ways to eliminate voids that will improve product performance.

1. Improve heat dissipation of components or solder joint structures (i.e., current density increases with voiding)
2. Improve long-term stability and reliability of solder joint against heat dissipation and vibration/shock
3. Improve chip performance in high-frequency applications
4. Maintain impedances within specification for components (e.g., power modules)
5. Mitigate or eliminate solder problems (e.g., bridging, solder splashes, etc.) at µBGAs

Advantages of Vacuum-Assisted Convection Reflow

The advantages of vacuum-assisted reflow are:

- Vacuum-assisted reflow has been shown to reduce the voids in a solder joint by 99%
- Vacuum pressure is reduced to 1-5 Torr during liquidous of the soldering process
- Existing voids escape externally through the solder when a vacuum is applied.
  - Trapped gas bubbles increase in size as pressure is reduced
  - Larger bubbles are more likely to collide with other bubbles and ultimately collide with the edge of liquid solder to escape
  - Larger bubbles are accelerated by stronger buoyancy forces making them more likely to escape

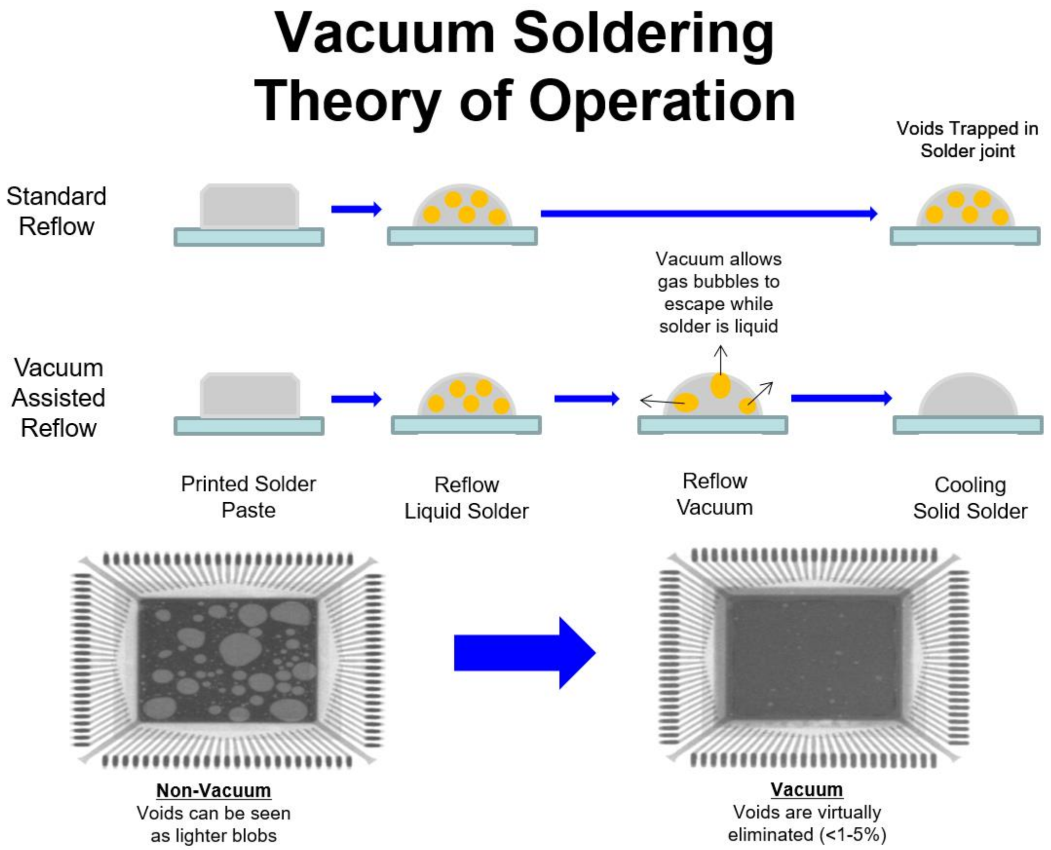


Exhibit 1: Comparison of Conventional Reflow and Vacuum-Assisted Reflow

The pressure inside trap gas per the **Young- Laplace Equation**

Pressure trapped inside a gas bubble changes according to Young-Laplace Equation

$$\text{Pbubble} = \text{Pambient} + 2g / r$$

(where “g” is surface tension and “r” is the radius of the bubble)

The ideal gas law using Pbubble determines the actual bubble size.

Vacuum Applications

- Convection reflow systems utilize a vacuum module that inserts directly in its reflow oven line
- Reflow liquidous can be achieved before or after entering a vacuum module
    - Vacuum module is inserted in a zone where reflow peak typically occurs
    - Alternatively, reflow liquidous can be achieved inside the vacuum module through IR heating
- Convection reflow with vacuum module is continuous and allows thermal profiles to be directly ported from non-vacuum reflow applications
- Continuous operation facilitates low cost of ownership (COO) and high UPH

Exhibit 2: Conventional reflow with vacuum chamber module

Exhibit 3: Vacuum Chamber

Vacuum Soldering Overview

- Vacuum-assisted reflow through the inclusion of a vacuum module in its reflow oven line is now standard technology
- Vacuum-assisted reflow with convection heating utilizes continuous operation thermal profiles for low COO and high UPH.
- Recent customer installation showed 10X reduction in voids, meeting specification of <1% total void area
- Reflow time under a vacuum of 15 seconds was able to achieve <1% total void area specification
- All pressures tested < 20 Torr met <1% total void area specification

Theory of Operation

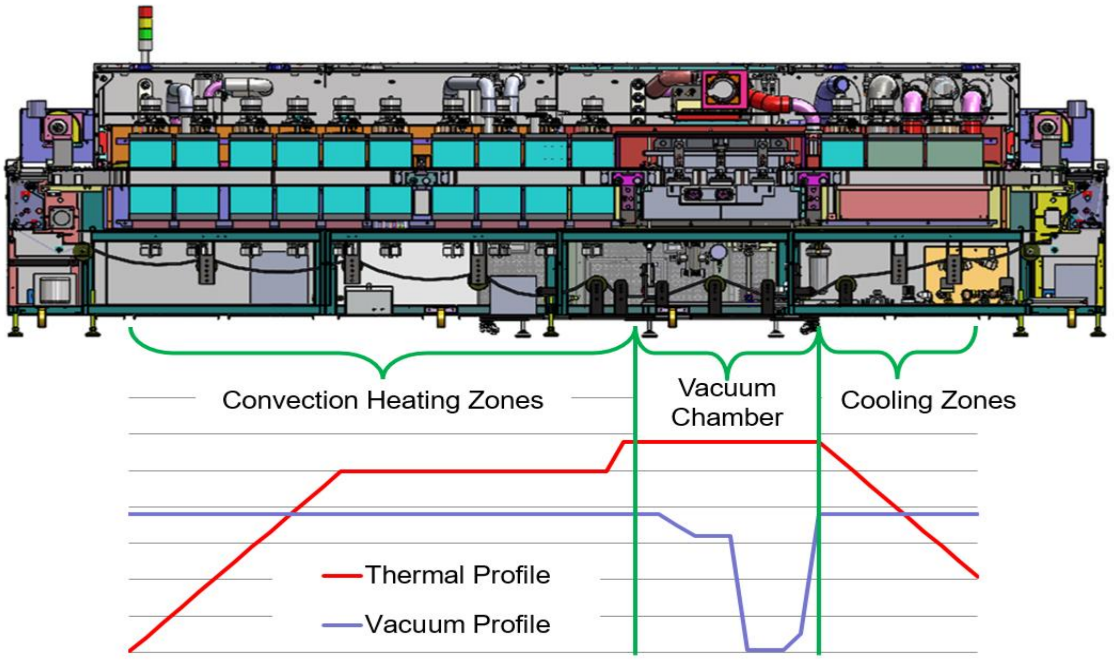


Exhibit 4: Thermal Profile and Vacuum Profile

A major issue and concern with vacuum reflow is solder splatter. If the vacuum pressure is reduced too quickly solder balls can be “splashed” across the substrate. Heller has developed a multi-stage step-down algorithm that is computer controlled and can be customized for your process -- thus eliminating solder splatter on the product.

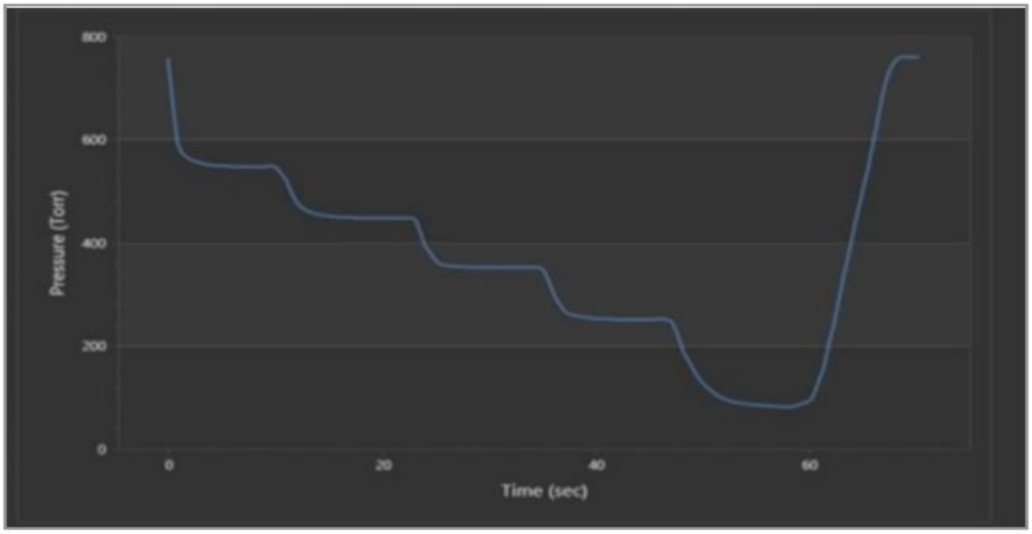
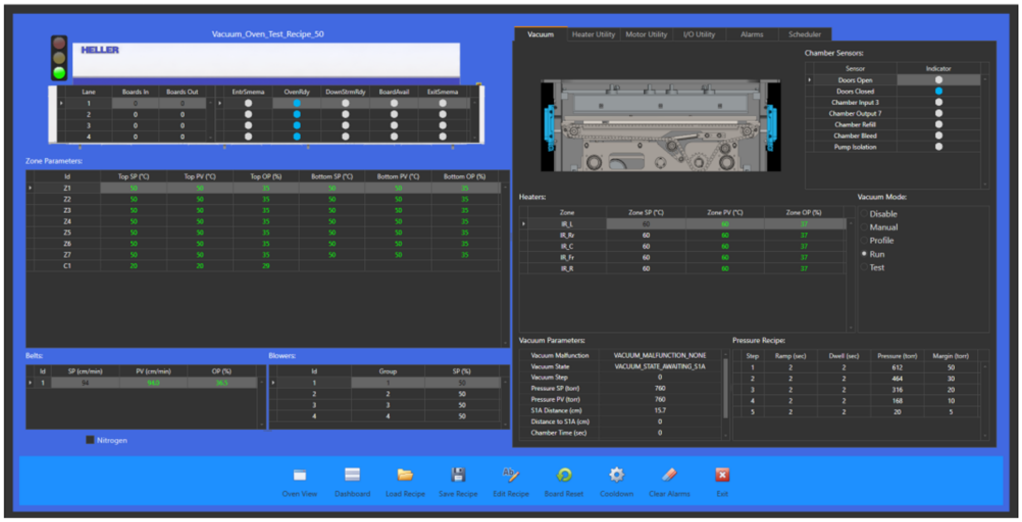


Exhibit 5: Multi-step Purge Down to Eliminate Solder Splatter

A user-friendly GUI makes this easy to set up. The user-friendly software package has many “knobs” to control the purge down process as well as timing for each phase of the thermal excursion. Including:

- Conveyor speed into the chamber
- Conveyor speed on exiting the chamber
- Residence time in the chamber
- Temperature in the chamber
- Refill time
- Refill rate



Vacuum_Oven_Test_Recipe_50

Lane	Boards In	Boards Out	EntrSmema	OvenRdy	DownStrmRdy	BoardAvail	ExitSmema
1	0	0	○	●	○	○	○
2	0	0	○	●	○	○	○
3	0	0	○	●	○	○	○
4	0	0	○	●	○	○	○

Zone Parameters:

Id	Top SP (°C)	Top PV (°C)	Top OP (%)	Bottom SP (°C)	Bottom PV (°C)	Bottom OP (%)
Z1	50	50	35	50	50	35
Z2	50	50	35	50	50	35
Z3	50	50	35	50	50	35
Z4	50	50	35	50	50	35
Z5	50	50	35	50	50	35
Z6	50	50	35	50	50	35
Z7	50	50	35	50	50	35
C1	20	20	29			

Belts:

Id	SP (cm/min)	PV (cm/min)	OP (%)
1	94	94.0	36.5

Blowers:

Id	Group	SP (%)
1	1	50
2	2	50
3	3	50
4	4	50

☐ Nitrogen

Chamber Sensors:

Sensor	Indicator
Doors Open	○
Doors Closed	●
Chamber Input 3	○
Chamber Output 7	○
Chamber Refill	○
Chamber Bleed	○
Pump Isolation	○

Heaters:

Zone	Zone SP (°C)	Zone PV (°C)	Zone OP (%)
IR_L	60	60	37
IR_Rr	60	60	37
IR_C	60	60	37
IR_Fr	60	60	37
IR_R	60	60	37

Vacuum Mode:

○ Disable
○ Manual
○ Profile
● Run
○ Test

Vacuum Parameters:

Vacuum Malfunction	VACUUM_MALFUNCTION_NONE
Vacuum State	VACUUM_STATE_AWAITING_S1A
Vacuum Step	0
Pressure SP (torr)	760
Pressure PV (torr)	760
S1A Distance (cm)	15.7
Distance to S1A (cm)	0
Chamber Time (sec)	0

Pressure Recipe:

Step	Ramp (sec)	Dwell (sec)	Pressure (torr)	Margin (torr)
1	2	2	612	50
2	2	2	464	30
3	2	2	316	20
4	2	2	168	10
5	2	2	20	5

Exhibit 6—User-Friendly Software with Multiple Control Points

Results: DBC at Heat Sink

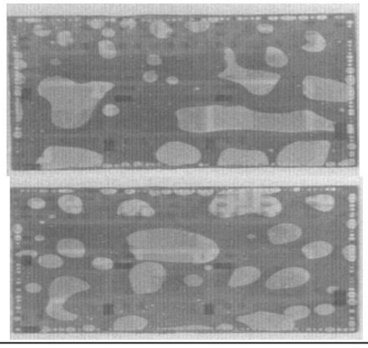
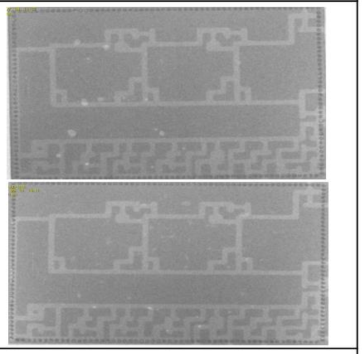
Process	DBC at heat sink	
Vacuum	**Not Applied**	**Applied**
X-ray		
Void rate	30-40%	<1%
Vacuum Parameters	Pump slow rate	Double cycle vacuum - 250torr/sec and 250torr/sec
	Dwell	Double cycle vacuum - 10torr for 15sec and 5sec
Void removed between DBC and heat sink		

Exhibit 7—No Vacuum vs. Vacuum on Heat Sink (<1% voids)

Results: Automotive QFN

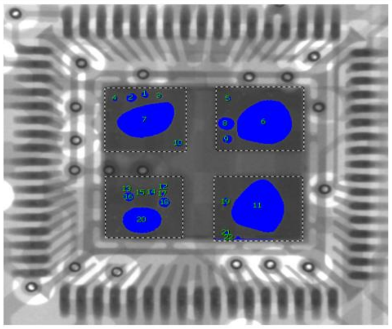
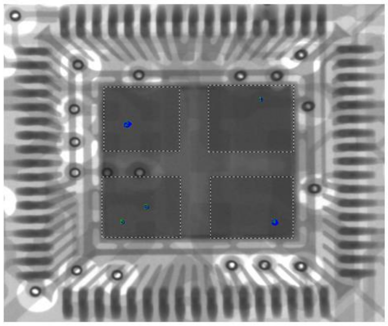
Process	Automotive - QFN	
Vacuum	**Not Applied**	**Applied**
X-ray		
Void rate	20-40% at all pads	Each pad <1%
Vacuum Parameters	Pump slow rate	300torr/sec
	Dwell	10torr for 15sec
Void removed between QFN package and PCB		

Exhibit 8—No Vacuum vs. Vacuum on QFN (<1% voids)

Comparison of Conventional Convection Reflow With Vapor Phase Soldering

One area we would like to discuss is a comparison of conventional convection reflow with vapor phase soldering.

Vapor phase soldering has been successfully applied in many applications.

Higher UPH and lower COO are the key advantages of convection reflow in comparison vapor phase soldering.

The design of the conventional convection reflow systems incorporates a belt transportation system utilizing multiple process lanes. This configuration maximizes total UPH in high volume applications. Customer applications have proven that they can achieve void rates < 1% with configurations of 5 production lines.

Depending on the customer application, the cost of chemicals to support a vapor phase system can be very high.

This high level of system output in terms of UPH coupled with the lower operational costs of conventional reflow results in a much lower cost of ownership per unit.

Dual Lane Conveyor Systems for Higher UPH

And for applications with ultra-high UPH, a dual lane conveyor is available. The dual-lane conveyor can provide double the UPH of the standard system -- thus satisfying the requirements for many consumer-related products.

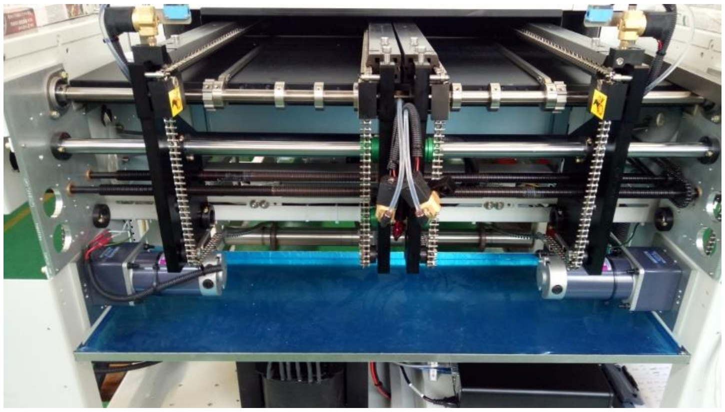


Exhibit 9—Dual Lane Conveyor System

Substrate and Wafer Warpage Mitigation

Warping of components and substrates is a serious problem facing the industry. Often it induces fatal interconnection defects and initiates a weak connection between the silicon die and substrate/wafer substrate and wafer package.

Defects that occur due to this warpage include:

- Misalignment of components
- Non-wetting
- Contact area decreases causing interconnection faults
- Vertical warping and curling of structures in the surface micromachining leads to degradation of the functionality of devices

Types of Systems

- A wide range of warpage mitigation solutions have been developed based upon customer feedback
- These solutions are utilized to mitigate substrate and wafer warpage during the convection reflow process
- The systems can include either stand-alone independent fixtures or fully integrated solutions
- Automation solutions include single and multiple lane configurations as well as pallet recycling systems

The two types of systems are outlined below

1. Independent Fixture Systems

- Vacuum chuck system operates by independently loading the substrate/wafer chuck with a vacuum charge
- The vacuum charge will last > 30 minutes
- The vacuum chuck can be manually or automatically loaded onto the conveyor system
- Heller offers full automation with automatic chuck recycling

2. Direct Suction Systems

- Direct vacuum system operates by utilizing a mesh belt conveyor system to provide vacuum suction from beneath the substrate/wafer
- The system can be used in multiple lane configurations
- There is no additional automation required

Summary

Vacuum reflow soldering has been shown to have a significant impact on void levels in various applications. Including:

- Improved heat dissipation of components or solder joint structures (i.e., current density increases with voiding)
- Improved long-term stability and reliability of solder joint against vibration/shock
- Improved device performance in high-frequency applications
- Maintaining impedances within specification for power modules
- Mitigating or eliminating solder problems such as bridging, solder splashes on various components (e.g., µBGA)

The Heller Vacuum-Assisted Reflow Ovens have been successfully implemented at numerous customers in both the semiconductor and SMT asembly industries. The system is highly configurable to eliminate solder splatter and provide void rates of <1%. Its user-friendly software makes set up easy and fast.

The current Heller 3rd Generation Vacuum Reflow Oven Line offers reliable, industry-leading solutions for the most challenging voiding issues

Heller is committed to continuous improvement and will work closely with customers to exceed all requirements and specifications