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THE THERMAL TECHNOLOGY LEADER

Warpage Mitigation Systems for Wafers and Panels for Use During Mass Reflow Processes

This paper will explore recent advances made by Heller Industries in warpage mitigation for wafers and panels during mass reflow processes. The two systems that will be presented are designed for use with high-productivity, horizontal in-line reflow ovens.

The first system to be discussed is the vacuum wafer chuck system. The system utilizes a vacuum charge to keep a wafer flat during the entire reflow process. After the reflow cycle is complete, the wafer is unloaded and a unique recirculating system utilizing elevators and a conveyor returns the chuck back to the entrance of the oven, where it is used by another wafer.

The second warpage mitigation system to be presented is the vacuum panel chuck system, which is for use with large panels, like those typically used in fan-out panel level packaging (FOPLP). This system is similar to the wafer vacuum system, but to deal with the more severe warpages seen in panels, it includes the additional capability of being able to mechanically press down and clamp the panel before the vacuum charge is applied.

Vacuum Chuck System for Warped Wafers

Wafer warpage is an increasingly critical issue in the semiconductor industry. It is caused by mismatches in coefficients of thermal expansion (CTE) between the

wafer and the layers of material deposited onto the wafer. In the case of fan-out wafer level packaging (FOWLP), the CTE mismatch occurs between the epoxy molding compound (EMC) and carrier wafer. During thermal processes, these layers expand at different rates than the wafer, which creates intrinsic stresses that cause the wafer to warp.

Wafer warpage can cause issues with automation, as handling wafers becomes more difficult when wafer geometries are subject to change. The greater issue, however, is that warpage can negatively impact yield. Yield-limiting defects that can occur during mass reflow due to warpage include:

- Incomplete wetting of the solder joint (head-in-pillow).
- Poor contact or stretched joints
- Bridged joints

To address these issues, Heller Industries has developed the vacuum wafer chuck system for use with horizontal reflow ovens. The system consists of a round chuck with o ring around the edge. The chuck has a fixture on the bottom which connects to a vacuum pump, and holes in the top surface which allow vacuum to pull down on the wafer. Versions of the vacuum wafer chuck are available for both 200mm and 300mm wafers, as well as 300mm wafers on film frame.

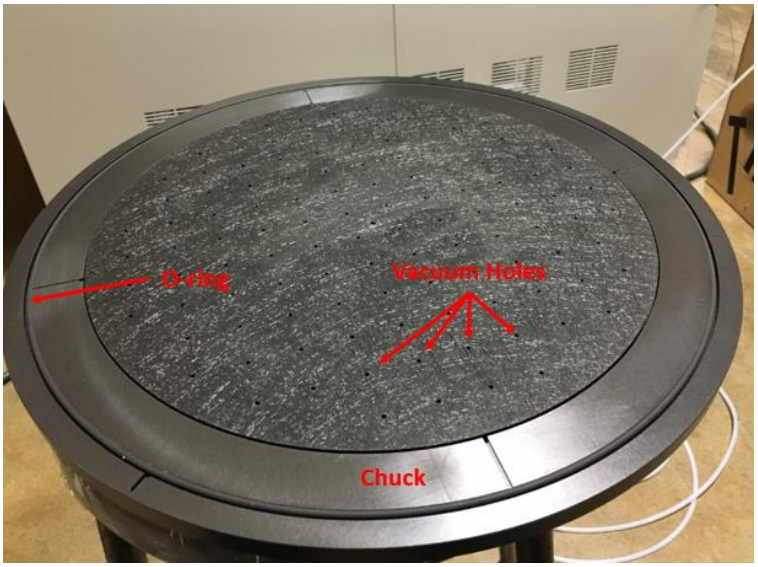

Exhibit 1: Wafer Vacuum Chuck for Film-Frame Wafer

The system works by loading a wafer to the chuck where vacuum is applied which pulls the wafer down and keeps it flat. Vacuum is applied only once at the beginning, and the chuck retains the vacuum charge throughout the entire reflow process. Wafer loading can be done either manually, or with automation, and once loaded the chuck with flattened wafer goes through the oven as a single unit. At the end of reflow process the wafer is unloaded and moved down the process line. The chuck is returned to the entrance of the oven via a circulating system.

A recirculating system has been developed that returns the chuck back to the entrance of the oven after its wafer has been unloaded. It operates by first lowering the chuck via an elevator to a plane below that of the reflow area, and a conveyor moves it back towards the entrance of the oven. A second elevator then lifts the chuck up back to the original loading station where it can then accept a new wafer. Multiple chucks are running within the system continuously to maintain a high UPH.

Go to https://hellerindustries.com/vaccum-reflow-video-form/ to see an animation of the chuck recirculating system.

The vacuum wafer chuck system can be implemented on any horizontal reflow oven offered by Heller Industries. It is cleanroom compatible (up to class 100) and can be used with formic or forming gas. Options for full automation are available.

Exhibit 2: Vacuum Chuck Loading Station

Exhibit 3: Wafer and Chuck Moving Through Reflow Oven

Vacuum Wafer Chuck Temperature Uniformity

Temperature uniformity data were collected using the vacuum wafer chuck system and a 300mm wafer on film frame. Thermocouples were positioned at the wafer center, top, bottom, left and right edges. Temperature data were taken for all thermocouples as the wafer and chuck were mass reflowed using a SAC305

profile. Results show excellent thermal uniformity across the wafer with a peak temperature ΔT of 2.89° C.

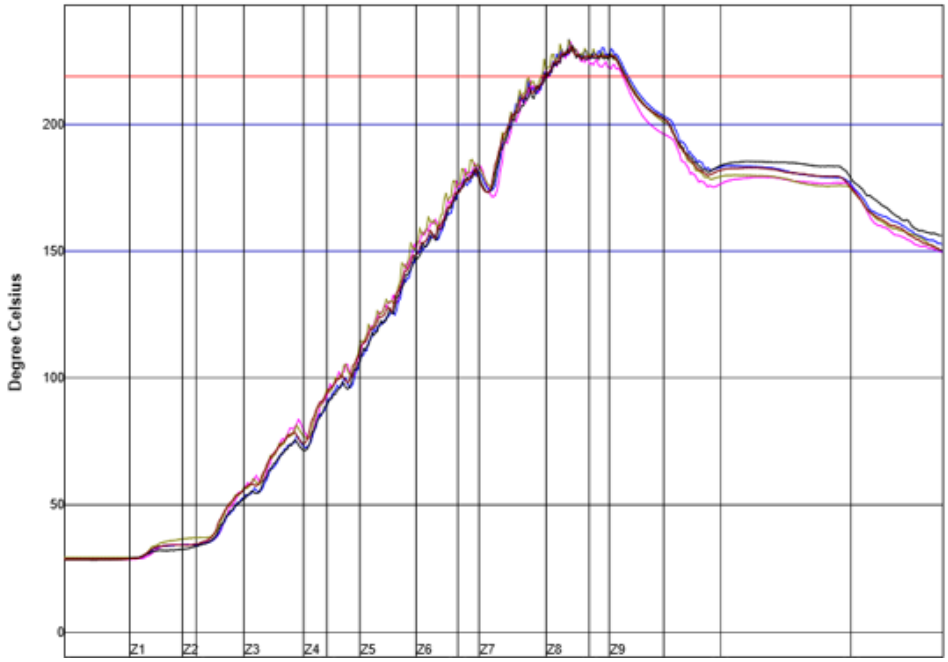

Exhibit 4: Temperature uniformity data for 5 points on wafer. Peak temperature ΔT is >3° C.

Vacuum + Mechanical Clamping Chuck System for Panels

While wafer warpage has been a known issue in fan-out wafer level packaging, as the industry moves towards panel substrates (FOPLP), the challenge becomes even more of an issue due to the rectangular shape and overall larger sizes (up to 600mm x 600mm) of the panels involved.

To counter these more extreme warpages, Heller Industries has developed the vacuum panel chuck and recirculating system, similar to what was described with the vacuum wafer chuck system. The panel system, however, includes the added capability of mechanical pressing down and clamping the panel.

During operation, the panel is loaded at the entrance of the oven where it is clamped prior to a vacuum charge. The loading sequence follows these steps:

1. The panel is placed onto the chuck surface either by manual loading or EFEM.
2. A frame comes down from above and applies an even pressure to flatten out the panel. The frame touches the panel only in exclusion areas at the panel edges.
3. Edge clamps, which are part of the chuck, are then slid into place to keep the panel held flat on the surface.
4. Vacuum force is then applied from below panel to flatten the panel further.
5. The frame is then lifted (edge clamps remain), and the chuck with panel can then enter the reflow oven.

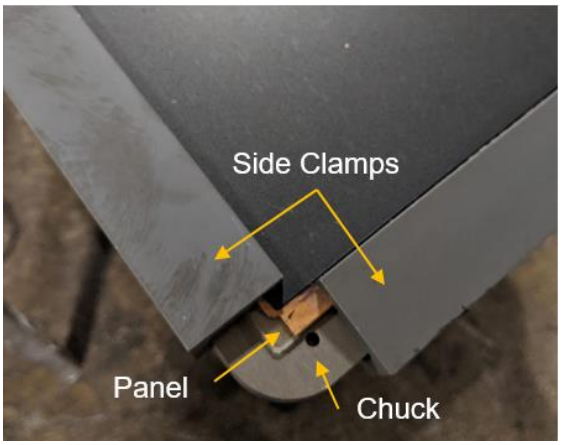

Exhibit 5: Vacuum clamp chuck with glass panel and side clamps applied.

Once reflow is complete, this process is reversed to unload the panel. Similar to the wafer system, multiple chucks are employed in a single system to allow for maximum UPH. The panel chuck system is cleanroom compatible (up to class 100) and can be used with formic or forming gas. It is also capable of full automation.

Vacuum Panel Chuck Temperature Uniformity

Temperature uniformity data were taken using a large glass panel (>500mm each side) with RDL, which was clamped to the vacuum panel chuck. Thermocouples

were placed at each corner and center of the panel, and temperature data were recorded as the panel with chuck underwent a standard reflow profile. Test results showed very good thermal uniformity across the panel with a peak temperature ΔT of 3.78° C.

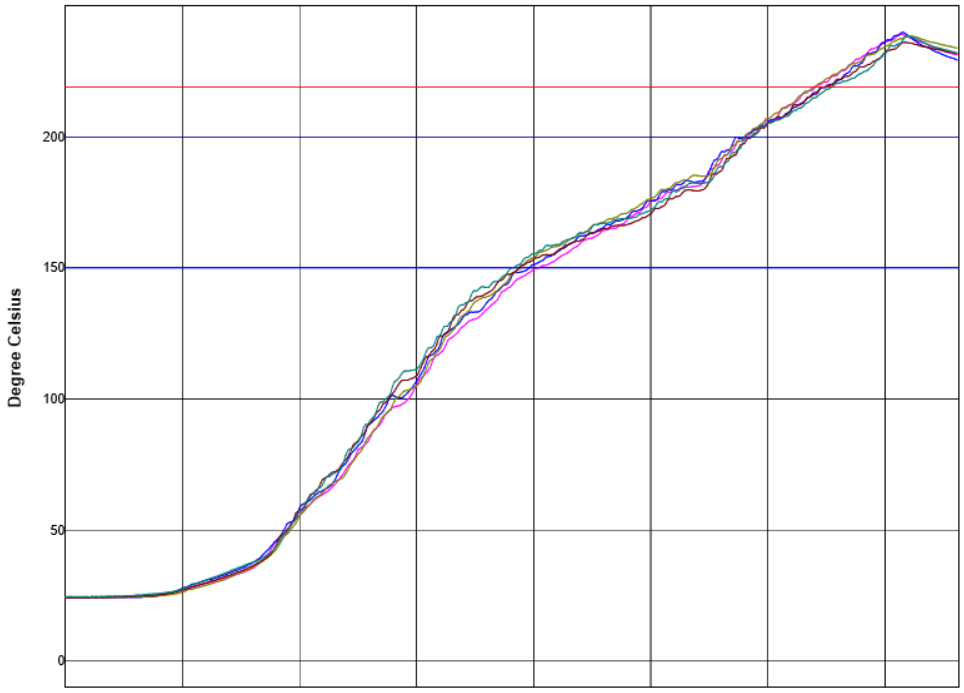

Exhibit 6: Temperature uniformity data for 5 points (4 corners and center) on panel. Peak temperature ΔT is >4° C

Vacuum Panel Chuck Flatness Measurement

The overall z-height of a warped large glass panel (>500mm each side) was measured using a Keyence sensor affixed to a gantry. Measurements were made every 10mm along axes at the panel's center. Prior to clamping, the panel showed a maximum deflection from warpage of around 6mm. After vacuum clamping, the overall flatness tolerance was measured to be 175um and 171um for the 2 axes measured. All measurements were taken at 25° C.

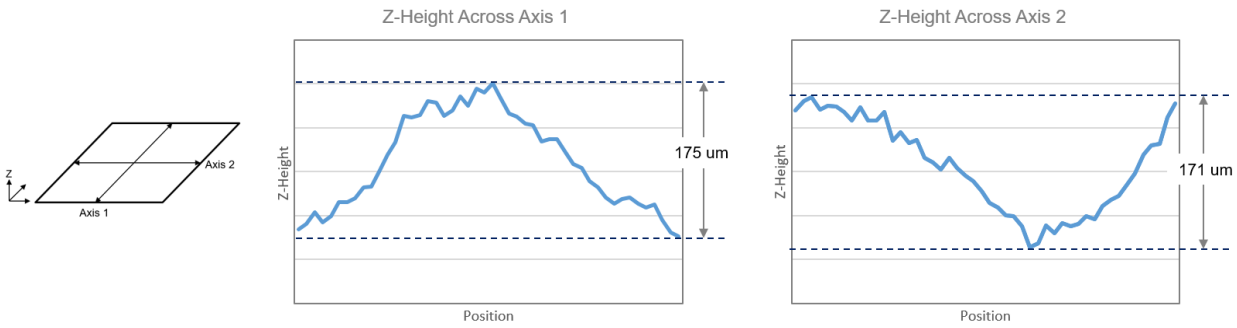

Exhibit 7: The vacuum panel chuck secures a ~6mm warped panel with an overall flatness of <175um.

Vacuum Panel Chuck Die Attach Results

The images in Exhibit 6 show cross sections of solder joints which were reflowed in a formic acid environment using the vacuum panel chuck. Test die were attached to a large panel (>500mm each side) with RDL using a standard flip chip die attach process in regions on the left side, right side, and center areas of the panel. Cross section analysis shows that all regions had good intermetallic formation for solder interconnects.

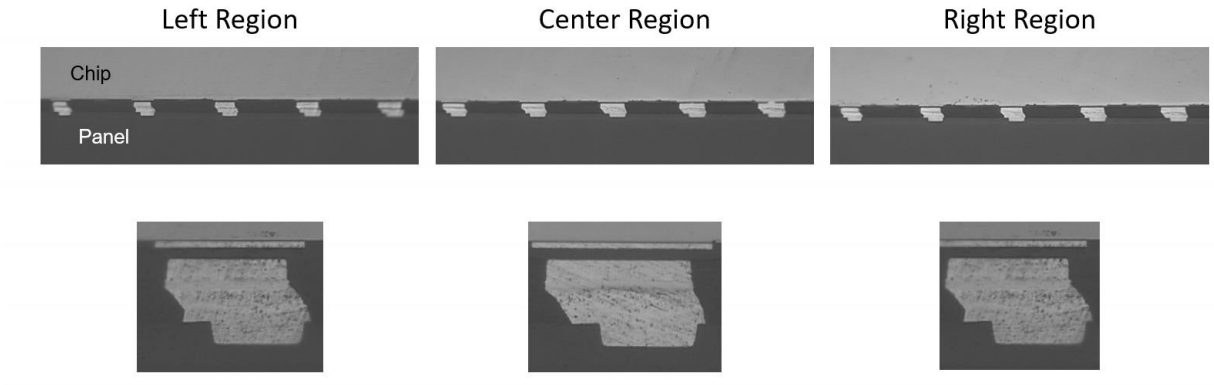

Exhibit 6: Solder joint cross sections of chips attached to glass panel with RDL.

Summary

To address the growing industry challenges of wafer and panel warpage, Heller Industries has developed unique and effective solutions for mitigating warpage during mass reflow using vacuum chucks and clamping systems. These systems include:

- A system for recirculating chucks back to the oven loading station after reflow is complete.
- Compatibility with in-line horizontal reflow oven for maximum UPH
- Compatibility with full automation for wafer/panel loading and unloading.
- Cleanroom compatibility (up to class 100)
- Compatibility with forming gas and formic acid processing environments.

Both the wafer and panel system have been successfully implemented at customer sites in the semiconductor industry for die attach processes. Heller remains committed to continuous improvement and will work closely with customers to address their unique warpage mitigation requirements.