Improvements in the Reliability, Costs and Processing of WLP/RDL Circuits

YES builds cure ovens that are specifically designed to address the concerns of manufacturers of the cured - characteristics of the multiple polyimide layers incorporated in Wafer-level Packaging (WLP)/Redistribution Layers (RDL) circuits. Polyimides are high temperature engineering polymers with excellent mechanical, thermal and electrical properties. The most important step of the process is the curing of the polyimide precursors, which can be done under atmospheric or vacuum process conditions. This paper will compare the characteristics of the polyimide film cured under these two conditions. The objectives of a proper cure process are to:

YES-PB12

1. Complete the imidization process,
2. Optimize film adhesion performance,
3. Remove all residual solvents and extraneous gases, and
4. Remove photosensitive components.

To convert the polyimide precursors to a stable polyimide film, an elevated temperature (~250° C to 450°C) extended bake is required for complete imidization; it also drives off the N-methylpyrrolidone (NMP) casting solvents and orients the polymer chains for optimal electrical and mechanical properties.

YES-VertaCure

Figure 1*: The manual load YES-PB12 oven (top left) is equipped with pre-heated and filtered N_2 purge in vertical laminar flow. It is also equipped with forced air cooling for increasing process throughput; and easily accessible disposable filter mounting and housing assembly at chamber exhaust for filtering and scrubbing process exhaust:* ***Figure 2:*** *(middle right) Automated vertical version (VertaCure)*

Process conditions for a properly cured polyimide film:

A. Controlled temperature ramp rates that are characterized for the polyimide film

The imidization rate of the polyimide precursors needs to be controlled to take into account the differences in thermal expansion coefficient between the polyimide film and the underlying substrate. If the imidization rate is not controlled properly, there can be localized mechanical stress variations across the wafer. In addition, if the casting solvents evolve non-uniformly across the wafer, film thickness non-uniformity can occur due to uneven imidization. The mechanical stress variations can be observed as wrinkled polyimide film or as distorted metal lines in the structures under the polyimide layer. The polyimide film can also delaminate because film adhesion performance has not been optimized. Because mechanical stress variations can affect the yield and reliability of the process, it is critical that controlled temperature ramp rates are used to provide a larger process window for the proper curing of a polyimide film.

Non-uniform heating can cause a skin to form on the surface of the polyimide film during the curing process. The skin can prevent the efficient evolution of the casting solvents and other volatile gases. If a cured polyimide film still has residual solvents or other volatile gases, then localized areas of the polyimide film can rupture in a phenomenon known as “popcorning”. These ruptures occur in subsequent process steps in tools, which have either a high vacuum or a high temperature environment. This rupturing is due to the sudden release of gas bubbles/solvents trapped in the polyimide film that is not properly cured. In addition, a “solvent-free” polyimide film will minimize the queue time needed to allow for outgassing when the next process step is a high vacuum process, such as metallization.

B. Complete removal of photosensitive components

Photosensitive polyimides offer the advantage of simpler processing by eliminating the need for photoresist compared to standard non-photosensitive polyimides. This reduces the number of process steps. The curing process parameters, such as temperature, vary with the type of photosensitive precursors in the polyimide film. For some types of precursors, the photosensitive components can be difficult to evolve from the polyimide film. Residual photosensitive polyimide precursors can cause greater internal film-induced stress than those in a standard polyimide film.

Some photosensitive polyimide precursors and their byproducts also have a tendency to form deposits on the process chamber walls. Heavy deposits can be difficult to remove if the byproducts are not efficiently removed from the chamber during the curing process. Furthermore, when these byproducts are exhausted from the chamber, they also need to be substantially removed from the exhaust stream as the byproducts can redeposit along the exhaust lines. In summary, the photosensitive components must be eliminated from the polyimide film and efficiently removed from the process chamber.

C. Oxygen level is < 20 ppm

The presence of oxygen in the process chamber inhibits the proper crosslinking of the polyimide precursors to polyimide thin film. The result is incomplete imidization which leads to a brittle film and variable stress in the polyimide film on the substrate. Also, ambient oxygen darkens the polyimide film. This film transparency is critical when multiple polyimide layers are used during subsequent processing. For multi-layer processes, the alignment marks for the process sequence can be obscured by the layers of low transparency polyimide films. In summary, pure nitrogen ambient is required to reduce the level of oxygen in the process chamber.

Review of Atmospheric Cure Process and Vacuum Cure Process

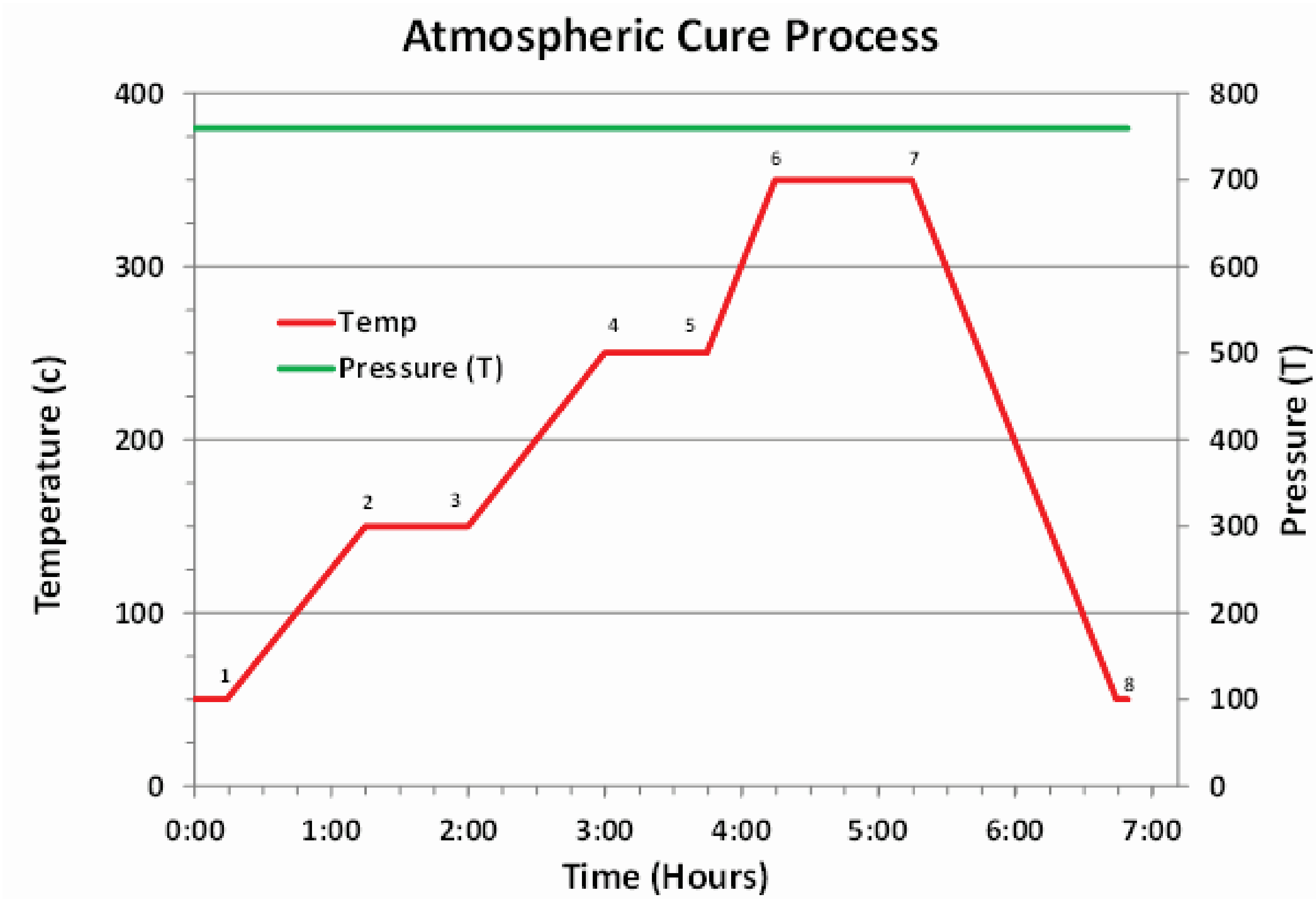

Figure 3: *Atmospheric Cure Process graph. Tests were run in an atmospheric oven. Numbers 1- 8 are temperature nodes.*

Node 1 to Node 6 - Solvent evaporation rates are limited by vapor diffusion across the flow boundary layer. As a result, low temperature dwell steps are required to allow for solvent evaporation. As the solvents evolve, imidization of the polyimide precursors occur. The imidization rate is also affected by temperature ramp rate of the process. Because atmosphere air is ~23% oxygen, a high flow of N_2 is required to reduce the oxygen level.

Node 6 to Node 7 - The process is held at the temperature required for complete imidization of the polyimide film. High flow of N_2 may still be required at this point to maintain low oxygen levels.

Node 7 to Node 8 - Process temperature is ramped down. Curing process is done.

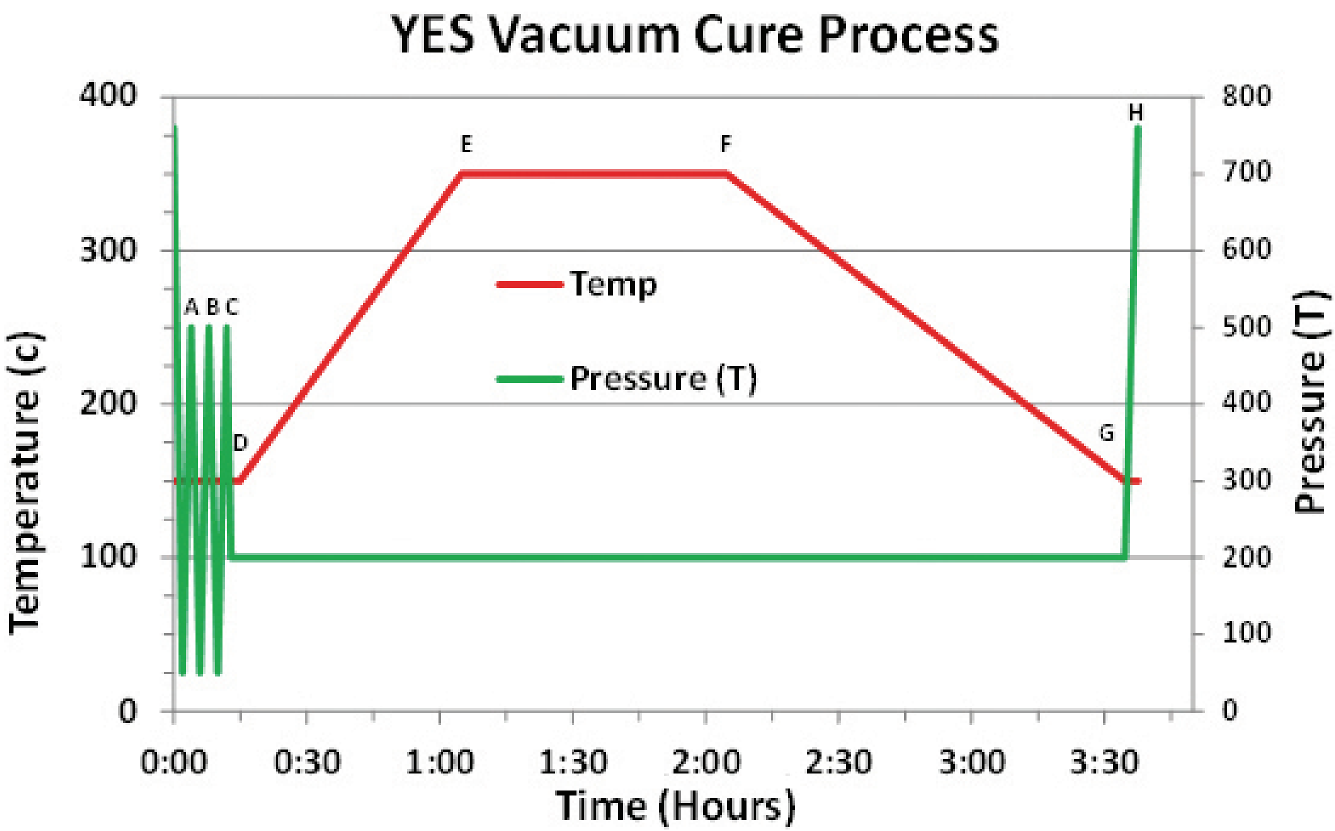

***Figure 4:** Yield Engineering Systems' Vacuum Cure Process graph. Tests were run on a YES-PB12 system. Points A,B,C are the high nodes for the vacuum/ N_2 purge cycles on the pressure graph. D,E,F,G, are on all the nodes on the temperature graph after that. The process is completed at node H when the chamber is vented to atmosphere.*

Point A to Point D - Three short vacuum/hot N_2 purge cycles reduce the oxygen level quickly, because oxygen is removed faster in a vacuum. The boiling point for the NMP casting solvents at 50 Torr is 135°C, Therefore, the first vacuum pull of the cycle purge sets the polymer, which can improve polymer thickness uniformity.

Point D to Point E - A laminar flow of hot N_2 purge balanced against a vacuum gives a 200 Torr pressure level which continuously removes oxygen. At this reduced pressure the NMP solvent is efficiently pulled off without any skin being formed on the polymer, thereby enabling a controlled temperature ramp to the imidization temperature.

Point E to Point F - The process is held at the temperature required for complete imidization of the polyimide film.

Point F to Point H - Process temperature is ramped down. Process chamber is vented to atmosphere. Curing process is done.

To evaluate the polyimide film parameters, third party vacuum/atmospheric comparison tests were completed by Evans Analytical Group. The tests compare the YES-PB12 vacuum oven with an atmospheric oven. The test ran a process matrix of 5 microns of HD-4000 in each oven. The samples were

soft-baked on a vacuum hot plate to remove solvents before further processing. The samples were then split into a YES process at 350°C and an atmospheric bake at 350°C. After the cure cycle was completed, the splits were treated to a three-hour gas chromatograph treatment and the evolved gases were measured and analyzed. The resultant graphs are below. Analysis shows a 5x higher amount of trapped solvents and gases in the atmospheric bake process compared to the vacuum bake process.

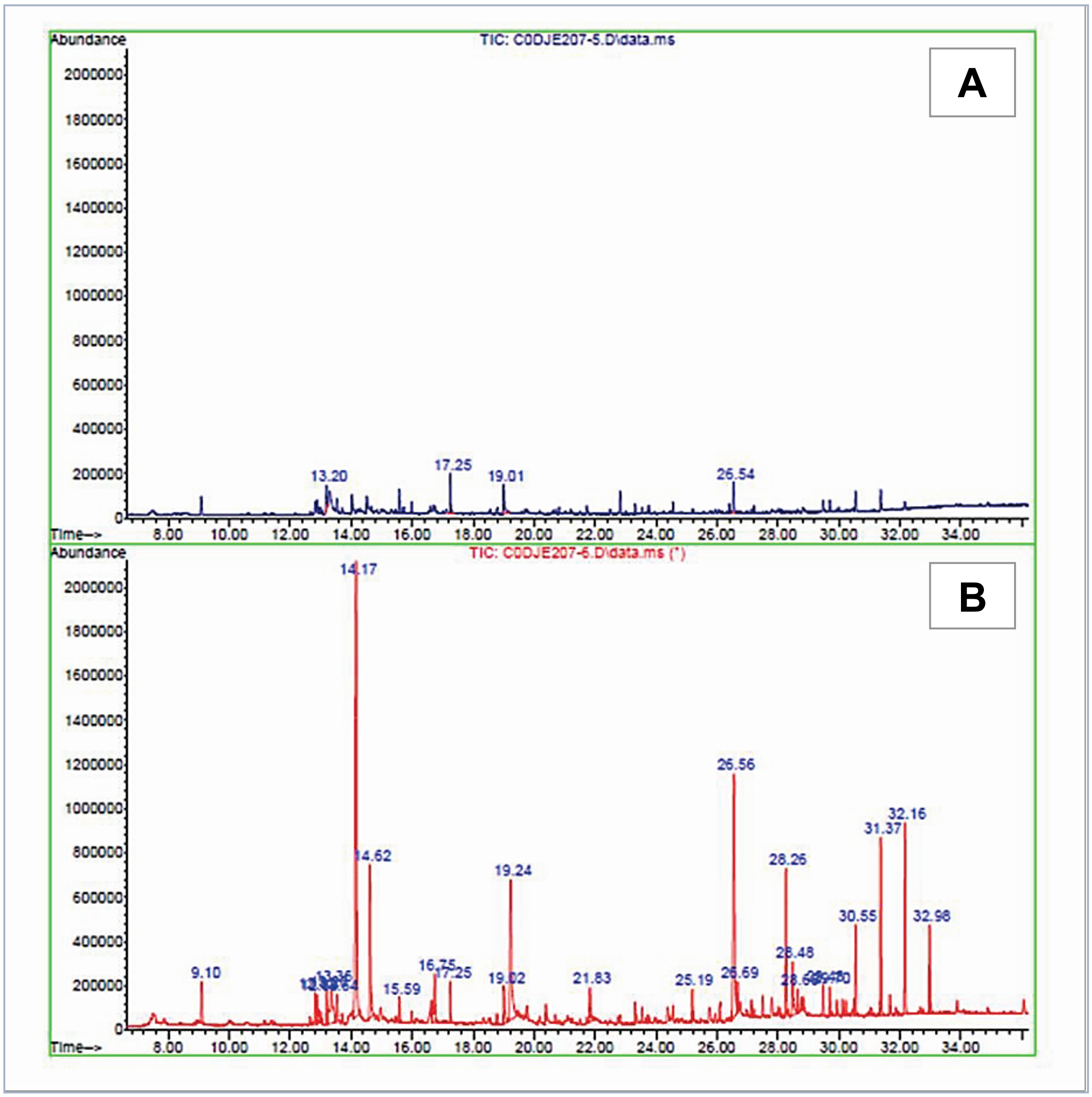

Figure 5: *Comparison plots of the chromatograms from two cured samples. The X-axis is retention time in minutes and the Y-axis is the ion number counts-(Abundance). The top of each peak is marked with peak's retention time for clarity. A) Vacuum process (YES-PB12 oven) B) Atmospheric process oven.*

Observations for the polyimide film cured under vacuum:

1. Process time for ramping the temperature to cure temperature is reduced - The reduced pressure enables the efficient evolving of NMP solvents, thereby eliminating the need for temperature dwell steps.
2. No wrinkles in the polyimide film – Imidization rates can be better controlled when the casting solvents are efficiently evolving from the film. As a result, the controlled temperature ramp rates can be adjusted to provide a larger process window for the proper curing of a polyimide film.
3. No popcorning - At this reduced pressure the NMP solvent is efficiently pulled off without any skin being formed on the polymer. There are no bubbles of solvents/ extraneous gases trapped in the polyimide film. A very low solvent load in the film should help with productivity due to reduced queue time needed for outgassing
4. A reduction in the amount of nitrogen needed to reduce oxygen levels - Three short vacuum/hot N2 purge cycles reduce the oxygen level quickly, because oxygen is removed faster in a vacuum.
5. Polyimide film is transparent - A steady flow of hot N_2 purge balanced against a vacuum gives a 200 Torr pressure level which continuously removes oxygen and keeps oxygen levels < 10 ppm.
6. For improved wafer cleanliness, the laminar flow of the pre-heated N_2 is preferred over the recirculating N_2 flow from a standard atmospheric bake oven.

Conclusion

Process control of the imidization rate of the polyimide precursors is an important factor in the proper curing of a polyimide film. This control is enhanced when casting solvents can be efficiently evolved from the film. A reduced pressure ambient enables the efficient evolving of solvents, without the use of temperature dwell steps. As a result, temperature ramp rates can be now optimized to provide a larger process window for the proper curing of a polyimide film.

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