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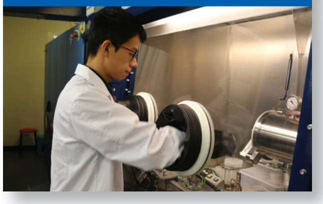
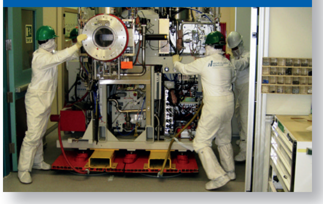
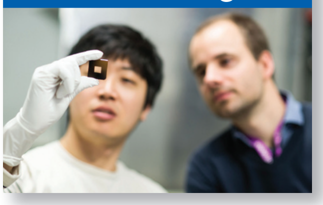
Mastering III-Vs and silicon



Managing relocations



EUVL high volume manufacturing



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AN ANGEL BUSINESS COMMUNICATIONS PUBLICATION

Answers for Today's

Packaging Needs

Creating smaller packaged IC devices with more input and output connections led to the creation of wafer-level packaging (WLP). Yield Engineering Systems details the benefits of vacuum cure processing for fan out wafer-level packaging.

CONSUMERS DEMAND for increased mobility and high functionality with ease of use is driving the need for 3D integration. Sophisticated packaging techniques are required to achieve platforms with reduced footprint and high performance.

This increased demand for 3D integrated devices requires more complex and sophisticated packaging techniques and processes. To save money and achieve higher yields requires equipment that combines quality, functionality, flexibility, and control for the process engineers. Yield Engineering Systems' (YES) PB Series automated and manual vacuum cure ovens are specifically designed to address the concerns of process engineers who are now faced with new challenges. One key challenge is the need to use new dielectric materials and create new processes to achieve the desired results.

The Use of Dielectric Materials – Wafer-level packaging (WLP)

Before the year 2000, polyimide and related materials were most often used as a stress buffer layer. Needing only the following, these layers were not critical and the cure process could be done in various methods.

- High temperature stability for multiple process and reflow
- Low outgassing
- Good adhesion to dies
- High elongation for die stresses

Today's material demands must support multilayer RDL and WLP packaging requirements. Some of these demands are:

Image 1: The YES VertaCure is equipped with pre-heated and filtered N_2 purge in horizontal laminar flow.

- High temperature stability for multiple processes and reflow
- Fast curing for multiple layers to keep up with throughput
- Low temperature curing for sensitive devices
- Chemical resistance to development solvents
- High elongation for die stresses
- Water-based development for less environmental impact
- Good adhesion to previous layer(s)

The objectives of a proper cure process are to:

- Complete the imidization process
- Optimize film adhesion performance
- Remove all residual solvents and extraneous gases
- Remove photosensitive components
- Create highly cured dielectrics for good adhesion
- Enable faster and lower temperature cures of PI and PBO
- Lower shrinkage - Lower stress
- Increase elongated toughness and resistance to crack propagation
- Decrease shrinkage, tension and brittleness

To convert the polyimide precursors to a stable film, proper temperature with extended bake (for polyimides) 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.

Desired process conditions for properly cured materials

Controlled temperature ramp rates (heating and cooling) need to be characterized for the desired material. The imidization rate of the precursors needs to be controlled to take into account differences in the thermal expansion coefficient between the 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 that is not uniform can occur due to uneven imidization. Mechanical stress variations can be observed as wrinkled film or as distorted metal lines in the structures under the film layer. The film can also delaminate because adhesion performance has not been optimized. Mechanical stress variations can affect yield and reliability. It is critical that controlled temperature ramp rates are used to provide a larger process window for proper curing.

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

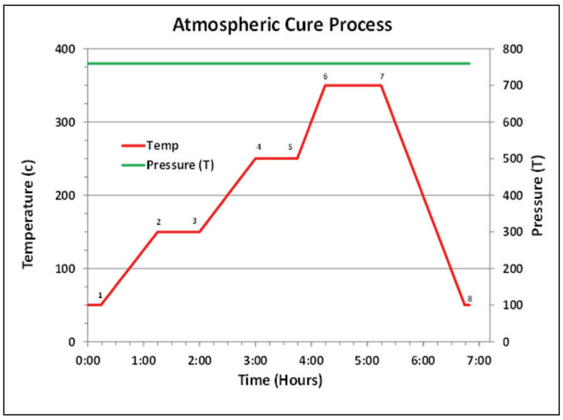

Figure 1: Atmospheric cure process graph. **Nodes 1-6** - Vapor diffusion across flow boundary layer limits solvent evaporation rates; low temp. dwell steps required for evaporation. As solvents evolve, imidization of polyimide precursors occur, affected by temp. ramp rates. Atmosphere is ~23% O; high-flow N_2 is required to reduce O. **Nodes 6-7** - Process held at temp. needed for complete imidization of polyimide film. High flow of N_2 may still be required. **Nodes 7-8** - Process temp. is ramped down; curing process complete.

Environment oxygen level needs to be <10 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 film. Film transparency is critical when multiple layers are used during subsequent processing. For multi-layer processes, alignment marks for a process sequence can be obscured by layers of low transparency polyimide films. In summary, pure nitrogen is required to reduce the level of oxygen in the process chamber.

Background O_2 level control is essential. Air cooling outside the door opening that enables the door and sealing O-ring temperatures to be maintained below 200°C while the oven operates is required for optimal performance. Process temperatures up to 550°C can occur, which makes meeting this requirement difficult. Superior O_2 leakage control through the door is maintained by employing double door gasket techniques. Low pressure nitrogen is flowed between

Image 2: YES-PB12-2P-CP manual vacuum cure oven

The Preferred Method!

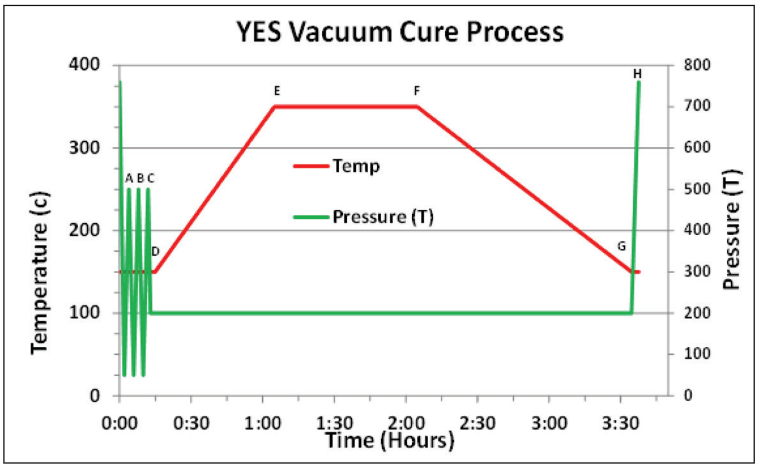

Figure 2: Yield Engineering Systems' vacuum cure process graph using a YES-PB12-2P-CP. **Points A-D** - 3 short vacuum/hot N_2 purge cycles reduce O level quickly. Boiling point of NMP casting solvents at 50 Torr is 135°C, so first vacuum pull of purge cycle sets polymer to improve thickness uniformity. **Points D-E** - A laminar flow of hot N_2 purge balanced against a vacuum gives a 200 Torr pressure level to continuously remove oxygen. At reduced pressure, NMP solvent is efficiently removed without skin forming; this enables a controlled ramp to imidization temp. **Points E-F** – Temp. held as required for full imidization of polyimide film. **Points F-H** – Temp. is ramped down; chamber is vented; curing process complete.

the two gaskets. If the inner seal should fail, the seal will 'leak' nitrogen inside the oven, not atmosphere, thus maintaining low oxygen levels.
Proprietary three cycle pre-process pump/purge O_2 level reduction aids the cure process. The chamber is pumped down to 50 Torr followed by a 600 Torr hot nitrogen purge back-fill producing a factor of 50/600 times background O_2 reduction during each cycle. This results in less than 10 ppm O_2 during ramp to process.

Management of cure oven conditions is essential. Maintaining critical O_2 levels, cure temperature, and pressure control for polymer cure ensures success. The polymer curing process is quite complicated and demanding in nature. Temperature uniformity is essential to avoid cracks in the polyimide layer and color variations. There are three major inhibitors affecting the curing of polyimide films: Oxygen, moisture and solvents.

- Oxygen inside the polymer can only be removed by inducing a pressure differential such as by an external vacuum.
- Water boils at 39°C at 50 Torr, a significant drop from the 100°C in atmosphere, making it easier to remove water at reduced pressure.
- NMP solvent boils at 205°C in atmosphere. Some polymers start imidization around 205°C, hence it is difficult to avoid the formation of a skin on the top of the polymer before all the solvent is removed in an atmospheric pressure bake. At a reduced pressure, in the 50 Torr range, NMP boils at 120°C. Therefore, all the solvents can be safely removed before imidization initializes. If the polymer surface is imidized before all the inhibitors are removed, it may result in wrinkles, cracks, discoloration and outgassing during any subsequent process steps. (See figure 1 + 2)

Observations of 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 film. Imidization rates can be better controlled when 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 removed without any skin being formed on the polymer. There are no bubbles of solvents; no 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. The amount of nitrogen needed to decrease oxygen levels is reduced. Three short vacuum/hot N_2 purge cycles reduce the oxygen level quickly because oxygen is removed faster in a vacuum.
5. Film is transparent. A steady laminar flow of hot N_2 purge balanced against a vacuum gives a 200 Torr pressure level that continuously removes oxygen, keeping levels <10 ppm.
6. For improved wafer cleanliness, the laminar flow of the pre-heated N_2 is preferred over recirculating the N_2 flow from a standard atmospheric bake oven.

Conclusion

Materials have expanded to meet the diversity of processes now common in semiconductor manufacturing.
These dielectric materials consist of:

- Polyimides
- PBO (Polybenzoxazoles)
- BCB (Benzocyclobutene – Cyclotene)
- Epoxy 'hybrids'

Uses depend upon the number of layers, low-k dielectric layers, and type of device as well as device properties, type of application, throughput, wafer size, technology node, environmental considerations and more.

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

As planarization continues, dielectric materials and process are critical. Material properties affect package reliability. New requirements continue to change. New chemistries, new processes…Ever changing for a better tomorrow.