Equipment That Answer's Today's Packaging Needs…

Integrated Fan-out Technology

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YES-VertaCure

Figure 1: 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. Automated.

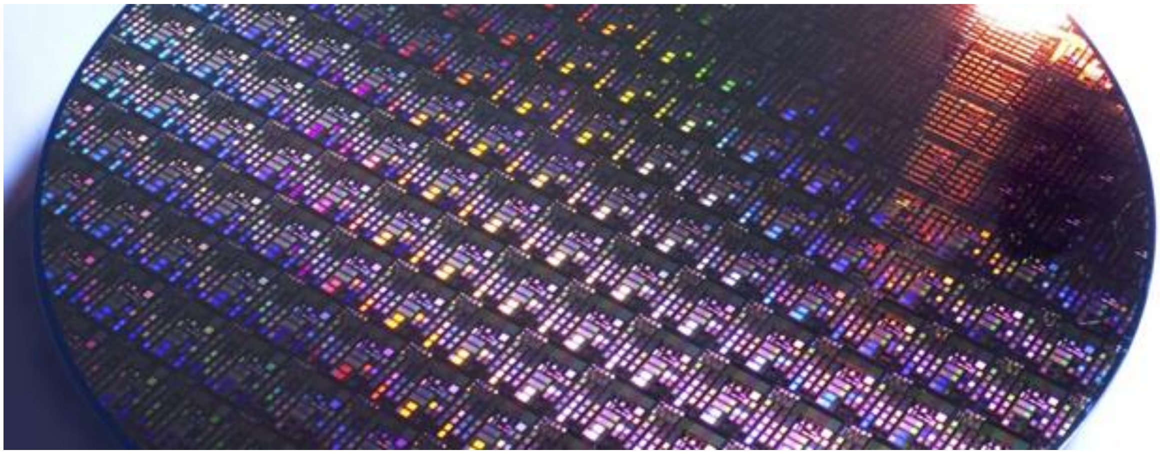
Consumer demand for increased mobility, high functionality with ease of use, is driving the need for 3D integration. Sophisticated packaging techniques are required to achieve platforms with reduced footprint and high performance.

This increased demand for 3D integrated devices, requires more complex and sophisticated packaging techniques and processes.

To save money and get higher yields requires equipment that combines quality, functionality, flexibility, and control for the process engineers.

Yield Engineering Systems, Inc. (YES) PB Series Vacuum Cure Ovens are specifically designed to address the concerns of process engineers who now are faced with new challenges.

One of these challenges is the need to use new dielectric materials and create new processes to get the desired results.



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

YES-PB12-2P-CP

Before the year 2000, the polyimide and related materials were most often used as a stress buffer layer. Needing only the following (below), these layers were not critical and 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

This paper describes the need for new materials/processes and compares cure processes.

Today's material demands must answer to multilayer for Redistribution Layers (RDL) and WLP. Some of these demands are:

- ➢ High temperature stability for multiple processes and reflow
- ➢ Fast curing for needed multiple layers to keep up with throughput
- ➢ Low temperature curing for sensitive devices
- ➢ Chemical resistance to develop solvents
- ➢ High elongation for die stresses
- ➢ Water-based development for the environment
- ➢ Good adhesion to previous layer

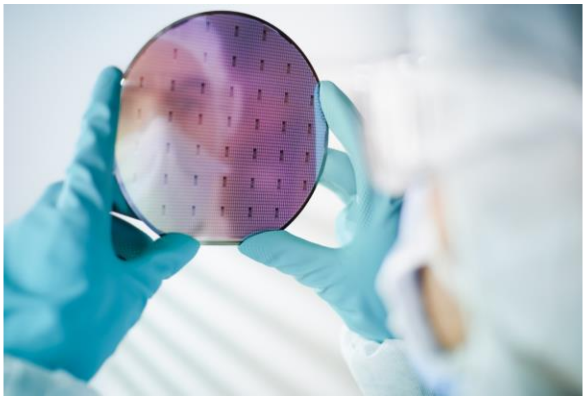
The objectives of a proper cure process are to:

- ✓ Complete the imidization process
- ✓ Optimize film adhesion performance
- ✓ Remove all residual solvents and extraneous gases
- ✓ Remove photosensitive components
- ✓ Highly cured dielectrics for good adhesion
- ✓ 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.

1. **Desired process conditions for properly cured materials:**

1A. Controlled temperature ramp rates (heating and cooling) that are characterized for the desired material -



The imidization rate of the precursors need to be controlled to take into account the differences in 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 non-uniformity can occur due to uneven imidization. The 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. The 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, 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” film will minimize the queue time needed to allow for outgassing when the next process step is a high vacuum process, such as metallization.

1B. 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 depositions 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.

1C. Environment Oxygen level < 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, 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.

2. Process Equipment Needs for a New Generation… YES-PB Vacuum Cure Ovens

2A. Background O_2 Level Control: YES high temperature vacuum ovens employ unique 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 at higher process temperatures of up to 550°C. Superior O_2 leakage through the door is controlled by employing double door gasket techniques. Low pressure nitrogen is flowed between the two gaskets. If the inner seal should fail, the seal will "leak" nitrogen inside the oven, not atmosphere, thus maintaining low oxygen levels.

2B. Proprietary three cycle pre-process pump/purged O_2 level reduction: In this procedure 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. Hot Nitrogen is channeled through stainless steel sponges that allow filtration and laminar flow to reduce particles.

2C. Vertical laminar flow of hot Nitrogen: Vertical laminar process gas flow provides improved temperature uniformity across the entire wafer load. The process Nitrogen is pre-heated to avoid any wafer cooling during its flow.

2D. Forced air cooling: Forced air cooling of the chamber significantly reduces post process chamber cooling time enabling a faster vent and unloading of the wafers, thus producing a significant improvement of the overall process throughput.

2E. Filtering and scrubbing of process exhaust gas: These tools are also equipped with elaborate filtering and scrubbing mechanisms of process exhaust gas to minimize any impact on the clean environment.

3. Applications

3A. Copper, low-K dielectric and other popular thin dielectric and metal films: For highly integrated semiconductor devices, copper and low-K dielectrics require a reduced thermal budget and low temperature annealing. An oxygen-free and pressure controlled curing environment is highly desirable for curing such films for corrosion prevention, relieving residual stress, improving interface stability in controlled curing and outgassing during curing. Almost all other metal and dielectric film curing processes can benefit from an oxygen-free and pressure controlled curing environment.

3B. Gettering, MEMS and WLP packaging: The packaged device performance and reliability rely on vacuum packaging for their long-term stability. In high volume manufacturing, wafer level packaging is often employed, where vacuum cure tools with their large batch process capability are finding increasing usage in all aspects of the process, starting from a simple bake-out of moisture and trace elements to getter anneal and activation processes.

3C. O_2 level, Cure Temperature, and Pressure Control for Polymer Cure: The success of 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.

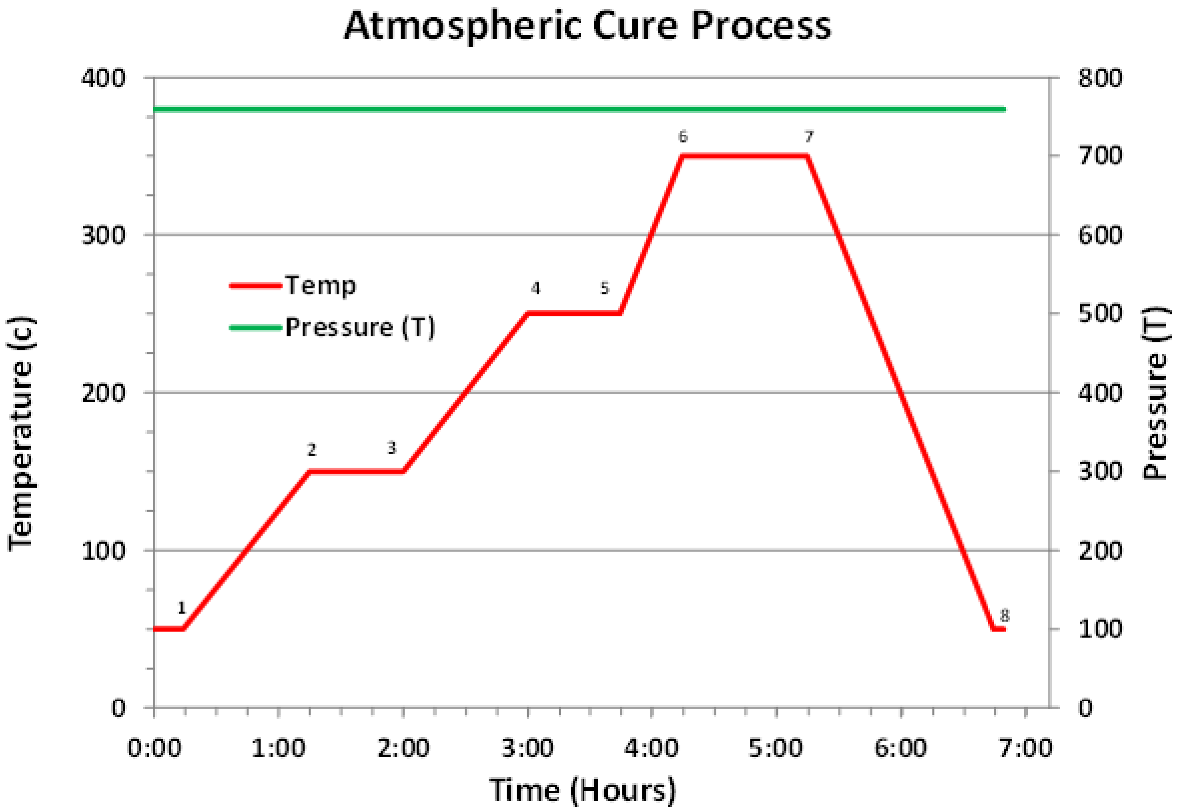


Figure 2: Atmospheric Cure Process graph. Tests were run in an atmospheric oven. Numbers 1- 8 are temperature nodes.

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.

The Preferred Method!

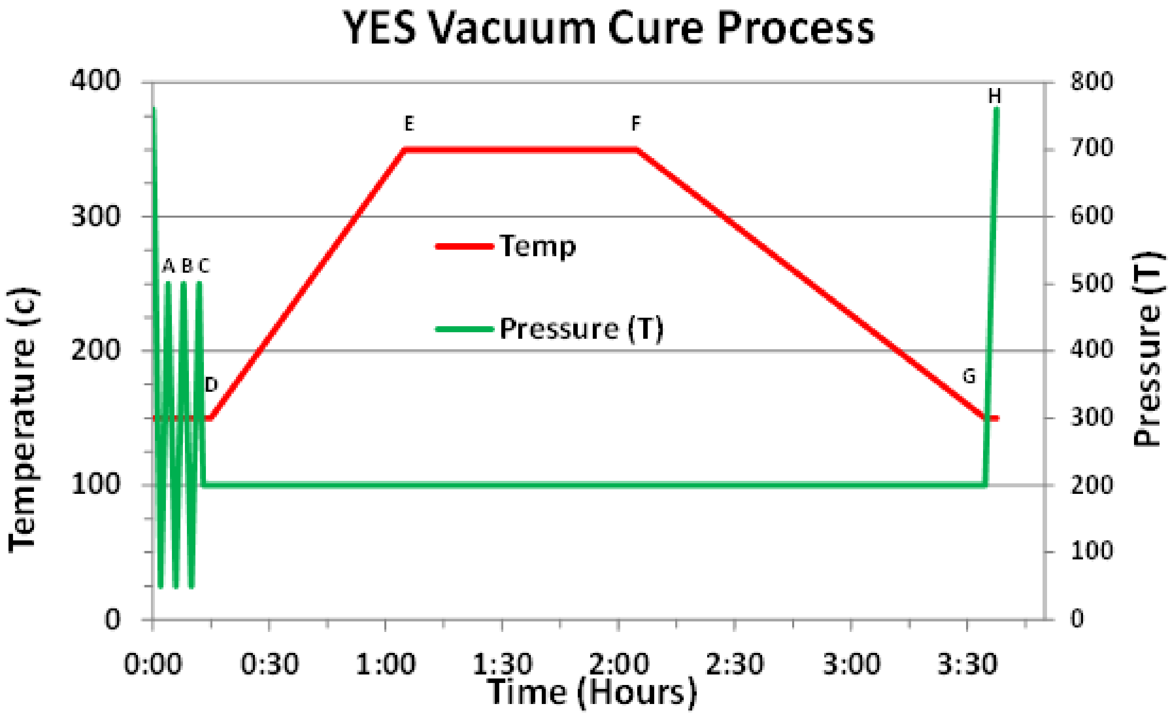


Figure 3: Yield Engineering Systems' Vacuum Cure Process graph. Tests were run on a YES-PB12-2P-CP. Points A,B,C are the high nodes for the vacuum/ N_2 purge cycles on the pressure graph. D,E,F,G, are on all the nodes on the temperature graph after that. The process is completed at node H when the chamber 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.

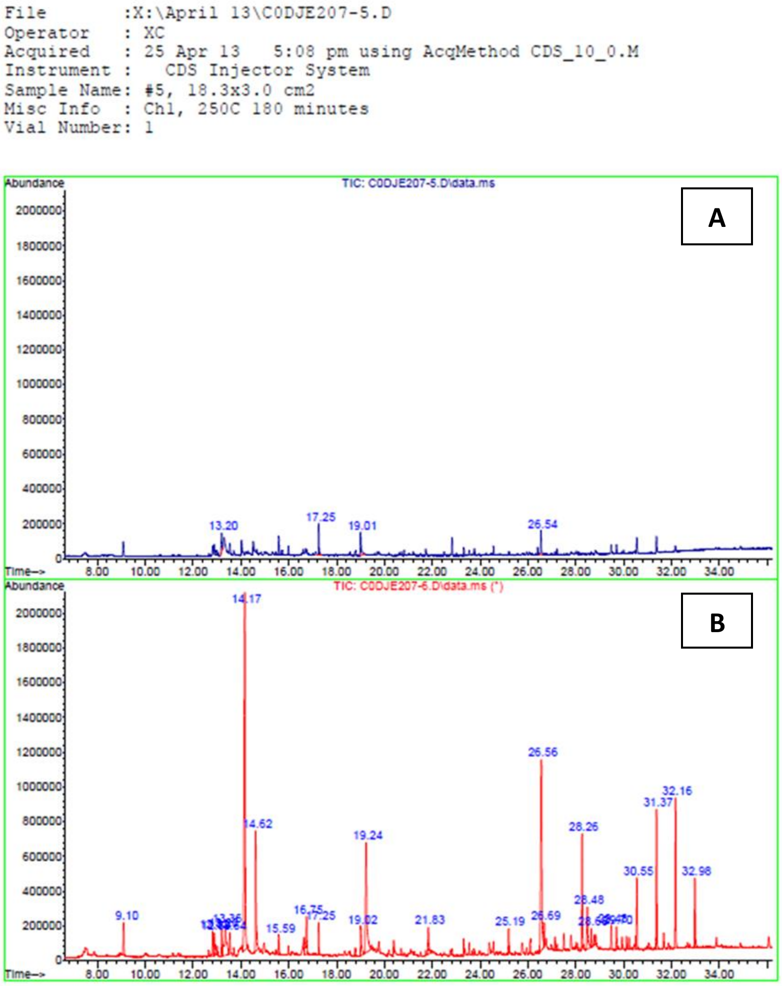
Point D to Point E - A laminar flow of hot N_2 purge balanced against a vacuum gives a 200 Torr pressure level which continuously removes oxygen. At this reduced pressure the NMP solvent is efficiently pulled off without any skin being formed on the polymer, thereby enabling a controlled temperature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

Evaluation of Process

To evaluate the polyimide film parameters, third party vacuum/atmospheric comparison tests were completed by Evans Analytical Group. The tests compare the YES-PB12-2P-CP 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.



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Operator   : XC
Acquired   : 25 Apr 13   5:08 pm using AcqMethod CDS_10_0.M
Instrument :   CDS Injector System
Sample Name: #5, 18.3x3.0 cm2
Misc Info  : Ch1, 250C 180 minutes
Vial Number: 1
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Figure 4: 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-PB12-2P-CP 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 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 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 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

Materials have expanded to meet the diversity of processes. These dielectric materials consist of:

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

Uses depend upon the number of layers, low-k dielectric layers, type of device, device properties, type of application, throughput, wafer size, technology node, environment 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. 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.

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

YES Equipment – Raising the bar higher.

Contact Us

If you have further questions, please contact us. Call +1 925-373-8353 (worldwide), 1-888-YES-3637 (US toll-free), or visit us online at www.yieldengineering.com

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