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Understanding UV Curing Options for Industry White Paper

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Contents

This review of established and emerging UV light curing methods is intended to help design and process engineers, specifically those in the electronics, aerospace, automotive, and medical device industries, that are constantly challenged to reduce costs and speed up production processes.

Introduction

This white paper sheds light on the past, present, and future of UV lamp technology, and the role it plays in the curing of silicone coatings for the electronics industry. This paper explores various considerations businesses must evaluate when incorporating UV lamp technology into their manufacturing processes.

From mercury vapor lamps to newer LEDs, UV light has long played a pivotal role in manufacturing and specifically, materials curing. With changing customer demands and new materials becoming available for production, selecting the most suitable technology for specific applications can be frustratingly complex.

As technology evolves and changes, manufacturers balancing time-cost-performance issues can be caught in challenging (and costly) positions. Time is rarely kind to the decision-making process, and because contracts need to be fulfilled and products need to be delivered now (or sooner), engineers don't have the luxury of waiting to see what will emerge as the best technology and technique. Advances come slowly in some specialties and more rapidly in others, complicating the timing of process updates and equipment-buying decisions.

Whether implementing a new curing system, or improving an existing process in use at a speed-sensitive electronic assembly facility, the challenge is the same: find a way for manufacturers to ensure consistent product quality while managing costs and constantly meeting delivery targets.

UV Light as Curing Agent: History and Background

In 1901, US Patent 682,692 was issued to engineer Peter Cooper Hewitt for a mercury vapor lamp. This emerging technology was applied in a number of fields and quickly yielded results. In 1903, Danish researcher Niels Finsen won the Nobel Prize for medicine for his work using a mercury vapor lamp to produce UV light as a method to combat tuberculosis.

While mercury vapor arc lamps were a breakthrough in UV light technology, they had several significant drawbacks. Because mercury's high heat output creates filament instability, establishing and maintaining the proper curing conditions in production was a time-consuming process requiring almost constant monitoring and recalibration.

Also, the initial investment, ongoing maintenance, and energy costs could be prohibitively high. Due to rapid degradation of the mercury vapor arc lamp (and resultant inconsistent output), industrial users were advised to select lamp systems and process settings that could provide three to four times the actual energy required.

Over the past decade, environmental concerns prompted bans in the EU and US, signaling the wind-down of the mercury vapor era. In spite of that, like many established technologies, mercury vapor arc lamps continue to find limited uses due to its germicidal properties.

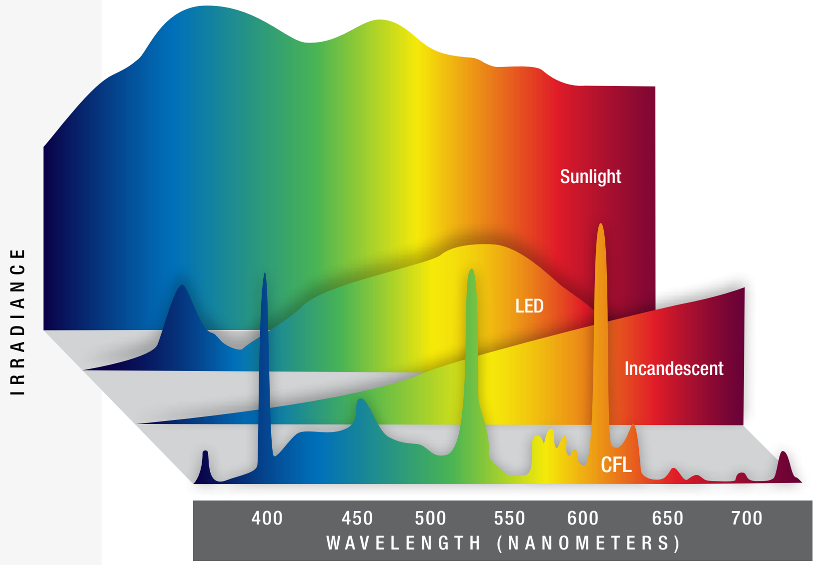
Another downside on the production line: mercury vapor arc heat output was detrimental to many of the components being treated - a growing problem, especially as thinner materials and plastic became common in assemblies.

And, as industrial production demands increased, bulb lifespan became a significant cost consideration.

To combat those shortcomings, electrodeless (microwave) mercury vapor lamps were developed. Using microwave energy to excite the mercury - irradiating rather than passing a current between electrodes - provided some much needed and welcomed advantages. Bulb life was vastly improved, lasting three to five times longer, and a near-instant on/off capability also appealed.

Perhaps most important to manufacturing, however, was that compared with standard vapor lamps, microwave lamps caused much less degradation to most materials being treated by reducing the risk of overheating.

What's Next?
Ongoing progress in emerging LED systems are having a tremendous impact on the industry. The benefits of LED are especially attractive in contrast to many of mercury's downfalls.



Light sources emit energy at different wavelengths, as shown above. Although the human eye cannot discern these individual wavelengths, the photoinitiators that operate in UV cured materials are highly specific in the wavelength(s) that activate them. Make sure your UV light source has the output wavelength required by your photoinitiator.

Most obviously, LED is a more efficient light source. Because LED emits at a far narrower frequency range than traditional broad-spectrum UV lamps, LED has much lower energy requirements. In addition to the corresponding cost efficiency, there is less risk of damage to certain plastics.

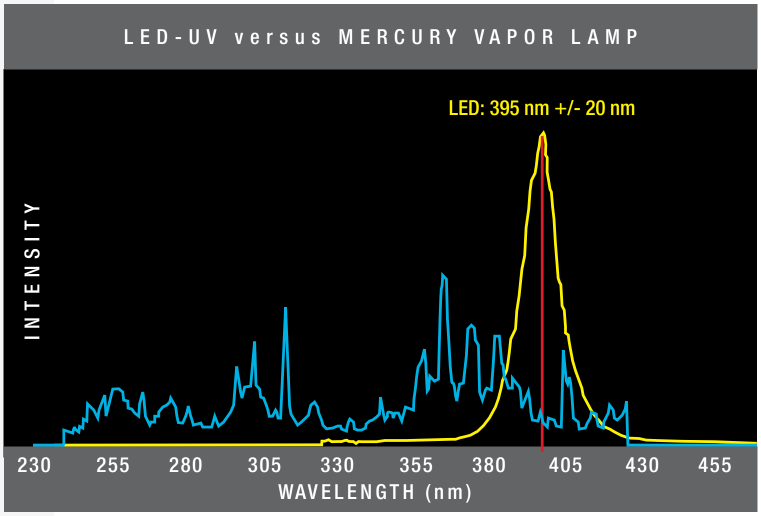
UV curing has applications outside manufacturing. For example, your dentist shines a blue (UV) light in your mouth to rapidly set your filling or crown. Nail salons use UV light to quickly harden gel-manicured fingernails. The science isn't quite the same, but helps to illustrate the benefits of UV curing.

LED is relatively more stable, which can result in both time and money saving benefits. As for maintenance, LEDs require less-frequent recalibration and they boast no degradation. The added benefit of saving time with its instant-on, instant-off functionality (no warm-up or cool-down period) is similarly appealing.

UV/LED offers relative stability, cooler cures, and consistent wavelengths. LED certainly has a bright future, but it is still an emerging technology. Most industry experts agree that improvements are needed before it reaches peak usefulness for manufacturers who rely on UV curable coatings, including silicone coatings. Watch for rapid development and exciting breakthroughs over the coming decade.

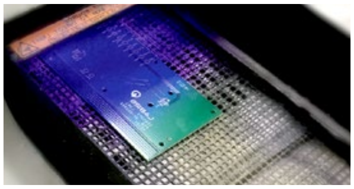
We're Not on the Same Wavelength (*Yet*)

One of the more problematic issues with LED is managing the narrow wavelength. Because the UV wavelength output is narrow, the challenge is to precisely match the wavelength of the UV lamp with the trigger wavelength of the photoinitiator for the material to be cured.



By operating at very specific wavelengths, LED lamps have the potential to be much more efficient than their broad-spectrum mercury counterparts. These narrow wavelengths mean that LED lights are far more selective in the photoinitiators they trigger.

Silicone photoinitiators, with wavelengths in the 245-365 nm range, are used to cure silicone. Only recently have LED curing lamps with outputs in the 365 nm wavelength range become available. At this time, there are no commercially available lamps with wavelengths below 365 nm, forcing manufacturers to use existing mercury technology to cure UV silicones. That will change as UV cure equipment manufacturers continue to develop and refine the next generation of UV curing technology.



Photoinitiators are available that can cure acrylic coatings using today's LED technology.

For many UV cure silicone systems, multiple UV wavelengths are required in order to achieve full cure at the surface and through the depth of the coating or potting section. A UV wavelength in the 365 nm range penetrates the coating for a deep material cure. For surface cure, a UV wavelength in the 245-260 nm is required. Without these two wavelength ranges present, the resulting cure has the potential to be incomplete.

Research and development is ongoing to develop and produce either LEDs that emit in the 250 nm wavelength range or photoinitiator packages that trigger both surface and depth of cure at a single wavelength.

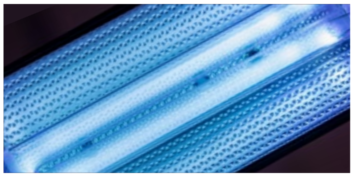
Now and in the near term, however, manufacturers seeking to utilize UV curable silicone systems should use the established broad-spectrum mercury vapor technologies – either traditional arc lamps or the newer electrodeless microwave lamps – as they provide consistent and superior results.

Why UV Cure is Standard Today

In most manufacturing situations, the greatest ongoing challenge is in maximizing the benefits of an emerging technology while exploiting existing products and technologies that have known success. It's the classic risk/reward question, or in accounting terms, the constant striving to achieve an acceptable ROI. Organizations that are tasked to drive down cost should not only examine their raw material costs, but expand their thinking to include a predictable Total Cost of Ownership (TCO).

From a TCO perspective, the UV curing process has proven superior to oven-curing methods. Even where large curing or conveyor processes are necessary, UV provides a faster, more reliable cure while using less energy, reducing maintenance costs, and having a footprint measured in inches, not yards.

For this reason, UV cure systems hold great promise for manufacturers of both simple and densely-packed electronic devices.



Irradiance (Light source intensity) = amount of energy at a given wavelength (milliwatts per cm-squared mW/cm^2)

Dose = amount of total energy applied to a surface over a certain time (irradiance level x time exposed)

What You Need to Know About UV Light

Broad-spectrum UV technology (arc or electrodeless) is known for producing a very efficient, high-energy output (i.e., energy per photon) with a relatively low initial investment and moderate maintenance costs. When paired with UV-activated silicone coatings, it produces what's commonly accepted as a neutral, non-toxic cure.

One of UV's greatest advantages is that it is a well-established technology. That maturity translates into predictability, reliability, and existing safety standards. Standards that are well-documented and well-understood on both the development and production side of the business. Due to its longevity in industrial manufacturing, many workers have experience in UV handling and curing applications, making it easier to hire a skilled workforce.

As the technology continues to innovate, there are many additional options in available equipment, including handheld or spot lamps, cabinets, conveyors, and a vast selection of mounting and stabilizing equipment in a broad range of sizes. UV lamps and reflectors are not only widely available, but also easy to replace.

In over three decades of common use, UV has proven to be a durable and reliable technology. Coupled with the superior performance and advantages of silicone, it's a game changer.

Understanding How Process and Material Variables Affect Curing

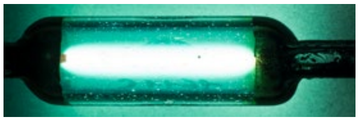
Many factors contribute to determining the most effective UV curing lamp and system. While many of those factors are qualities of the lamp and light source (emission spectrum, beam area, and power), others are situation-specific and include:

- materials
- product design
- process
- properties of adjacent/related components in the final assembly
- certification and specification requirements

Mature UV Technology is Still Improving with Dual Cure Mechanisms

The electrodeless mercury vapor UV lamp, with its broad spectrum and cure range of 222 - 450 nm, is essentially today's standard. Although it is considered a mature technology, our understanding of it continues to evolve as our knowledge of industrial UV applications expands.

"UV curing is not an art but a precise science. Every manufacturing process has a unique set of limiting and environmental factors, and every cure has different requirements." Michael Kister, Vice President of Product Management, Novagard.



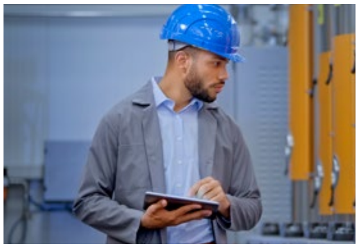
Even as a mature technology, UV curing is still improving, as materials scientists, manufacturers, and design and process engineers continually refine methods to maximize their results.

Material manufacturers recently added a second cure mechanism to the UV curing process, combining the rapid cure of UV (light) with a secondary moisture (air) cure mechanism. The UV cure portion of the resulting UV/dual cure allows manufacturers to move materials without "rack and stack" waiting periods, eliminating work in process (WIP) working capital – a time and cost improvement. The secondary alkoxy moisture cure mechanism ensures "shadow" areas – areas on the assembly that may not be adequately exposed to the UV light – can fully cure. Depth of cure and adhesion also improves with the secondary alkoxy moisture cure system.

Furthermore, these vetted UV dual cure silicones eliminate the need for oven curing, thus proving anew that it is a cost-effective and highly efficient process. Large, high-cost ovens are no longer needed, reducing the manufacturing footprint and lowering utility costs while improving your sustainability position through decreased energy consumption and zero solvent emissions.

Safety and Other Considerations

To maximize the life of your equipment, it is always wise to follow the manufacturer's guidelines on maintenance and general safety procedures.



Commit to regular inspections to monitor lamp output, and change bulbs as soon as they approach the established required energy of your process.

Basic Maintenance Considerations

- Maintenance is always dependent on process/line variables, however, as a baseline for planning purposes, UV bulbs should be changed regularly based on the manufacturer's use-hour recommendation.
- Lamps need to be monitored to ensure they are running at proper operating temperatures, and fan speeds should be adjusted as necessary for seasonal and production changes.
- Note that contamination can affect any lamp performance. Spray, powder, or dust particles in the air can bake onto the surface of lamps, decreasing their output. Train your staff to avoid leaving fingerprints on lamps and reflectors. Little adjustments can make a noticeable difference.

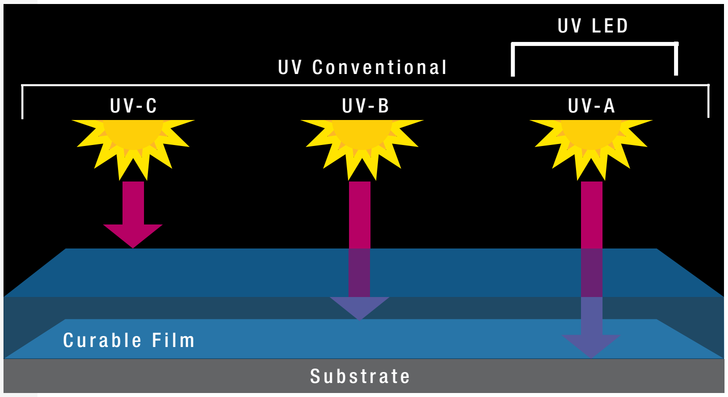
Basic UV Safety Precautions

- For ideal protection, UV lamps should be used in an enclosed cabinet.
- When using UV in an open area, screens and shields can partially enclose the treatment area to provide a protective barrier.
- Eyewear should be ANSI 787.1, typically indicated with a mark U followed by a number between 2 – 6. Proper PPE may include a lab coat, a face mask and/or neck gaiter, and gloves (with nitrile, latex, or tight woven fabric being recommended instead of vinyl).

As with any equipment, consult the manufacturer's recommendations for all operational safety guidelines.

The Wave of the Future

LED's best-known advantage is that it's a highly efficient light source which offers significant energy-savings potential. It is also compact, which appeals to manufacturers concerned about equipment footprints.



How different UV light penetrates materials depends on the wavelength generated. By carefully matching the photoinitiator and light source, it is possible to simultaneously achieve both surface and deep section curing.

It's well understood that LED emits light in specific, relatively narrow wavelengths. Currently, these narrow wavelengths do not correspond to the commercially available photoinitiators in the sealants and coating industries (specifically when it comes to silicone-based coatings). This has prevented the broad adoption of UV technology for the sealant industry. We are in regular communication with the manufacturers of both the light sources and the photoinitiators to close this gap in the market.

LED for UV curing has untold potential for future applications, but the technology is still evolving. Because stable, consistent, repeatable performance is not yet on the horizon, UV LED has not quite reached the tipping point from a technology availability standpoint for industries that rely on silicone coatings. It's an emerging technology worth watching, but few manufacturers are ready to bet their current production lines on LED's future.

Although emerging LED technologies may require less energy than mercury-based technologies, any UV curing process is very efficient.

What Light Cure System Is Recommended Today?

As process engineers and operations managers evaluate turn time, production footprints, and quality issues, investing in UV/dual cure technologies makes sense from a TCO standpoint.

If delivering consistent product quality is the most important manufacturing requirement, cost containment is certainly among the top considerations for operations management. In most organizations, this leaves decision-makers in agreement, with both preferring to avoid the cutting edge - unless experimentation is encouraged and underwritten by a friendly benefactor.

When considering the overall cost of ownership, an operational review should include capital costs, ongoing energy, and maintenance expenses - specifically, bulb lifespan. Data about solutions and their suitability for particular applications and production methods – for current work as well as future contracts - should also be considered.

Selecting the right light source for a specific curing application requires very specialized knowledge of materials and processes. Energy use is an important consideration, but it is rarely the deciding factor.

Depending on many variables, either a LED or a mercury vapor UV cure process may be appropriate. Ultimately, the determination will be based on the efficiency of the entire process, so arriving at a good decision requires the involvement of multiple departments and consultation with your UV cure material supplier.

Ultimately, production must meet the customer's curing requirements.

Once you've identified the best solution for your needs, hesitating to implement it on your production line could have untold costs in terms of lost business opportunities.

While UV-LED holds promise for the (near) future, there is good reason to continue to invest in UV-mercury vapor technology. As well understood as the technology is, manufacturers and innovators continue to find productivity improvements through new combinations of materials and methods that utilize UV.

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Disclosures

This paper is intended to explore the current state of the art in UV curing lamp technology and where the industry is evolving to provide low energy, high-speed manufacturing options for UV cured silicones.

Novagard does not sell UV equipment or other light-curing systems. Company representatives work with UV and LED partners to advance systems and materials that are recognized as necessary in the industries Novagard serves, including electronics, EV, aerospace, automotive/transportation, building systems, electrical, industrial, and military applications.

Thanks to Doug McKinzie, a broad-based executive with experience in research and development, plant management, quality control, and process who contributed to this paper. In 2020, Doug retired from Novagard as Vice President of Transportation and Industrial Products.

For more information or to discuss UV/moisture cures, processes, or requirements, contact:

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