Semiconductor Light Matrix (SLM) –
A new UV technology for curing adhesives

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Introduction:

Photopolymer material chemistries were introduced in the 1960's as an alternative for solvent-based material chemistries, and their advantages were so readily apparent that they were quickly adopted for many industrial applications.[1] Photopolymer chemistry offers an attractive replacement for solvent-based adhesives by eliminating the volatile organic compounds (VOCs), fumes, and the complexity and risk associated with mixing materials to initiate hardening. The adhesives industry has pioneered many new fast-growing applications, enabled by UV-curable adhesives, including dental composites, electronic "glob top" coatings, medical and optical adhesives, DVD bonding adhesives, and many others.[2]

For the last forty years, mercury-based arc lamps were the primary UV light source available for activating photopolymer materials. Over the years, new bulb-based light sources such as Excimer bulbs, microwave mercury lamps, etc. have been developed, but essentially this industry remains dependent on a lighting technology that predates the Edison light bulb. While they have been amazingly useful, bulb-based light sources have a variety of disadvantages:

- **Environmental, Health & Safety Concerns** – The plasma in medium pressure mercury lamps generates considerable heat, and the bulbs are vulnerable to breakage which can expose the environment to toxic materials. Disposal of mercury-based lamps is a significant and growing problem. Mercury lamps emit short wavelength UV which can cause skin and eye damage if not operated properly. They also generate toxic ozone which must be exhausted.
- **Expensive to operate** – These lamps consume electricity inefficiently; converting less than 20% of the energy into useful UV light., Their output dergrades noticeably and they need to be replaced frequently causing equipment downtime. Cleaning/maintenance of bulb-based systems requires filters, and controlling the light may require use of mechanical devices such as shutters.
- **Cause process variability** – Use of lamps can cause heat damage to parts, while degradation of light over life and bulb-to-bulb variability can produce inconsistent process results.

Over the years, semiconductor devices have replaced most other bulb- and tube-based technologies. For instance, vacuum tubes have long ago been replaced with transistors, and LEDs are rapidly displacing light bulbs in indicators, traffic signals, and vehicle tail lamps. Semiconductor lasers have replaced arc lamp sources in many production processes, but have had little impact in industrial UV curing applications. Recent developments with semiconductor light sources are providing a new alternative with significant advantages in operating costs, processing speed, quality of illumination, reliability, safety, and enabling new applications to be possible for the first time.

Introducing Semiconductor Light Matrix (SLM) Technology
SLM technology is implemented with an array of thousands of light emitting semiconductors (Figure 1) that are configured into a system which performs the following:

1. The light is efficiently collected and directed at the target using tiny lenses.
2. The heat generated by the array is managed with conductive packaging technology.
3. Electronic control allows on/off, pulsing, and light intensity control, and is insensitive to failures of individual semiconductor devices.
4. The uniformity, intensity, and size of SLM arrays meet or exceed production requirements at acceptable cost.

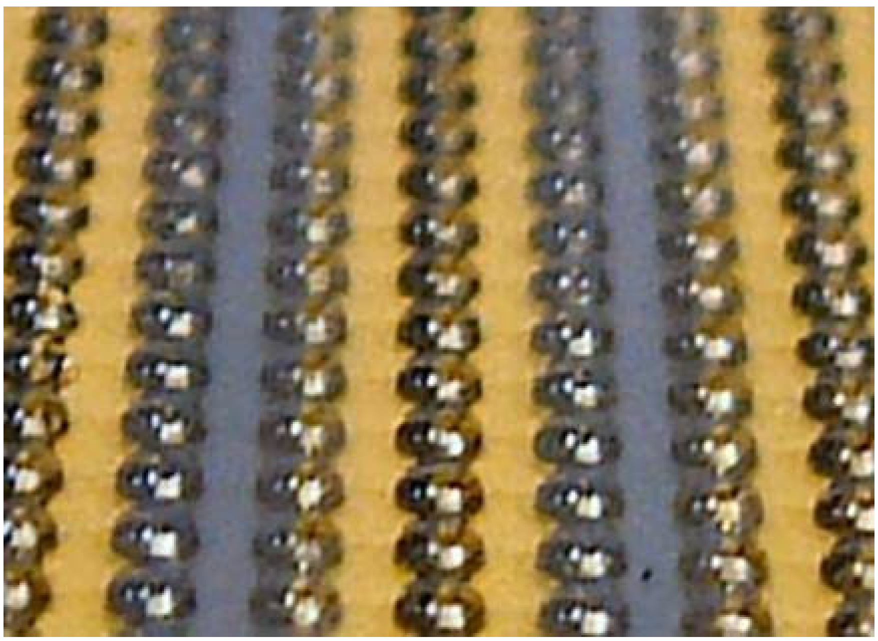
Figure 1. SLM array

Benefits of SLM UV Light Sources

As the data in figure 2 indicates, there are clear cost and performance benefits to be had by using SLM light sources compared to other technologies. These include:

1. Low cost of ownership and operation
Semiconductor UV light sources use far less power and require less cooling water than bulb-based curing systems to provide an equivalent amount of light energy. Since there are no bulbs to burn out, the cost of consumables is less and the labor cost required to maintain the equipment is less.

Arc lamps have well-known failure modes and a characteristic power drop with time. Failure can result from several causes, including contamination of the quartz envelope encasing the ionized gas, and degradation of the electrodes of arc lamps. Unless the bulb breaks, the output of arc lamps will gradually decrease in radiant output and the relative intensity of each wavelength will change during this degradation. This can effectively limit their use in many applications to less than 1000 hours (see figure 2), which results in not only significant cost in replacement of bulbs, but also significant cost in lost productivity due to the time required to cool the bulbs before they can be physically removed and replaced at the end of their lifetimes. There is also a hidden design cost since engineers specify their systems with a certain amount of "padding" (i.e., they specify a bulb that is brighter than it needs to be) to ensure that the rated output of the bulb will remain above the required specification for its expected lifetime.

In contrast, SLM Light sources show virtually no degradation over as long as 15,000 hours of operation as shown in figure 2.

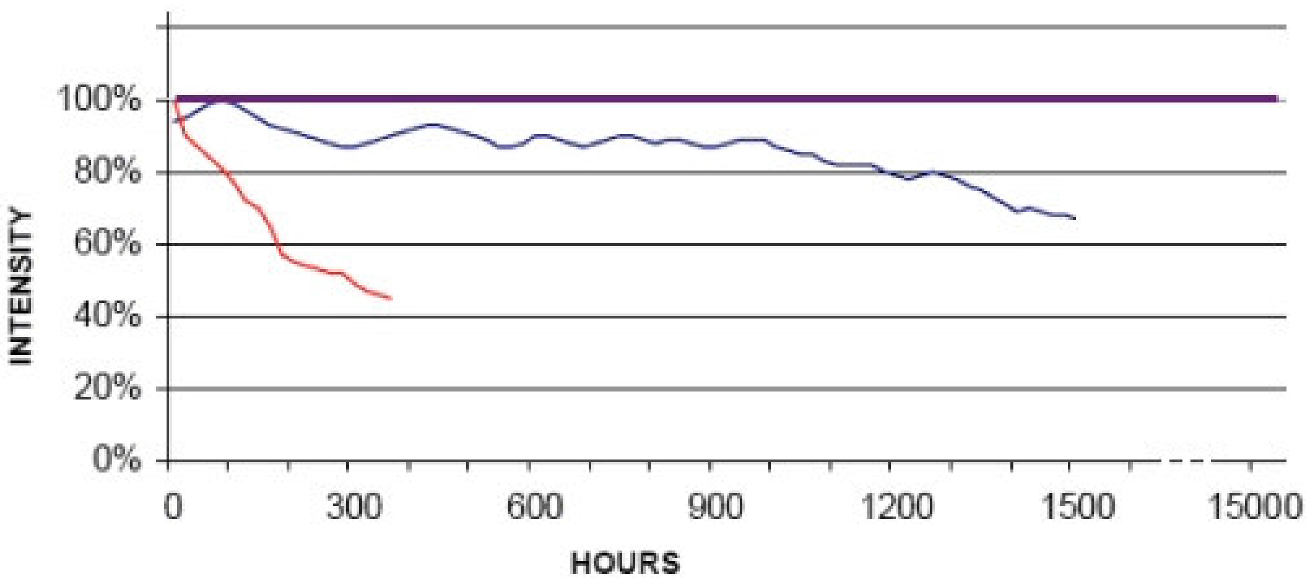

Figure 2. Lifetime data for two commercially available arc lamps (red and blue curves) and SLM Light Source (purple). While no appreciable degradation was observed during this test, > 10,000 hrs of full-intensity life is typically specified for the SLM source.

SLM light sources' ability to be turned on/off during the curing cycle saves money by reducing electrical use. This capability also enables the use of programmed light profile "recipes" not previously possible, and reduces cooling requirements.

SLM sources also eliminate the need for shutters, Faraday cages, heat filters, and spinning or cooling stations in the integrated solution. In most cases the cost of ownership is 60-80% lower with SLM sources when compared to traditional light sources.

Description	Arc Lamp	Flash Lamp	Microwave	SLM UV Light
Performance:				
Cost of Ownership	High	High	High	**Low**
Light Source Life Time	200-2,000hrs	200-2,000hrs	3,000-6,000 hrs	**>10,000 hrs**
Consistency of output over time	Continual drop over time	Continual drop over time	Minimal drop for 3-6,000 hrs.	**No drop for >10,000 hrs.**
Output Uniformity source to source	Good	Poor	Good	**Excellent**
Light source Uniformity at work surface	<20%			**<5%**
Spectral distribution	Wide spectral bandwidth where only 5% of light generated useful for curing			**Narrow band (40 nm typical)**
Irradiance	> 1 Watt/cm^2			**> 1 Watt/cm^2**
Ease of Integration:				
Size-	Bulb with bulk optics and power supplies	Bulb with bulk optics and large power supplies	Bulb with bulk optics. large and expensive magnetrons	**Thin, flat panel**
Electrical	High power, complex supplies			**Low Power, PC control**
Safety	High voltage Possible ozone, bulb breakage			**Low-voltage No ozone, no bulb to break**
Efficiency:				
Electrical-to-optical efficiency (for light used in curing process)	5% of light output is used for curing	5% of light output is used for curing	5% of light output is used for curing	**>10%**
Thermal efficiency	5%	5%	5%[3]	**> 5X arc lamp, depending on application**

Production issues:				
Warm-up time	30min	High-speed on/off	Slow on/off	**Instant On/Off**
Consumables	Bulbs	Bulbs	Microwave components	**None**
Preventive Maintenance	Replace bulbs Clean Reflectors	Replace bulbs Clean Reflectors	Repair/maintain magnetron and other microwave components	**None**

Figure 3. Summary table comparing various UV Light Sources [4].

2. Uniform Coverage over Wide Areas

SLM light sources have an impressive range of control that is unavailable from any other light source, making them uniquely beneficial for UV curing applications that require uniform illumination. Figure 4 shows the power density of the Phoseon RX20 UV light source over an area measuring 200mm square (8 inches by 8 inches). The power density of the center 95% of the illumination pattern has an RMS value of less than 4%.

The output intensity can be set at any value between the minimum and maximum by simply adjusting the current that is supplied to the array. The intensity varies almost linearly from zero to maximum output with no variation in the uniformity of light distribution.

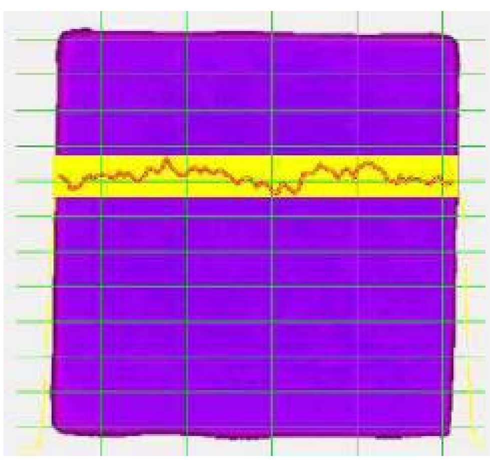

Figure 4. Illumination pattern (8 inch by 8 inch) produced SLM light source, with superimposed intensity graph showing uniformity variation less than 4% at curing intensities.

3. No Wasted Energy

Light from a typical mercury arc lamp is distributed over the spectrum, from deep UV to the infrared (see yellow plot in Figure 5). Some of the long IR is due to the fact that the surface temperature of an ultraviolet lamp under normal operating conditions is between 600° C and 800° C, which means these lamps waste energy and can cause significant heating of the work piece, which may result in deterioration and damage.

By contrast, the spectral distribution from the SLM is concentrated in an intense narrow spectral range (purple area in Figure 5). Since the photons generated by SLMs have a narrow spectral distribution (typically 40nm), all the light produced is useful for initiating the desired chemical reactions.

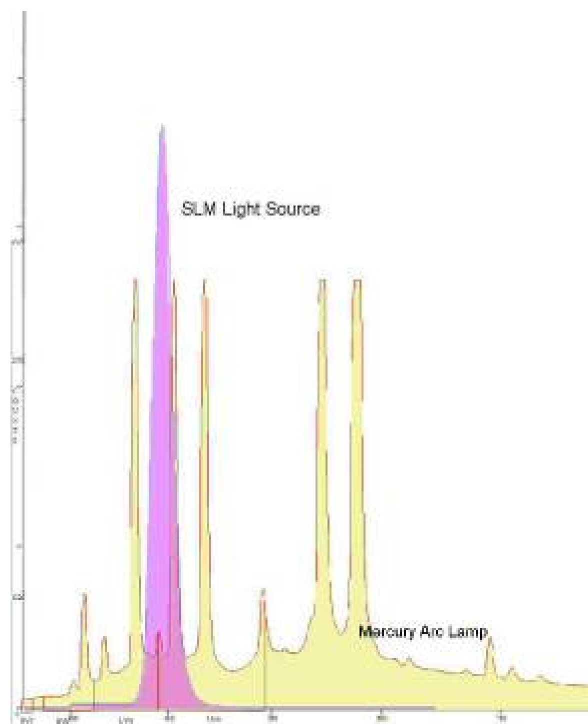

Figure 5. Spectral output of a medium-pressure mercury arc lamp and SLM, showing the SLM to be both more intense and have a more narrow band of emission.

While some photopolymer systems available today use photoinitiators that are not designed for SLM light sources, it is easy to develop a new photopolymer system for such a uniform, high intensity source. Internal studies have confirmed that there are significant advantages to increasing the intensity at the same dose for any given material, and that longer UV wavelengths allow deeper penetration and inside-out curing. There are other curing advantages when using SLM technology that are beyond the scope of this article.

UV-curing is typically done in the presence of air, and oxygen inhibition has been a persistent problem.[5,6,7]. Several techniques are used to overcome this problem, with pulses of high-intensity light and inert gas envelopes being two of the most common[8]. The ability of SLMs to pulse the light source allows the user to program "recipes" that might, for example, involve a high intensity pulse for deep cure and overcome oxygen inhibition, followed by a lower-intensity continuous dose of a lower amplitude to cure without generating heat, and then turning off between cure cycles. Sensitive components such as medical or optical media can be cured without significantly heating the parts above ambient temperatures (see Figure 6).

Figure 6. Heat sensitive media are an ideal fit with SLM light sources, which only heat the media slightly above ambient temperatures during the cure cycle.

5. Easy to Integrate

SLM systems are also significantly easier to integrate than lamp-based illumination systems because they are smaller, lighter, and allow complete computer or PLC control. Additionally, the light sources are modular, so several can be grouped to match a desired curing area.

Figure 7. SLM UV light source mounted in series to create a 500mm bar

6. Safer and more environmentally friendly
Modern, high-power arc lamps typically use mercury, generate ozone, generate significant heat and light, and users are typically required to protect themselves from the toxic materials and known carcinogens and wear safety equipment to protect from burns and eye damage.

SLMs present no inherent health risks for personnel using them, beyond the obvious (and necessary) requirement that proper eye protection be used to guard against their bright light. SLMs use no mercury, produce no damaging or carcinogenic wavelengths, do not produce ozone and do not generate or contain any toxic waste products.[9]

7. A Cleaner Process
The extreme temperatures on the mercury lamps quartz surface require continuous cooling. This is ordinarily accomplished by pulling or pushing air across the bulb using blowers. The cooling air is disruptive to the process environment, frequently causing contamination by stirring up airborne contaminants. SLMs require cooling at the mounting surface, but not at the sources face. No air movement between the source and substrate means no danger of contamination.

The lack of moving air, combined with the low heat output of SLMs, allow the source to be placed extremely close to curing surface if desired. This arrangement would be impossible with traditional lamps.

UV Curing Results on Adhesives and Coatings

SLM-based curing has been applied to over 120 different coating materials (including the adhesives and coatings listed in Figure 8) and customers have verified that SLM sources cure better, faster or as good as other UV light sources. For more information on the curing performance of a particular adhesive, sealant or protective coating, please contact the author.

Alberdingk Lux 440 wood coating
Araldite adhesive XD-4762, XD-4763
Daicure Clear Adhesive SD-6103, SD-6200, SD-645, SD-698
Daido adhesive P-5790
DELO-KATIOBOND_4594_(TIDB-D)
DELO-PHOTOBOND_4302_(TIDB-D)
DELO-PHOTOBOND_GB368_(TIDB-D)
DYMAX Light-Cap TM adhesives 9616
Eques adhesive 1322 995 89573
Eques Coatings 13778x
Jema J97-81-18-90X & J97-81-18M
KIWO BOND UV 3002
LMD adhesive 2563/XD804
LOCTITE® 5091TM Acetoxy silicone
Cashew Coatings cell phone clear-coat
Loctite 3335 Cationic Epoxy
Loctite 3341
MacDermid MACuMage 9408 UV Etch Resist
Millennium EN-239-2 & EN-239-2T2
Nagase XNR 5517
Ormocer USS4
PJK-002 UV
Sony Adhesives 3200, SK6500, SK6542
Tank Spot Repair Coating 459Y1
Toyo Gosei PAK-1
UPES resin from AOC (XR 1535)
UV240-7M
Vitex 501
White UPES gel coat
World rock XVL-90K

Figure 8. Sample list of adhesives and coatings that have been cured with SLM arrays.

Conclusions

Mercury based arc and microwave lamps are the traditional and well-established source for UV and will continue to be required for certain material formulations and applications. However, Semiconductor Light Matrix sources are already in full production that match or exceed the curing performance, enable new applications, and exceed the characteristics of arc lamps in a variety of production applications including electronic, optical, and medical device assembly, protective coatings, and heat sensitive applications such as optical media.

References

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