Novel, Compact Radio Frequency Excited Ultraviolet Curing Lamp System

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INTRODUCTION

The use of ultraviolet light as a “photon-catalyst” for UV curing is ubiquitous in today’s marketplace. The use of UV in industrial processing is well-known and well-established in today’s manufacturing industries. Fusion UV Systems Inc. is the world leader in microwave excited, electrodeless UV sources in power densities from 120 W/cm to 240 W/cm in 11 cm, 15 cm and 25 cm tubular lamps. Electrodeless lamps offer fundamental advantages over arc lamps in regard to lifetime, spectral stability, and greater flexibility in fill chemistry (which lead to spectra more optimised for the curing task.)

Most commercially available electrodeless sources of UV light are high power (1800-6000 W) units powered by magnetrons. These sources are excellent choices for fixed installations needing copious amounts of light. However, there is a need to bring the advantages of electrodeless systems into applications requiring the UV be focused at smaller targets. Examples of such applications would be “spot curing” of adhesives in small or “micro” assemblies, and the curing of inkjet inks for industrial/commercial wide format printers. One of the challenges of these applications is that the light source must move in space across the substrate or work piece after the coating or ink is applied. Conventional UV solutions for micro-assembly applications use liquid filled light guides or fused silca fiber optic bundles to direct the UV light onto the substrate or work piece. Systems employing light guides or fiber optic bundles are usually referred to as “spot cure lamps”. Spot cure lamps have several disadvantages - light guides and fiber optic cables sacrifice transmission for cable flexibility and have a notoriously short life; the short arc bulbs that are employed have rapidly decaying outputs and shifting spectra; and typically only one type of spectra is available.

Figure 1: The compact size and low mass (300 grams) of the PC1 irradiator set a benchmark for high irradiance UV light sources.

Fusion UV’s Power Cure® 1 (PC1) lamp changes the paradigm by using an ultra-light irradiator containing a bulb, reflector, integrated cooling and a RF coupler remotely connected to a radio frequency power source via an RF cable. The RF cable is flexible, long-lived and only has small RF losses. Therefore, the irradiator can be easily moved to the location where the light needs to be applied.

LAMP DESCRIPTION[1]

The PC1 can be conceptualised into two basic pieces: the lamp irradiator (see Figure 1) and the radio frequency power source. (The system does need an RF cable, however this technology is well known and understood and is not discussed in this paper.)

[1] The Fusion Power Cure® 1 (PC1) is protected by US and international patents, both issued and pending.

The RF generator (not shown) consists of a semiconductor oscillator feeding a semiconductor power amplifier. The RF power output of the supply can be adjusted in the range between 75 and 250 W by changing the drive voltage applied to the oscillator. The RF generator of the PC1 contains circuitry to monitor and stabilize the power that is being delivered to the irradiator. This circuitry is used to check for fault conditions and for closed loop stabilization of the forward power. The entire unit can be controlled remotely via RS232 communication protocol or through a touch switch control panel on the unit. The RF power supply operates at a frequency of 615 MHz. The lamp complies with all applicable international safety, EMC, EMI, and emissions regulations, including CISPR 11, FCC Part 18, EN55011, EN61000, UL61010A, and CAN/CSA-C22. Therefore, the PC1 will not interefere with other equipment in the environment in which it is operated. Safety certification was carried out under the auspices of TUV and the system carries a fully-qualified CE mark.

Any HID lamp must meet several basic requirements. First, whether delivered via electrodes or otherwise, a significant voltage (for the one inch long lamp, we estimate sustaining voltages to be on the order of 200-300 V) must be applied to the plasma to sustain a steady state discharge. Furthermore, the breakdown voltage needed to initiate the discharge can be on order of thousands of volts. The circuit that drives the lamp must be agile enough to create these voltages in the face of radically changing plasma impedance as the lamp makes its way from the un-ignited state to steady state operation. Microwave or RF excited sources typically are designed to drive loads of 50 ohms, that is, have relatively high current and low voltage. Therefore, the circuit must include a voltage transformer; typically in the form of a resonant circuit (e.g. cavity, autotransformer.) Additionally, there are circuit elements that match the impedance of the resonator/lamp to the 50-ohm source. Usually, it is impossible to match both the starting impedance and the steady state impedance. Therefore, the RF or microwave source must either be isolated from reflection or robust enough to survive some transient reflection. The PC1 has a novel center-fed coil structure (the coupler mechanism) that acts simultaneously as the impedance matching circuit, resonant transformer and field application structure. The coil structure comprises a multi-turn wire coil. This coil structure is placed within an elliptical reflector and the bulb is placed within the coil. In this configuration, typical RF to plasma power coupling ratios exceed 98%.

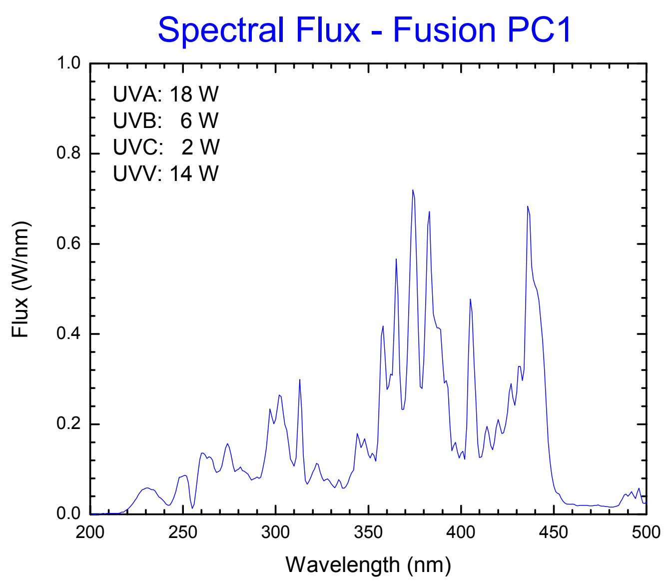

Figure 2: The spectra of the PC-1. The balance of deep UV and UVA provides both good depth of cure and surface cure.

The bulb is a 9 mm OD, 20 mm long fused silica capsule containing mercury and metal halides. The spectral output of the lamp is shown in Figure 2. The lamp is intentionally peaked in the UVA region, maximizing depth of cure, but has adequate deep UV to ensure quality surface cure. Different spectra can be easily obtained by changing the bulb fill.

For comparison, Figure 3 shows the normalized spectral output from a commercially available spot cure lamp along with the normalized spectral output of the PC1. Note the richer UVA flux content contained in the PC1 versus the spot cure lamp. As well, note the presence of significant amounts UVB and UVC from the PC1 as compared to the absence of flux in the UVB and UVC ranges in the spot cure lamp. This means that, compared to typical spot cure lamps, the PC1 will yield better cure performance, both through cure as well as surface cure as compared to a spot cure lamp.

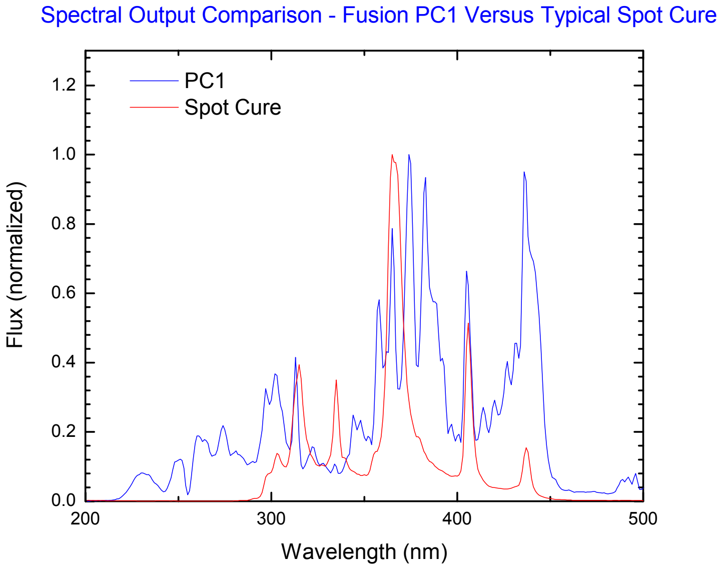

Figure 3: The spectra of the PC-1 compared to that of a typical spot cure lamp. The significant amount of UVC and UVB light in the PC1 versus the absence of UVC and UVB with the spot cure lamp implies better surface cure when typical coatings and adhesives are cured with the PC1.

The bulb, coil and reflector of the PC1 are housed in a metallic sleeve that serves as a RF shield and an air duct to direct air from an integral fan across the bulb and coil surfaces. A quartz plate at the output of the lamp prevents heated air from flowing onto the target substrate.

PERFORMANCE

The key performance metric of a curing lamp is the peak irradiance. The nominal peak irradiance of a lamp operated at 145 RF W (as measured at the irradiator) is 1200 mW/cm^2 of UVA radiation (measured with EIT PowerMap). Higher peak irradiances are achievable with higher RF power. The 50% of peak focal spot measures approximately 30 mm x 10 mm. Figure 4 shows the irradiance profile (along the bulb as well as transverse to the bulb) of the PC1.

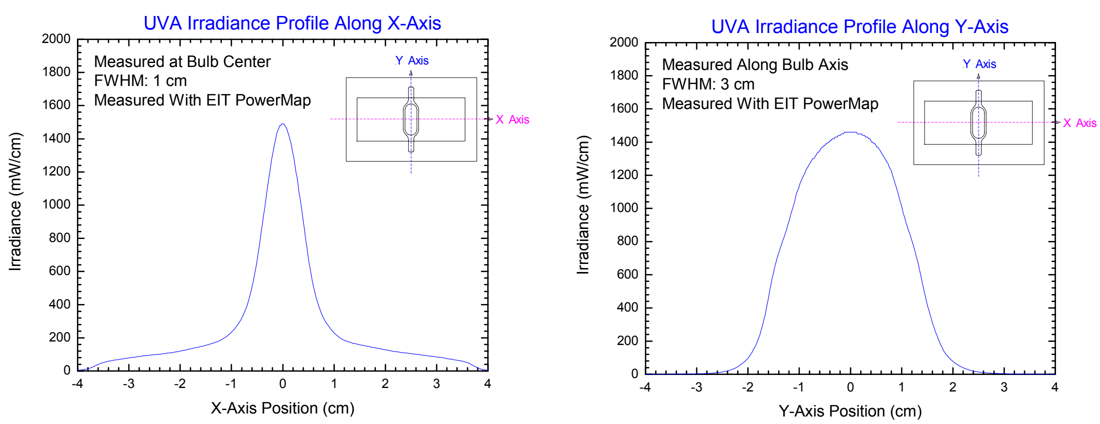

Figure 4: Irradiance profiles of the PC1 at focus. Focal spot dimensions are (at half maximum) 30 mm x 10 mm.

The cold start time of the PC1 ranges from 25 to 45 seconds depending on applied power level. The PC1 is hot-restart capable from a low power "simmer" level with a restart time of under 2 seconds. In effect, this gives the PC1 an "electronic shutter" capability, which means that a mechanical shutter is not required in step-and-repeat, duty cycle applications. Life testing has shown no spectral shifts or component failures in the irradiator after 2000 hours. Since it is semiconductor-based, there are no consumable components in the RF power source.

Cure performance of the PC1 has been tested on various commercially available coatings, adhesives, and inks. Table 1 shows the cure performance of the PC1 as measured by the time to achieve a tack-free cure as well as by crosslink density obtained at a conveyor speed of 1.8 m/min via FTIR measurements for various commercially available UV adhesives versus the same data for a spot cure lamp at high power. Tests were performed with the samples placed at 2 mm from the face of the PC1 and 6 mm from the end of the light guide of the spot cure lamp.[2] The data show that the PC1 achieves equivalent or better through cure performance while simultaneously providing superior surface cure performance versus spot cure technology.

Table 1: Cure performance with commercial UV adhesives, PC1 versus spot cure. Cure performance of the PC1 is clearly superior to that of a typical spot cure lamp.

Sample	*Lamp*	*Time To Achieve Tack Free Surface (seconds)*	*Surface Crosslink Density at 1.8 m/min*	*Bottom Crosslink Density at 1.8 m/min*
A				
	Spot Cure	60	28%	30%
	PC1	30	47%	38%
B				
	Spot Cure	50	29%	64%
	PC1	30	50%	62%
C				
	Spot Cure	60	37%	90%
	PC1	30	55%	97%
D				
	Spot Cure	30	29%	37%
	PC1	15	42%	48%
E				
	Spot Cure	30	24%	25%
	PC1	15	66%	35%
F				
	Spot Cure	40	35%	68%
	PC1	25	48%	76%

[2] The 6 mm cure distance for the spot cure lamp was chosen because it represents a typical cure distance for spot curing. It should be noted that the cure areas for each lamp are very different in this experiment – the PC1 area was approximately 30 mm^2 whereas the area for the spot cure lamp was 0.3 mm^2. Hence, not only does the PC1 give better curing performance, it can do so over a larger static area than the spot cure lamp.

CONCLUSION

The Fusion Power Cure® 1 lamp system exhibits enabling characteristics for applications requiring flexible lamp placement, moderately high peak irradiance, and stable spectral output. Its unique characteristics yield superior cure performance versus typical spot cure lamps. The combination of performance and weight make it the benchmark for high performance UV curing in microassembly as well as other applications.