Semray® UV4003 LED performance and applications: A versatile modular air-cooled UV LED system

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1. Introduction

In recent years, the dramatic increase of UVA LED chips performance has led to a rapid adoption of the LED technology in a wide variety of industrial applications ranging from printing to optical fibre curing. The main advantages of UV LED systems over their counterparts lay in the low energy consumption, long lifetime, instant ON/OFF capabilities and lack of hazardous substances. In this paper, we give insights in R&D activities in chip on board (COB) fabrication and optics at Heraeus Noblelight. In terms of system integration, we present a method for flexible up-scaling and tool-free servicing of UV installations. The Semray UV4003 LED Lamp consists of up to 30 segments (77mm wide each) in a backplane up to 2,3m wide, DC power supplies, a controller unit, and cables up to 20m long.

2. COB Technology

Heraeus's expertise lies in the development of customized UV LED systems from the UV LED bare die to the full system for implementation in industrial surroundings as shown in Figure 1.a. The control over the complete system integration is key for matching the system performance with the application needs. It guarantees that the photon utility is maximized for a given application ensuring the lowest energy consumption and the right balance

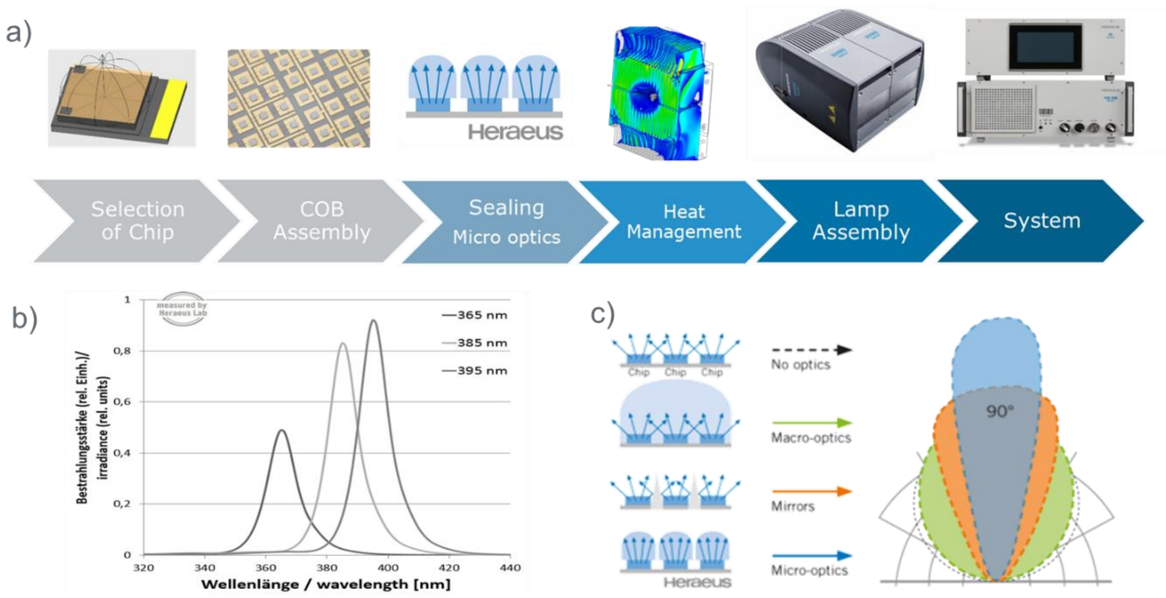

Figure 1 - From chips to a complete system. Heraeus Noblelight's know how. a) Typical system integration steps. b) Wavelength of a UV LED system. c) Effect of the micro optics technology.

between irradiance per area at the target (typically measured in W/cm² in UV energy) and the total flux emitted by the lamp per unit length of the lamp (typically measured in W/cm). This matching requires a great flexibility in the design of the LED arrays, the COB, the optics, the lamp geometry and the system as a whole.

It begins with the choice of the die where many factors must be taken into account such as the wavelength (λ), emission characteristics, typical lifetime at given junction temperature, forward voltage (Vf) of the diode, footprint, refractive index of the semiconductor and chips structure, contacts material and processes, etc. Depending on the application, the lamps can be equipped with either 365 nm, 385 nm, 395 nm or 405nm chips (Figure 1.b). UVC and UVB chips can also be used, however at a higher cost and lower efficiency and lifetime due to the limitations at the chip level.

Once the right "bare" die has been chosen, it is attached on a substrate with a high thermal conductivity. Although the efficiency ($P_{optical}$ / $P_{electrical}$) of the chips in the UVA has reached over 40%, it is still required to efficiently cool the chip as ~60% of the total energy is dissipated as heat at the chip level. A good rule of thumb indicates that for each 10°C increase in junction temperature, the chip lifetime is halved.

The layout of the LED array is usually designed to meet the needs of a particular application. It determines firstly the optical homogeneity, the irradiance and the total flux of the lamp and secondly the electrical parameters required to drive the lamp as well as the heat concentration at the substrate level. Figure 2 shows two examples of substrates: LED arrays with different packing density, different contacting pattern and different amounts of chips. With 60 chips closely packed together, the substrate on the left hand side is designed for applications that require a higher irradiance at the target but with a smaller UV flux than with the substrate on the right hand side.

Taking a closer look at the light extraction of the chip is key to the system performance. With UVA chips typically emitting as a Lambertian

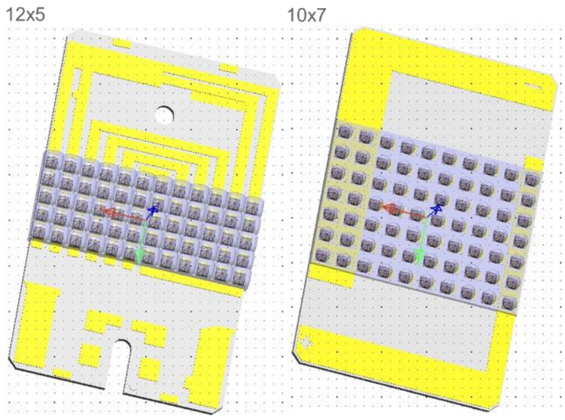

Figure 2 – Two different array designs on a substrate: 60 closely packed chips (left) and the 70 chips array (right).

source (Figure 1.c), the emission of the lamp is diverging leading to a rapid decrease of the irradiance of the lamp with the target distance. Many methods have been tried on the market to collimate the UV radiation and concentrate the beam on a smaller area and hence reducing the radiation divergence. We found that a UV transparent sealing, structured with a dome

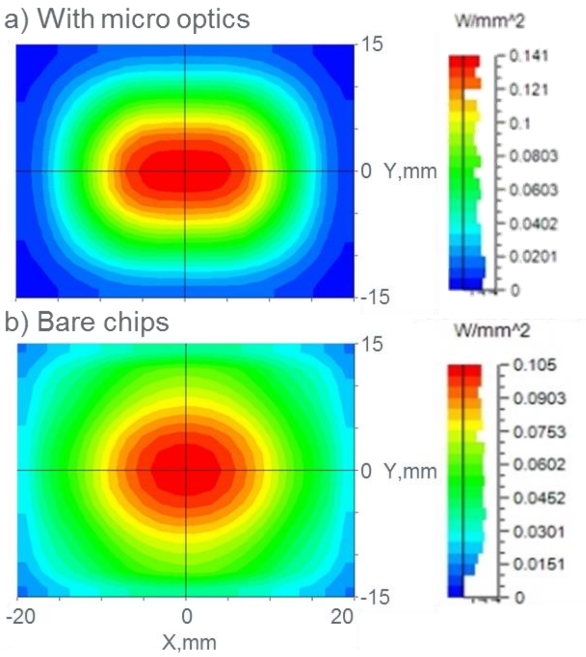

Figure 3 – Ray tracing irradiation simulation at the lamp window of an LED array as shown in Figure 2 (right) with (a) and without (b) silicon micro-optics.

above each chip, best reduces the emission solid angle. These so-called micro-optics also protect the chips and the bond wires from external stress and thus facilitates handling of such substrates. Figure 3 explains the benefits of the micro-optics at the substrate level. It shows a ray tracing simulation of the irradiance of a 25 mm wide substrate for a 10x7 array as shown in Figure 2 (right) with and without micro-optics. The collimation effect increases the irradiance at the window from 10 W/cm² to 14 W/cm² (Figure 3) and modifies the typical decrease of UV irradiance with increasing target distance. These theoretical results are supported by optical measurements with a Nobleprobe® UV sensor.

In some applications however, the curing targets cannot be exposed directly at the lamp window due to mechanical specificities of the industrial equipment. To guarantee high irradiance at a given distance from the lamp, a secondary optics can be placed above the substrate to concentrate the UV beam at the desired distance from the lamp window. The careful choice of array design, and dimensioning of both primary and secondary optics enables the desired concentration of the beam at a given target distance before diverging again with increasing distance from the lamp.

3. Smart Lamp

The original Semray® Smart UV4003 LED lamp is made of segments with typical 77mm width. Within each segment, several LED arrays are mounted on substrates, together forming so called "channels" and these are soldered on a metal plate which is used as a heat spreader. The plate is then screwed on a heat sink. The metal plate is pressing on a carefully chosen thermal interface material so as to optimally dissipate the heat generated at each LED junction.

Each segment further contains a powerful fan and an electrical board (PCB). The PCB has two components:

- i) A power converter that powers the fan and delivers a controlled current to each channel from a constant 48 V voltage source.
- ii) A logic board that controls I/Os from sensors and triggers, stores important information about the lamp and runs the software.

The embedded intelligence enables a versatile use of a system of variable length for various applications. It allows to:

- Cycle the system on and off
- Dim the smart lamp with a control at the segment level
- Choose the curing length by turning on or off the segments or even individual channels at the extremities of the lamp
- Monitor the environment
- Send alarms and errors for temperature / system failure
- Write a log for alarm / error messages
- Guarantee individual UV calibration settings for each segment, leading to a homogenous UV radiation across the curing width
- Signal if the Smart Lamp is ready to operate and if it is running

4. Scalability

Figure 4 – UV4003 backplane 02 with a mounted segment (right slot) and an empty slot (left). The mounting/release mechanism allows to plug in and out a segment without tools while ensuring a stable segment alignment and power/data connection.

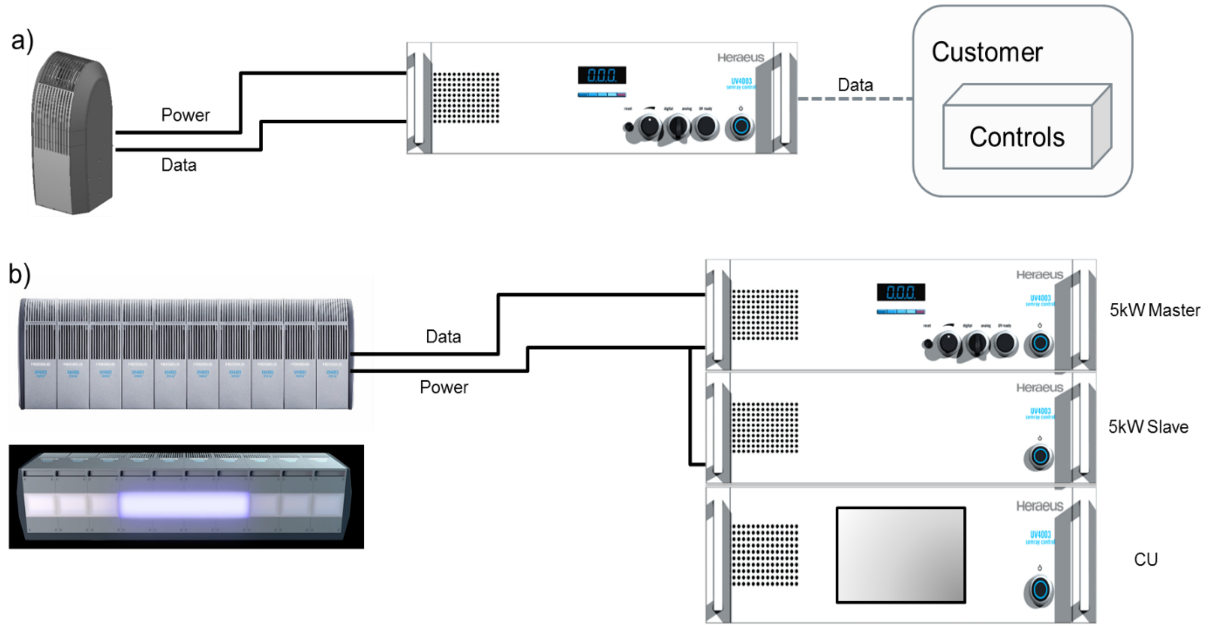

Figure 5 – Semray® UV4003 LED topology in a) its minimal configuration and b) showing the scalability concept of the system.

The scalability of most commonly available UV LED modular system on the market is achieved by bringing borderless lamp heads next to each other individually attached inside the machine, each lamp head having independent cable sets. This can lead to an uneven mount of the lamps with unaligned emission windows, radiation inhomogeneity and large bundles of cables. These issues have been overcome in the Semray® UV4003 by using a UV4003 backplane of configurable size. One backplane can host up to 30 segments and allows operating each row of 10 segments with just one power cable and the complete backplane with just one data cable. The solid mechanical mount of the individual segments in the backplane shown in Figure 4 yields a gap-free row with an even irradiation surface. Furthermore, mounting a segment in the backplane can be done without removing the neighbouring segments and ensures power and data connection. Clicking in and out a segment is a tool-free procedure which can be done in minutes and allows quick replacement of non-functional segments or upgrades with minimum machine down time.

5. System

Figure 5 shows the full Semray® UV4003 LED topology. In its simplest form (Figure 5.a), the system comprises one segment in a backplane 01, a power supply (for instance a Heraeus Semray® PSM), a power cable, a data cable and a customer specific control mechanism such as an industrial standard PLC. The communication is achieved with the open and widespread protocol Modbus RTU. The full turn-key multiple-segment solution is achieved by choosing the desired backplane size, install power supplies providing the required power and a control unit (Semray® CU). Heraeus provides 3kW and 5 kW power supplies: the 5kW in both master and slave configuration. A PSM5000 master can handle up to 5 PSM5000 slaves providing up to 30 kW of electrical power at 48V, enough to power 30 segments. This power is split on max. 3 power cables each connected to the backplanes for each 10 segments section. Note that no physical boundary exists between each ten segment sections and the homogeneity is guaranteed across the whole curing width. The CU controls the Semray® UV4003 via a touch display. It enables the following features:

- Dimming from 40% to 100% nominal power.
- Choosing curing format by switching on or off the segments or individual channels at the extremities.
- Setting irradiation times.

- Setting cycle programs.

An operation without PLC or a Semray® CU is also possible. Complete control of the smart lamp is granted via the Semray® PSM. It allows:

- To turn on/off the Smart Lamp.
- To dim from 40% to 100% via rotary switch, dimming level is displayed on the touch-panel.
- To visualize errors or warnings
- To grant external control with an ext. dimming, ext. enable input and outputs for ready to operation and PSM error.

6. Customized systems and applications: Web curing in an inerted atmosphere

Thanks to its flexibility and scalability, the Semray® UV4003 system can be integrated in a wide range of customized applications. The case below is only one example of projects fully utilizing the system features.

Web curing in an inerted atmosphere

Some curing processes cannot reliably be done in ambient air due to the presence of oxygen which inhibits the curing chemistry. Thus the targets need to be irradiated in a nitrogen atmosphere chamber. Heraeus Noblelight can provide on demand such customized chambers, including for very large systems. Also other turnkey solutions e.g. conveyor system for UV applications are also possible for new machines but also for retrofit. Figure 6 shows an example of a system with two LED rows of 30 segments each irradiating through a UV transparent quartz pane inside a nitrogen flooded chamber. The remaining oxygen level can be controlled down to a guaranteed ppm level. The more than 2m wide curing target is led in and out of the chamber with synchronized rotating axes. An additional air cooling of the quartz window and the UV lamp emission window lowers the risk of system overheating and hot air jam around the lamp. Furthermore the 30 segment backplane is mounted on a manual elevator on racks to bring the segments closest to the target in the lowest position and to allow easy access to the segments in the highest position for servicing and maintenance purposes. Each row is powered by 6 PSMs with 5kW each. They are embedded in one control cabinet and directly controlled by a dedicated PLC.

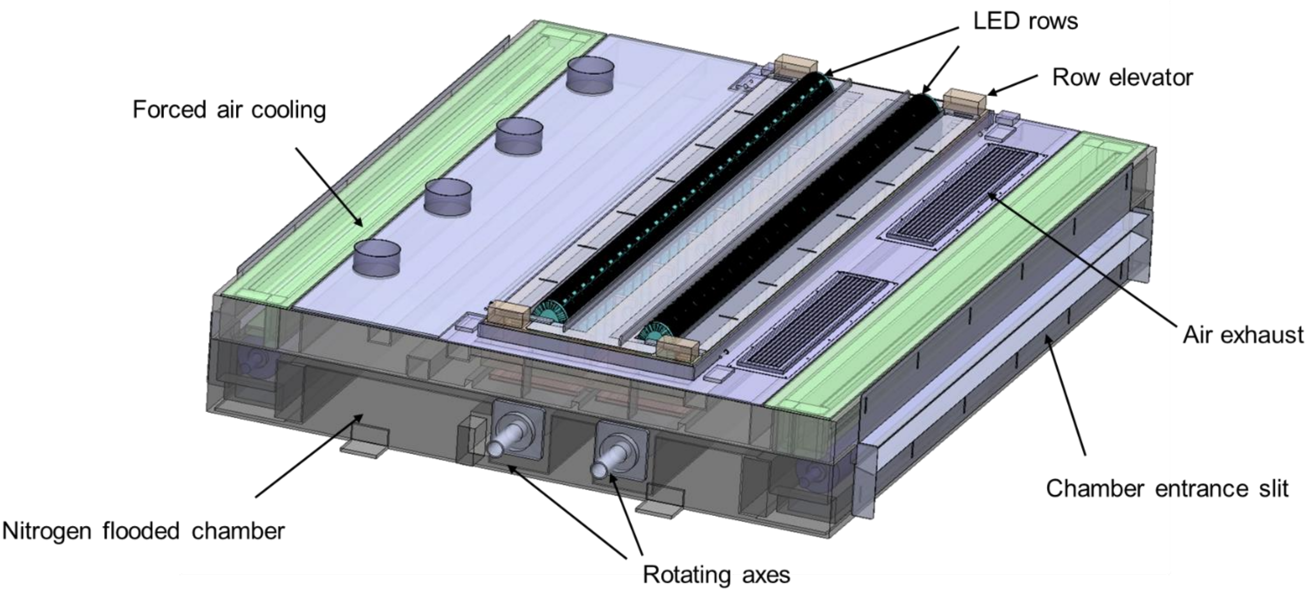

Figure 6 – CAD 3D drawing of a nitrogen flooded chamber for a web curing process with a 30 segment curing width, i.e. about 2,2m. These systems come with an electronic cabinet with power supplies outputting more than ~ 30kW electrical power and with controls. They are customized turnkey solutions delivered by Heraeus Noblelight.

7. Conclusion

In conclusion, we have presented a scalable and versatile UV LED equipment suitable for a variety of applications. Thanks to a close control of the whole value chain from the COB design to the system topology and interfaces, Semray® UV4003 constitutes a flexible platform that can be easily built up upon.