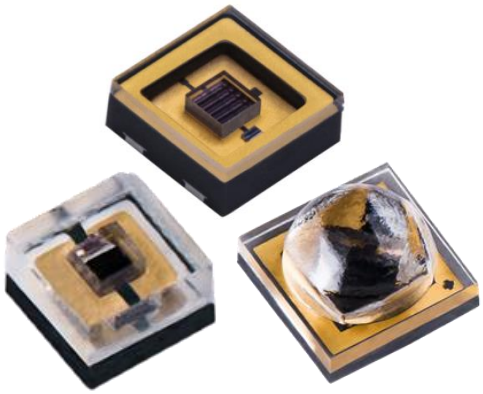
UV-C LEDs for Disinfection and Sterilization



Luminus UV-C 1313 and 3535 270-280 nm devices

Summary

The Luminus UV-C LED portfolio includes a range of power options and package configurations to support the broadest set of applications across a variety of industries. Radiation in the UV-C range (with a wavelength between 200 nm and 280 nm) is described as being germicidal. Radiation in the rest of the UV spectrum of light (between 280 nm and 400 nm) may also have some germicidal capabilities over extended periods of time, however a majority of studies and research have focused on the UV-C spectrum. Bacteria, viruses and fungi collectively are referred to as germs.

Advantages of Luminus UV-C LEDs

- UV-C LED technology is very effective and can be easily targeted to objects, surfaces, or substances needing disinfection.
- Using lenses, the beam can be easily collimated to increase directional density.
- UV-C light does not alter water quality (potability).
- UVC-LEDs are a relatively inexpensive technology, offering low operating costs.
- LED footprint is extremely small allowing integration into a broad range of applications.
- UV-C LED technology is easy to operate.
- Using UV-C LEDs means no chemicals are needed to ensure sterilization.
- Disinfection rates can be adjusted via design to meet dosage requirements.
- No warm-up requirements.
- Does not generate Ozone (O_3) that is typically generated at 222 nm.

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Ultraviolet Light for Disinfection and Sterilization

Though the generally accepted wavelength range for UV-C is 200 nm to 280 nm, researchers now consider the ultraviolet germicidal range to extend to 300 nm. Exposure to germicidal light initiates a photochemical reaction within germ molecules that destroys their DNA, RNA and/or proteins, which in turn renders them unable to replicate. While it is not the case that the germs are 'killed', a colony of germs is effectively destroyed as a result of the exposure. The degree to which a colony is impacted is the sterility assurance level (SAL). In the laboratory setting, this is a logarithmic measurement and may be reported as 1 Log to 6 Log.

The common representation of these measurements is as a percentage reduction in the number of germs, called germicidal effectiveness, as shown in Table 1. The typical example is for a colony of one million germs. The effective percentage is commonly published on the packaging of household cleaning solutions. A 6 Log, or 99.9999% elimination of germs is generally considered to be the level required for sterilization in a medical facility. For each Log effectiveness, it has been observed that doubling the 1 Log dose rate will increase the Log from 1 to 2, tripling the 1 Log dose will increase the Log to 3, etc.

Table 1: Sterility Assurance Levels on a Colony of 1M Germs.

	Number of germs remaining	Germicidal effectiveness
1 Log	100,000	90% reduction
2 Log	10,000	99% reduction
3 Log	1,000	99.9% reduction
4 Log	100	99.99% reduction
5 Log	10	99.999% reduction
6 Log	1	99.9999% reduction

Explanation of Dose Rate

The degree of germicidal effectiveness is related to the dose rate on the incident surface. Dose is a product of intensity and exposure time in seconds.

$$Dose\ Rate = \frac{mJ}{cm^2} = \frac{mW}{cm^2} * sec$$

The dose, also known as fluence, is typically described by mJ/cm^2, whereas other technologies will refer to J/m^2 depending on the technology and output power. (Note that in Europe and some other parts of the world, the units W/m2 for irradiance or fluence rate and J/m^2 for fluence (UV dose) are more commonly used. One mW/cm^2 = 10 W/m^2 and 1 mJ/cm^2 = 10 J/m^2).[1]

[1] – Malayeri, A.H., et al. (2006). Fluence (UV Dose) Required to Achieve Incremental Log Inactivation of Bacteria, Protozoa, Viruses and Algae". International Ultraviolet Association (IUVA) News. (Retrieved October 12, 2020 from https://www.iuvanews.com/stories/pdf/archives/180301_UVSensitivityReview_full.pdf)

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Observed dose requirements for organisms

Below in Table 2 are dose requirements for common micro-organisms. As mentioned in the prior section, to increase the germicidal effectiveness from 90% to 99%, we can double the dose to reach the next level. For example, to increase the effectiveness for *Legionella pneumophila* (Legionnaires' disease), we can move the dose applied to the organism from 3.1 mJ/cm^2 to 6.2 mJ/cm$^{2.}$ The doses listed below are based on studies on 254 nm, which is the typical peak of Mercury lamps used at the time, as UV-C LEDs were not yet available. With recent advancements in UV-C LED technology, we can expect studies based on 270 nm-280 nm to be conducted in the future.

Table 2: Organism dose rate requirements for 1Log disinfection based on 254 nm.

Species	Dose (mJ/cm^2)	Source
Bacillus subtilis ATCC6633	24	Mamane-Gravetz and Linden 2004
Legionella pneumophila ATCC 43660	3.1	Wilson et al. 1992
Streptococcus faecalis ATCC29212	6.6	Chang et al. 1985
Hepatitis A Virus	5.5	Wiedenmann et al. 1993
Poliovirus Type 1 LSc2ab	5.7	Wilson et al. 1992
Escherichia coli ATCC 11229	3.5	Sommer et al. 2000
Staphylococcus aureus ATCC25923	2.6	Chang et al. 1985
SARS-CoV-1 Coronavirus	0.9	Duan et al., 2003
SARS-CoV-2 Coronavirus	3.75	Mt. Sinai *

* Mt. Sinai's research results regarding this virus have yet to be published; the dose rate was determined from a test that confirmed 4 Log @ dose of 1.5 J/cm^2 on N95 mask.

Coronavirus statement and research investigations

Published studies on the effect of UV-C light on SARS-CoV-2, also known as COVID-19, are not yet available. However multiple studies on prior coronaviruses have been done in which the prior virus strains do not differ structurally by a great extent from the COVID-19 strain. It appears that coronaviruses are sensitive to UV doses 10.6 mJ/cm^2 (1 Log/90% reduction) at the upper limit. True value for effective disinfection is expected to be closer to 3.7 mJ/cm^2 [2]

The U.S. Centers for Disease Control and Prevention (CDC) recommends a minimum UV-C dosage of 1000 mJ/cm^2 for N95 mask sterilization based on studies ≥ 3 Log at this dosage. This translates to 33 3 mJ/cm^2 at 1 Log. The sample pathogen was not SARS CoV-1, however, but SARS-CoV-2, a close relative.[3]

For Table 1 Sources, please contact techsupport@luminus.com

[2] - Hessling, Martin & Hönes, Katharina & Vatter, Petra & Lingenfelder, Christian. (2020). Ultraviolet irradiation doses for coronavirus inactivation -review and analysis of coronavirus photoinactivation studies Ultraviolette Bestrahlungsdosen für die Inaktivierung von Coronaviren - Review und Analyse von Coronavirusinaktivierungsstudien. *GMS Hygiene and Infection Control*. 15. 10.3205/dgkh000343.

[3] - Arguelles, Paolo. (2020). Estimating UV-C Sterilization Dosage for COVID-19 Pandemic Mitigation Efforts. 10.13140/RG.2.2.12837.65761.

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Germicidal effectiveness of Luminus UV-C chip technology

To support the custom design of Luminus UV-C LEDs for specific applications, an antimicrobial efficacy study was conducted to evaluate the ability of Luminus UV-C LEDs to inactivate microorganisms common in daily life. The microorganisms included in the study were *E. coli*, *Staphylococcus aureus* (MRSA) and *Candida albicans*. The inactivation of the microorganisms by UV-C LEDs was evaluated under different drive currents, treatment time conditions, and distance. Treatment of the inoculated surfaces and the UV-C module test was performed by SSCTA Chemical Lab in Qingdao City, China, a CMA & CNAS certified laboratory.

Material & Methods

The test microorganisms consisted of *E. coli* ATCC 25922, *Staphylococcus aureus* (MRSA) ATCC 6538 and *Candida albicans* ATCC 10231. Each test organism was cultured separately and in advance of each designed test. The inoculation area on the coupons was 16 cm^2 in size, placed under the Luminus UV-C LED module. The UV-C LED module consisted of LED chips that emit radiant power between 278 nm and 282 nm, a range known to provide surface disinfection capabilities. The UV-C LED module was placed at various distances from 10 mm to 100 mm above the inoculated coupon with the specified drive current and treatment time for each microorganism (as shown in Table 2). An untreated control sample of all microorganisms was included in the study. Following the UV-C LED treatment, the inoculated 16 cm^2 plates were incubated for 48 hours before a count was performed and recorded as colony forming units (CFU) per square cm (CFU/cm^2).

Module Under Test

To verify the disinfection rate of the UV-C LEDs, a module was created that output 117 mW @ 350 mA for these tests. Comparatively, this module is equivalent to approximately 4 XBT-3535 or 3 XST-3535 pieces depending on the desired beam pattern. Alternatively, 25 pieces of the XBT-1313 driven at its maximum current of 40 mA would output close to the expected output of this module and may even have better uniformity depending on the application. The module also was tested with output of 29.26 mW @ 100 mA which would approximate to about 5 pieces of the XBT-1313 driven at its maximum current of 40 mA. Additional optical design and verification is recommended for all applications utilizing UV-C LED's for disinfection and sanitization.

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Results

The controls of all three microorganisms, *E. coli*, *Staphylococcus aureus* (MRSA) and *Candida albicans* were all in the targeted 4 log reduction range with 99.99% disinfection results. The count performed after 48 hours shows that the UV-C module successfully disabled the DNA & RNA of the microorganism rendering it unable to replicate. The results shown in Table 3 demonstrate successful disinfection of *E. Coli* and *Staphylococcus aureus* (MRSA) and *Candida albicans* with both 278 nm and 282 nm modules and a shorter duration of 10 seconds.

Table 3: Surface Efficacy Test Configuration Results.

Microorganism	Drive Current (mA)	Setup Distance	Module Wave-length	Treatment Time (secs)	Untreated Control (CFU/plate)	After Treatment (CFU/plate)	Log Reduction	Efficiency (%)
Escherichia coli ATCC 25922	100	10 mm	278 nm	20	1.86×10^6	< 1	≥4.00	> 99.99%
	350	10 mm	278 nm	20	1.53×10^6	< 1	≥4.00	> 99.99%
	350	100 mm	278 nm	20	1.29×10^6	< 1	≥4.00	> 99.99%
Staphylococcus aureus (MRSA) ATCC 6538	350	10 mm	278 nm	20	1.49×10^6	< 1	≥4.00	> 99.99%
	350	10 mm	278 nm	10	1.50×10^6	< 1	≥4.00	> 99.99%
	350	10 mm	282 nm	20	1.13×10^6	< 1	≥4.00	> 99.99%
Candida albicans ATCC 10231	350	10 mm	278 nm	20	1.13×10^6	< 1	≥4.00	> 99.99%

Conclusion of study

The test configurations included in this study, consisting of wavelengths, drive currents, and treatment times, were effective at reducing levels of all microorganisms tested at 4 Log germicidal reduction rate. The lower drive current and treatment times were still able to demonstrate successful disinfection effectiveness of 99.99%. The module used for antimicrobial efficacy test produced 29.26 mW @ 100 mA and 117 mW @ 350 mA drive current with an exposure time of 20 seconds. The UV-C LED module consisted of LED chips that emit radiant power of 278 nm and/or 282 nm and provide surface disinfection capabilities. Though earlier studies are typically based on 254 nm mercury lamps, UV-C LEDs can still be used for disinfection and sterilization as seen in the study above. We encourage all designers to do additional studies during design as additional factors may affect the expected disinfection rate of the final application.

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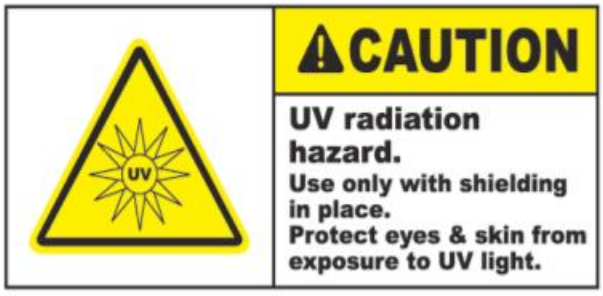
History of Changes

Rev	Date	Description of Change
1	6/13/2018	Initial Release
2	9/4/2020	Device information added. Dose requirements for common organisms.
2.1	9/20/2020	Editorial Changes
2.2	10/15/2020	Editorial Changes



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