1 Introduction

This application note gives you an overview how disinfection with UV-C light works, the benefits of UV-C LEDs and safety issues that need to be considered when using UV-C LEDs in applications.

Due to the recent COVID-19 pandemic the need for disinfection technologies has skyrocketed. One of these technologies is disinfection using UV-C LEDs. Ultraviolet (UV) light radiation is more energetic than visible light. It is classified by its wavelength into three subgroups:

- **UV-A (315-400 nm)**: Mainly used for material curing applications and horticulture.
- **UV-B (280-315 nm)**: Mainly used for phototherapy and horticulture.
- **UV-C (100-280 nm)**: Used for disinfection purposes.

The disinfection capability of UV light has been known since 1877 and already gained great interest in the fight against diseases such as preventing the spread of tuberculosis. In the past, low-pressure mercury-vapor discharge lamps were used for disinfection as they emit at the germicidal wavelength of 254 nm and have relatively large radiant powers. To date, they are often the most economic solution for large scale disinfection.

However, UV-C LEDs do have significant advantages. They do not contain hazardous materials such as Mercury (Hg), they do not need long warm up times i.e. they turn on immediately and are suited for frequent on/off switching. Additionally they are not vibration/shock sensitive and are relatively small compared to gas discharge lamps which makes them suitable for a variety of applications.

In recent years, research developed commercially available UV-C emitting LEDs. Even though, the initial UV-C LEDs had lower output, the year 2020 - boosted by the COVID-19 pandemic - has seen a huge increase in radiant power and drop of production price making them a more viable solution for widespread disinfection application.

The following will show the working mechanism of disinfection by UV-C LEDs, discuss the disinfection efficacy at different wavelengths, show an example of disinfection and give a few hints on safety aspects.

2 Work mechanism of UV-C disinfection

2.1 Principle of UV disinfection

Disinfection with UV-C is based on the fact that UV-C radiation can damage the DNA or RNA. This high energetic UV light can induce formation of pyrimidine dimers and other damages to the DNA which can inhibit multiplication of cells such as bacterial, fungal, plant and animal cells. Similarly the UV light can damage the RNA of viruses leading to their inactivation.

The following will show the working mechanism of disinfection by UV-C LEDs, discuss the disinfection efficacy at different wavelengths, show an example of disinfection and give a few hints on safety aspects.
Application Note

Disinfection with UV-C LEDs

convert electrical power to optical power. The WPE of our standard 275 nm LEDs (PN 15335327BA252), is higher than other UV-C emitting LEDs with shorter wavelength. The optimal wavelength with the best sterilization efficiency will be an LED solution where both the WPE and the wavelength are as ideal as possible. An overview of the combined sterilization efficiency of some LED solutions available on the market is shown in Figure 4. Here the combined sterilization efficiency is calculated as the product of the corresponding LEDs’ WPE as well as the wavelength-dependent RNA damage. For the investigated LED wavelengths the most efficient solution for disinfection is in fact the 275 nm wavelength LED.

A number of studies have investigated the D90 dose for viruses, other germs and specifically for the corona virus [4] [5] [6] [8]-[9]. Due to different experimental setup this dosage varies widely among the different research groups. To get a usable value, it is possible to get a median value of 37 J/m² [8], excluding the outliers. Even though these studies where performed with UV-C low pressure lamps we may assume a similar D90 dose for our 275 nm LED. Figure 3 shows that the damage done to the RNA is similar for 275 nm emitted by Würth Elektronik eiSos LEDs and the 254 nm mainly emitted by UV-C low pressure lamps. Additionally some publications, such as [9] show the D90 dose to be quite similar for low-pressure (LP) lamps as for 275 nm LEDs (see following table). An overview of the D90 doses for a few germs is shown in the following table:

<table>
<thead>
<tr>
<th>Germ type</th>
<th>Information on the germ</th>
<th>D90 Dose (J/m²)</th>
<th>Lamp type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corona virus [4]</td>
<td>Corona viruses such as SARS-CoV-2</td>
<td>6-117540 Median: 37</td>
<td>LP</td>
</tr>
<tr>
<td>Hepatitis virus [10]</td>
<td>Causes Hepatitis</td>
<td>40</td>
<td>LP</td>
</tr>
<tr>
<td>Adenovirus [12]</td>
<td>Causes the “Common Cold”</td>
<td>390</td>
<td>LP</td>
</tr>
<tr>
<td>Bacteria</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salmonella typhimurium [13]</td>
<td>Can cause food poisoning</td>
<td>39</td>
<td>LP</td>
</tr>
<tr>
<td>Escherichia coli [9]</td>
<td>Can cause food poisoning</td>
<td>43 (275nm) LED</td>
<td></td>
</tr>
<tr>
<td>Legionella pneumophila [14]</td>
<td>Can form in water supplies</td>
<td>17 (254nm) LP</td>
<td></td>
</tr>
<tr>
<td>Fungi</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: D90 doses for some common germs

In a German water disinfection guideline [16] the required value for water disinfection is 400 J/m² for disinfection with UV-C pressure lamps. This value is higher than the D90 dose for most typical germs and can be considered as a guideline for designing disinfection systems. As the disinfection result is depending on many conditions such as surface properties or UV-C absorption, studies have to be performed for each system to prove the reliable disinfection!

2.3 Dose

To quantify how well disinfection works, the terminology of log reduction is used. A log reduction of n implies that only 10⁻ⁿ of the previous germs survived. For example, 1 log reduction means that only 10⁻¹ = 10 % of germs survived, i.e. 90 % of germs were inactivated. For 4 log reduction, 10⁻⁴ = 0.01 % survive, i.e. 99.99 % were inactivated. To achieve this amount of germ inactivation, a certain amount of UV-C light has to be absorbed by the germs. This amount is called the dose (irradiance x Exposure time) and is measured in J/m². For 1 log reduction, the dose D90 is the amount of UV-C light needed to inactivate 90 % of the germs. For 4 log reduction, the dose D99.99 is needed to inactivate 99.99 % of the germs. To estimate the value for the D99.99 dose the D90 dose can simply be multiplied by 4.

<table>
<thead>
<tr>
<th>Log reduction</th>
<th>Percentage of germ inactivated</th>
<th>Corresponding dose required</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>90 %</td>
<td>D90</td>
</tr>
<tr>
<td>2</td>
<td>99 %</td>
<td>D99</td>
</tr>
<tr>
<td>3</td>
<td>99.9 %</td>
<td>D99.9</td>
</tr>
<tr>
<td>4</td>
<td>99.99 %</td>
<td>D99.99</td>
</tr>
</tbody>
</table>

Table 1: Relation between log reduction, germ inactivation and dose
Application Note

Disinfection with UV-C LEDs

When designing disinfection applications it is important to understand how to achieve a certain dose. For this, a few figures need to be understood:

- **Radiant flux:**
  The radiant flux is the total optical power output of the LED and is measured in units of \([W]\). This is a value that can be read from the datasheet.

- **Irradiance:**
  The irradiance is the amount of radiant flux received by a surface per irradiated area and is given in units of \([W/m^2]\). This irradiance can be simulated (see Section 2.4) or measured for different configurations of LEDs.

- **Exposure time:**
  The time that a surface is exposed to radiation.

- **Radiant exposure:**
  The radiant exposure or fluence is the amount of energy received by a surface. It is calculated from Irradiance \(\times\) Exposure time.

- **Dose DX:**
  The dose is the amount of energy per surface required to achieve a certain percentage of disinfection (\(XX\%\) inactivation). To achieve a certain amount of disinfection, the surface needs to be exposed until it received a radiant exposure that equals the desired dose.

This implies that the time needed for a desired disinfection results can be estimated knowing the desired dose and the irradiation of your system. An example is shown in the following.

### 2.4 Example simulation

In Figure 5 the irradiation distribution for different heights of a PCB with 9 WL-SUMW 15335327BA252 LEDs is shown.

When sterilizing with UV-C light, there might be some concern regarding the generation of ozone. However this is not relevant for Würth Elektronik eiSos 275 nm LED as they emit well above the threshold for ozone generation. The generation of ozone becomes only relevant for wavelengths below 240 nm. When disinfecting water with 275 nm LEDs the light is absorbed by germs or escapes the water. The UV-C light is not stored in the water, meaning it can not do any damage after the disinfection process. This implies that the UV-C disinfected water is not harmful for consumption, but also has the disadvantage that there can be some reinfection of the water after the disinfection process.

### 3 Material degradation

UV light is known to lead to degradation in polymers \(^{[17]}\), namely showing change of color, reduction of elasticity and strength that might result in cracks under stress. When using UVC LEDs the user has to consider using UV persistent materials such as metals and UV persistent polymers in their applications. The UV resistance of materials may be checked by official labs \(^{[18]}\).

According to BIFMA \(^{[19]}\) the materials are tested with a dose of 288 kJ/m\(^2\) which would relate to \(\sim\)720 disinfection cycles with using 400 J/m\(^2\) per disinfection cycle, or \(\sim\)15 h of constant irradiation with the example UV panel from Section 2.4 at 4 cm distance. When testing the materials with this dose, some damage can be observed, whereas the amount of damage is depending on the type of material \(^{[20]}\).
4 Safety

UV-C light is especially potent of damaging the DNA of all cells, including human, animals and plants. Furthermore, UV-C radiation is naturally blocked by the ozone layer and does not reach the earth’s surface. This is why organisms on earth did not develop any repair mechanisms for the damage caused by the UV-C light. Because of this reason, UV-C is so potent for killing germs.

However this also implies, that it is especially dangerous for our eyes and skin, causing long term damage such as skin cancer even long time after the exposure [21]. Great caution must be exercised when implementing UV-C light in applications. According to the maximum allowed dose per 8 h work day must not be higher than 30 J/m². For continuous exposure this implies that the irradiation should not be more than 0.001 W/m². Appropriate personal protection equipment and shielding have to be applied to ensure product safety. The following example gives an idea of what the requirements for the shielding look like.

4.1 Example calculation of shielding material:

For the example UV panel shown above at a distance of 20 cm the maximum irradiation is 0.6 W/m². To get below the maximum allowed irradiance of 0.001 W/m² assuming a long time exposure, the shielding must have a transmission smaller than \( \sim 10^{-3} \). However, it is highly recommended to reduce the transmission of the shielding material even further, as the damage done by UV-C radiation is cumulative over a long time scale [21]. It has to be noted, that the irradiance is highly dependent on the distance to the UV-C source. In our example, if the distance between UV panel and skin/eyes is 4 cm, the transmission of a shielding material should already be smaller than \( \sim 10^{-4} \). For 1 cm distance the transmission should be below \( \sim 10^{-5} \).

4.2 Safety considerations

Several documents cope with the safety relating to UV-C radiation such as [22], [23], [24], [25] and [26]. To give a brief overview and tips for working with UV-C LEDs, some key points are summarized here:

- The exposure of the end user (eyes and skin) must be kept to a minimum. The limit is less than 30 J/m² per 8 h work day.
- Products using UV-C must be marked with appropriate warning signs and an appropriate instructional safeguard and user manual must be included.
- Degradation of materials exposed to UV-C light needs to be considered.
- If too much UV-C light is leaving the application, such as in handheld lamps, all people that are potentially exposed need appropriate training and sufficient personal protection equipment such as face shields, gloves and protective clothing.

5 Summary

UV-C LEDs are an exciting new technology for disinfection purposes such as corona virus inactivation. But they will continue to play a big role in preventing future pandemics and coping with healthcare issues such as multiresistant germs. For general reduction of germs in many consumer applications, in air filtration systems, in water supplies and in food industry, the UV-C LEDs will continue to be in high demand long after the pandemic is over.

This application note explained the working mechanism of disinfection with UV-C and gives hints for the required radiation doses for different germs found from various publications. Furthermore it gives a calculation example using Würth Elektronik eiSos UV-C LEDs and also some tips and references on UV-C safety in your application.
Application Note

Disinfection with UV-C LEDs

A. Appendix
A.1. Literature


Application Note

Disinfection with UV-C LEDs


Application Note

Disinfection with UV-C LEDs

IMPORTANT NOTICE

The Application Note is based on our knowledge and experience of typical requirements concerning these areas. It serves as general guidance and should not be construed as a commitment for the suitability for customer applications by Würth Elektronik eiSos GmbH & Co. KG. The information in the Application Note is subject to change without notice. This document and parts thereof must not be reproduced or copied without written permission, and contents thereof must not be imparted to a third party nor be used for any unauthorized purpose. Würth Elektronik eiSos GmbH & Co. KG and its subsidiaries and affiliates (WE) are not liable for application assistance of any kind. Customers may use WE's assistance and product recommendations for their applications and design. The responsibility for the applicability and use of WE Products in a particular customer design is always solely within the authority of the customer. Due to this fact it is up to the customer to evaluate and investigate, where appropriate, and decide whether the device with the specific product characteristics described in the product specification is valid and suitable for the respective customer application or not.

The technical specifications are stated in the current data sheet of the products. Therefore the customers shall use the data sheets and are cautioned to verify that data sheets are current. The current data sheets can be downloaded at www.we-online.com. Customers shall strictly observe any product-specific notes, cautions and warnings. WE reserves the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services. WE DOES NOT WARRANT OR REPRESENT THAT ANY LICENSE, EITHER EXPRESS OR IMPLIED, IS GRANTED UNDER ANY PATENT RIGHT, COPYRIGHT, MASK WORK RIGHT, OR OTHER INTELLECTUAL PROPERTY RIGHT RELATING TO ANY COMBINATION, MACHINE, OR PROCESS IN WHICH WE PRODUCTS OR SERVICES ARE USED. INFORMATION PUBLISHED BY WE REGARDING THIRD-PARTY PRODUCTS OR SERVICES DOES NOT CONSTITUTE A LICENSE FROM WE TO USE SUCH PRODUCTS OR SERVICES OR A WARRANTY OR ENDORSEMENT THEREOF.

WE products are not authorized for use in safety-critical applications, or where a failure of the product is reasonably expected to cause severe personal injury or death. Moreover, WE products are neither designed nor intended for use in areas such as military, aerospace, aviation, nuclear control, submarine, transportation (automotive control, train control, ship control), transportation signal, disaster prevention, medical, public information network etc. Customers shall inform WE about the intent of such usage before design-in stage. In certain customer applications requiring a very high level of safety and in which the malfunction or failure of an electronic component could endanger human life or health, customers must ensure that they have all necessary expertise in the safety and regulatory ramifications of their applications. Customers acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of WE products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by WE. CUSTOMERS SHALL INDEMNIFY WE AGAINST ANY DAMAGES ARISING OUT OF THE USE OF WE PRODUCTS IN SUCH SAFETY-CRITICAL APPLICATIONS.

USEFUL LINKS

- Application Notes
  www.we-online.com/appnotes

- REDEXPERT Design Plattform
  www.we-online.com/redexpert

- Toolbox
  www.we-online.com/toolbox

- Product Catalog
  www.we-online.com/products

CONTACT INFORMATION

appnotes@we-online.de
Tel. +49 7942 945 - 0

Würth Elektronik eiSos GmbH & Co. KG
Max-Eyth-Str. 1 · 74638 Waldenburg · Germany
www.we-online.com

www.we-online.com AN0008a // 2021-06-16 // DoK