Crystal IS™
High Performance UVC LEDs

APPLICATION NOTE:

Biofouling Control Using UVC LEDs

July 10, 2015

THIS APPLICATION NOTE DESCRIBES THE USE OF UVC LEDS AS A SOURCE OF GERMICIDAL RADIATION TO PREVENT BIOFILM FORMATION AND BIOFOULING IN INSTRUMENTS. BASIC DOSAGE CALCULATIONS AND MODELING RESULTS ARE OUTLINED.

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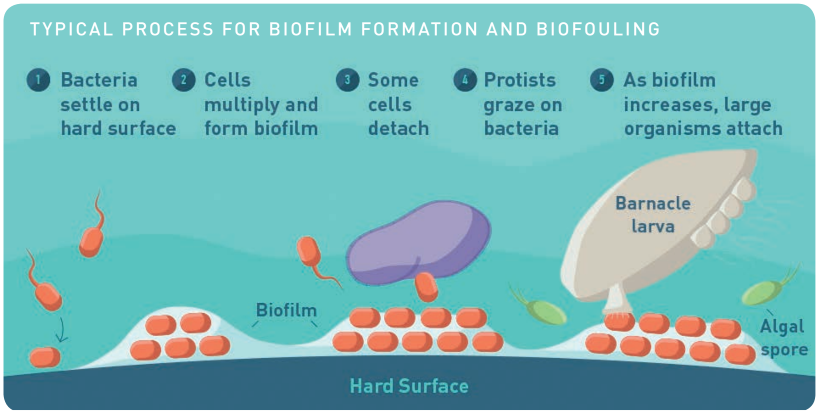
Biofouling is the accumulation of microorganisms, plants, algae, or other organisms on wetted surfaces. The mechanism of fouling consists of initial bacterial settling followed by formation of a biofilm on the surface and attachment of larger marine organisms. Biofouling affects a range of systems and components across many industries, from piping and cooling towers to power plants and other instruments exposed to water. Overall, the cost to industry due to biofilms is estimated to be at least $200 billion per year in the United States alone.

In the marine environment, biofouling affects:

- Optical sensors used in water quality
- Non-optical sensors used for conductivity measurements
- Acoustic sensors (sonar) for ocean current measurement
- Underwater cameras, lighting, and lenses used for optical communication

In ocean monitoring, biofouling has long been considered a limiting factor to the length of deployment of instruments and sensors under water. The Alliance for Coastal Technologies has estimated that maintenance costs due to biofouling consume 50% of operational budgets.



Traditional Biofouling Control Methods

There are several traditional methods of anti-fouling (or biofouling control) that have been used in spite of inherent limitations. Biocides are effective, but they are on the decline in recent years due to concerns for the environment. The most common biocide over the past 40 years, Tributyltin (TBT), was banned in 2008 due to its toxicity to other organisms and the environment. Additionally, some microorganisms form a resistance to biocides over time, making this technique less effective.

Mechanical cleaning is common as an alternative to or in combination with biocides. This method uses wipers to clean a surface that is in the early stages of biofouling. However, wipers have a high failure rate and have relatively high power consumption. They also cannot effectively clean surfaces with complex shapes. Other techniques, such as copper or tin plating, have been used to limit and slow organism growth but are not effective in all environments. Many companies are seeking alternative solutions for bio-fouling control due to environmental concerns and the relative ineffectiveness of these traditional methods.

TABLE 1: COMPARISON OF TRADITIONAL BIOFOULING CONTROL METHODS

TECHNOLOGY	BENEFIT	LIMITATION
Mechanical wipers/shutters	• Established technology • Environmentally friendly	• High faillure rate • High power consumption • Must be customized for every surface • Effective in early stages, but not fully preventative
Tributyltin (TBT)	• Established technology • Effective for full prevention	• Toxic • Banned due to regulations
Copper paints	• Works in marine environments • Effectiveness of three months/ one year	• Not as effective in freshwater • Can result in galvanic reactions
Other non-toxic coatings	• Works by preventing attachment • May be cost effective for large areas	• Most coatings are not optically transparent

Biofouling Control with UVC Radiation

Radiation in the UVC range of 250-280 nm can be used to prevent and control biofouling. Light in these wavelengths deactivates bacteria, viruses, and other microbes by destroying the genetic information encoded in the DNA (Figure 2).

FIGURE 2: UVC RADIATION DISRUPTS DNA

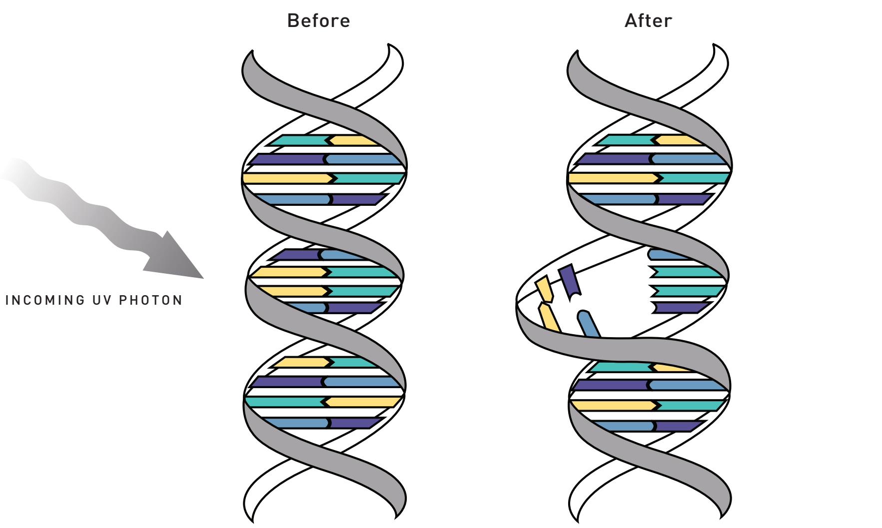


Figure 2: UVC radiation renders microorganisms ineffective by disrupting their DNA, thereby rendering them incapable of reproduction.

The amount of UVC radiation needed to control biofouling of any given system is referred to as the required UV dose. Some microorganisms are more susceptible than others to UVC radiation and require less exposure, while others require more light for complete deactivation. The UV doses for common types of bacteria are listed in the Crystal IS application note AN002 UVC LEDs for Disinfection.

UV dose is composed of two factors—the intensity of the light and the length of exposure to radiation. Dosage is typically measured in milli-joules per centimeter squared (mJ/cm^2) and is the product of UV intensity (in mW/cm^2) and the exposure time (in seconds).

Formula 1: UV Dose = UV intensity (I) x Exposure time (t)

Although the potential of UV radiation for biofouling control has been known for some time, traditional mercury lamps had been the only viable source of UVC light. Mercury is toxic to marine life and the environment as a whole. Additionally mercury lamps are bulky, fragile, and consume a great deal of power.

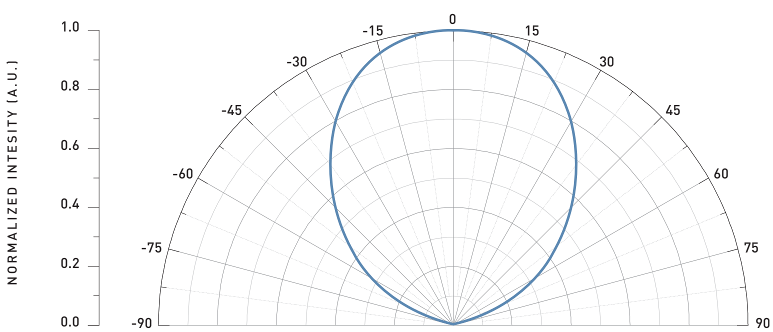
LEDs that emit UVC light offer a more suitable solution. Many of the initial commercialized UVC LED products were fabricated on sapphire and suffered from low light output and short lifetimes. The low light output meant an extensive exposure time, which resulted in multiple LED replacements over the life of the sensor.

Crystal IS UVC LEDs are grown on aluminum nitride substrates, which result in a million times fewer defects than UVC LEDs based on sapphire substrates. The relatively lower defect density in Crystal IS UVC LEDs leads to significantly higher light output and longer lifetimes, thus making UVC light a viable option for biofouling control. With these improvements in LED attributes deployment times in oceanographic and other environments can move from months to years.

Designing with UVC LEDs

The following example illustrates the design parameters to prevent biofouling with UVC LEDs on a flat two-dimensional surface which is 10 mm x 10 mm. This area is characteristic of a variety of sensor surfaces that require protection, including camera lens, optical window, or electrode. A UVC LED with a wide radiation pattern, such as a Crystal IS Optan SMD LED, can flood an area with UVC light for maximum disinfection (Figure 3).

FIGURE 3: THE RADIATION PATTERN OF OPTAN SMD LEDS



The intensity of the UV light and the exposure time determine disinfection effectiveness. The intensity distribution on the surface depends on the light output of the LED, the light emission pattern, and the distance between the UVC LED and the surface to be irradiated.

Figure 4 shows the light intensity distribution on a surface at a distance of 10 mm from a UVC LED emitting 2.5 mW. As LEDs are point sources, the intensity on the surface is highest directly below the center of the LED and steeply drops off as the distance from the center increases (Figure 4b).

FIGURE 4A

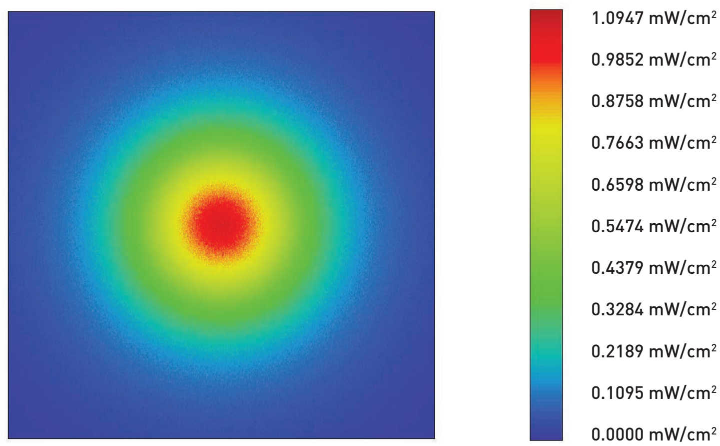
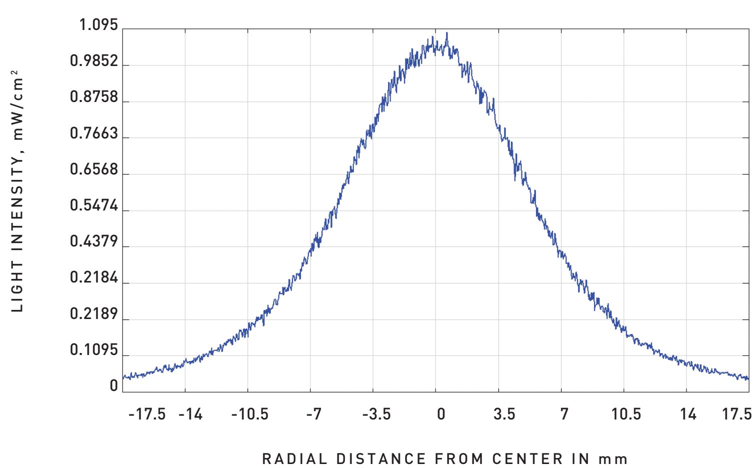


FIGURE 4B



Ray tracing simulation of the intensity distribution of a 2.5 mW Optan SMD LED at a distance of 10 mm from LED surface.

This relationship between the light intensity and distance from the center is also illustrated in Table 2. The table compares data for two different distances from a light source to a surface. For a 10 mm x 10 mm surface located at 10 mm from the LED, the minimum UV intensity at the edge of the surface (i.e. at 10 mm from the center) is 0.20 mW/cm^2.

TABLE 2: UVC LIGHT INTENSITY

	RADIAL DISTANCE FROM SURFACE CENTER		
DISTANCE FROM LED TO SURFACE	**0 MM**	**5 MM**	**10 MM**
10 mm	1.09 mW/cm^2	0.60 mW/cm^2	0.20 mW/cm^2
20 mm	0.30 mW/cm^2	0.22 mW/cm^2	0.17 mW/cm^2

A preponderance of microbiological data in the literature indicates that a reasonable minimum dose for prevention of bacteria accumulation on a surface is 40 mJ/cm^2. In this simulation, the calculated minimum required time for UV irradiation using Formula 1 would be 200 seconds, or approximately 3 minutes. Thus a reasonable reference design would suggest irradiation of this prescribed dose periodically as water flows across the sensor's 10 mm x 10 mm surface. If this target area for prevention were increased, the system would require longer exposure times and/or the use of multiple LEDs for protection.

Summary

The example in this note illustrates that effective biofouling control can be achieved with relatively short doses of UVC irradiation. The short exposure times helps to limit power consumption and conserve UVC LED life which is particularly important in remote monitoring applications. Furthermore, the small footprint of the UVC LED enables use in sensors of varying geometries.

High brightness UVC LEDs from Crystal IS are effective, environmentally friendly solutions for biofouling control. By controlling biofilm growth, UVC LEDs allow manufacturers to extend the duration of in situ deployments in the marine environment while reducing maintenance costs.

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We invite you to learn more about our UVC LEDs.

Crystal IS™
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