UNIVERSIDAD DE SANTIAGO DE CHILE

HLUVX

Relevant key parameters to migrate Hg lamps to LEDs, in the UV range for fluence determination

Pablo Fredes [1][2] and Ulrich Raff [1]

[1] Optics and Semiconductors Lab, Physics Department, University of Santiago de Chile

[2] Hydraluvx, Ultraviolet Disinfection Technologies, Maipú, Santiago, Chile.

NIST National Institute of Standards and Technology U.S. Department of Commerce

Applied Fluence

The disinfection process is based in a photoreaction, that is directly proportional to the product of the absorbed photon flux and the time of illumination (Bolton, 2015).

$$C_{\text{viable}} + hv \rightarrow C_{\text{inactive}} \quad (1)$$

hv is the photon energy referred at specific wavelength λ

$$d(Fluence) = dI \times dt \quad (2)$$

dF is a differential fluence applied on a differential volume of interest, where water flow (Q) is irradiated with UV intensity dI during dt time.

$$Fluence = \bar{I} \times t = \bar{I} \times (Vol / Q) \quad (3)$$

Fluence is the total applied Fluence in the interest volume irradiated , $\bar{I}$ is the nominal UV intensity, this is a representative value applied on the wáter flow Q.

Schematic process description using UV LEDs

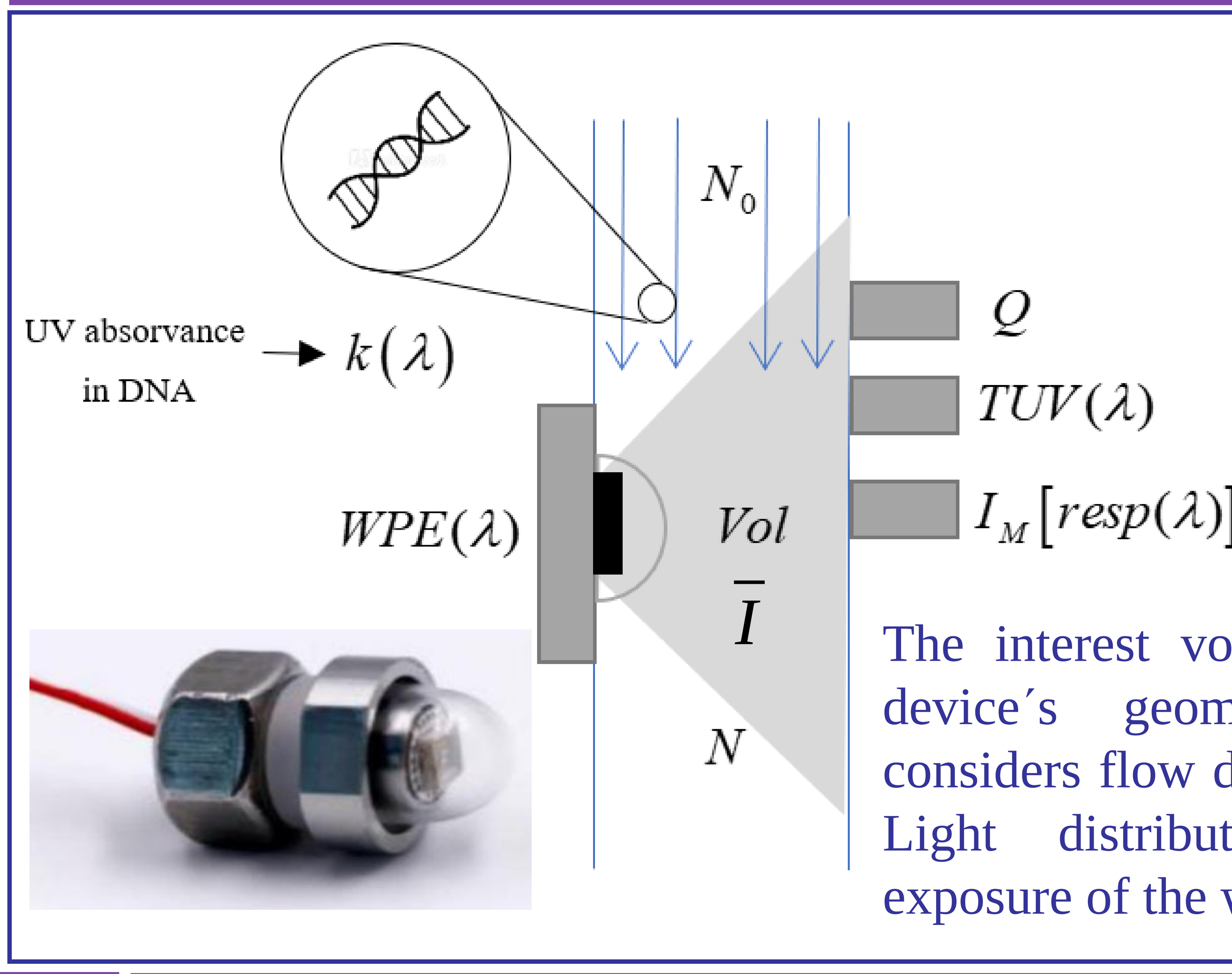
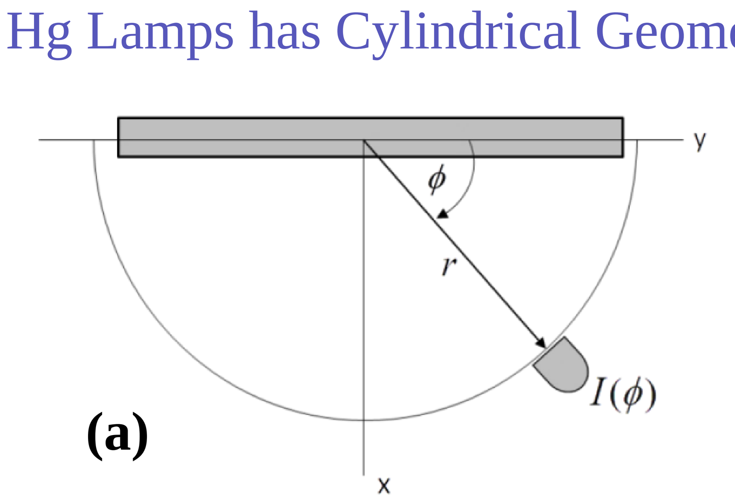


Figure 1. Key parameters for fluence determination in water disinfection process. *WPE* is a UV LED property, I_M represent the instant intensity measured, in the same way *TUV* and *Q* are empirical measured values. The values for N_0, N and k are found after bioassays analysis.

The interest volume irradiated depend of the device´s geometry. The device´s design considers flow dynamics, and homogeneous UV Light distribution. Additionally the time exposure of the water flow must to be optimized.

Intensity distribution of Hg Lamps and UV LEDs

Hg Lamps has Cylindrical Geometry



Single Led is a Lambertian emitter

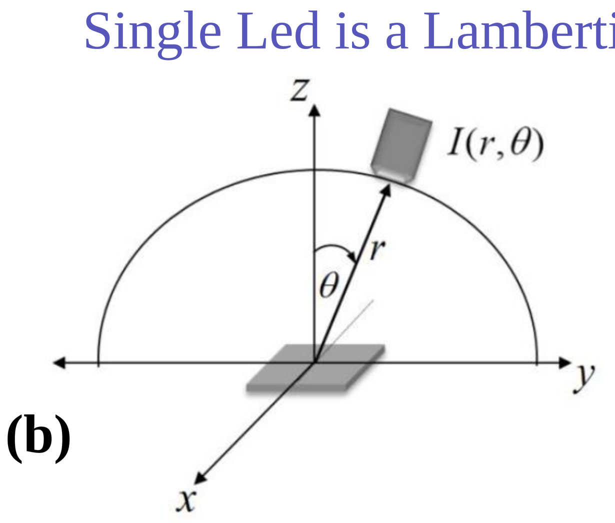
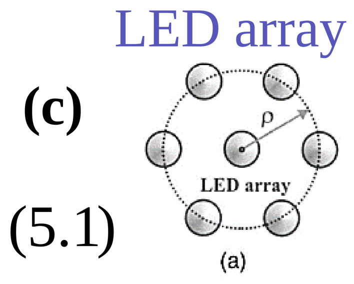


Figure 2. a) Hg Lamp, b) single LED and c) array geometries

LED array

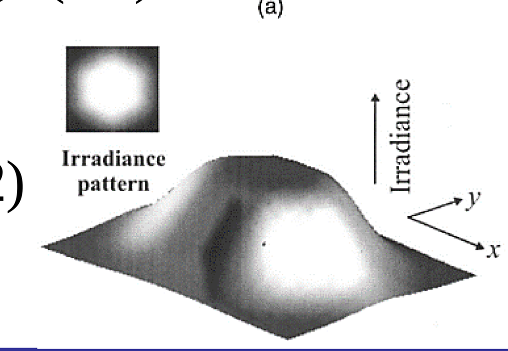


Total optical output power.

$$P = 2\pi r^2 \int_0^{\pi} I(\phi)\sin(\phi)d\phi \quad (4.1) \qquad P = \pi r^2 \int_0^{\pi} I(\theta)dA(\theta) \quad (5.1)$$

Spatial Intensity distribution

$$I(\vec{r}) = I_0 \frac{R_l}{|\vec{r}|} 10^{-a(|\vec{r}|-R_l)} \quad (4.2) \qquad I(r,\theta) = \frac{I_0 \cos^m \theta}{r^2} \quad (5.2)$$



UV Intensity and Transmittance monitoring

Most of the Intensity and Transmittance monitoring devices are commonly calibrated at 253.7 nm.

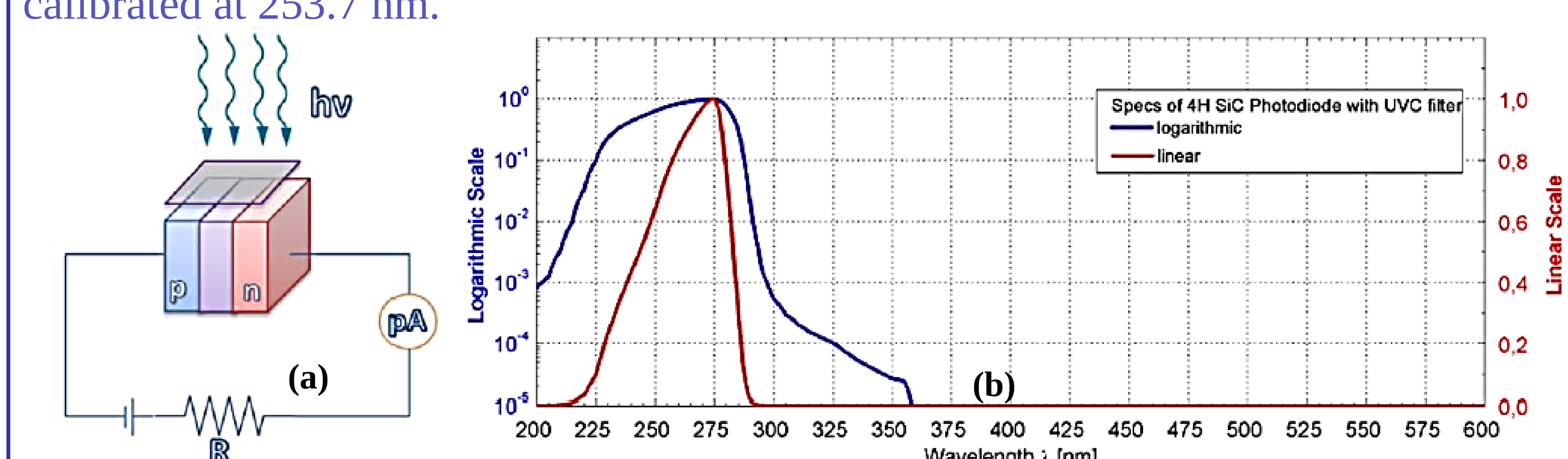


Figure 3. a) Representation of basic semiconductor structure of photodiode and b) Spectral Responsivity of SiC photodiode SGLux model SG01D–C18, source: Data Sheet SG01D–C18, Max-Planck-Str. 3, Berlin.

Inactivation Kinetics and Fluence

First order inactivation dynamics.

$$\int_{N_0}^{N} \frac{dN}{N} = k(\lambda)\bar{I}\int_0^t dt \quad (6.1)$$

Chick´s Law

$$N = N_0 10^{-k(\lambda)\bar{I}t} \quad (6.2)$$

Kinetic constant of inactivation of specific microorganism can be related with the fluence (Rattanakul, 2018).

$$N = N_0 10^{-k(\lambda)Fluence} \quad (7)$$

Wavelength dependence of DNA absorption

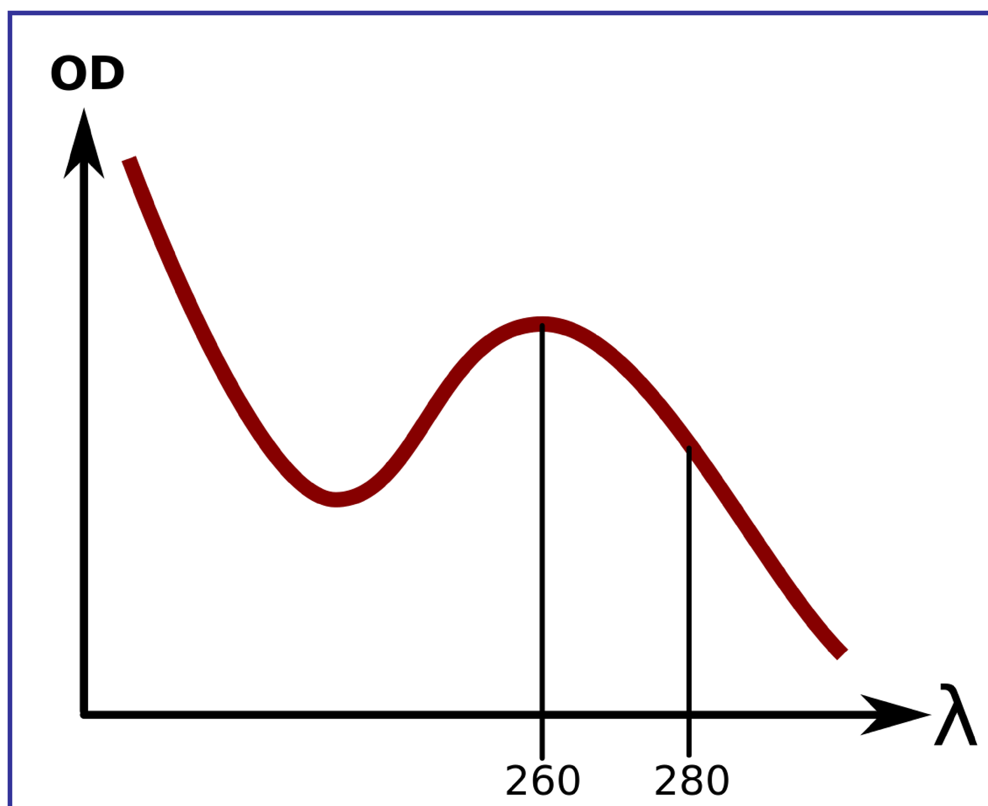


Figure 4. DNA absorbs 1.8 times as much UV at 260 nm

The absorption value refers to a specific wavelength (λ) related to the ultraviolet transmittance (UVT) by the Lambert-Beer Law. Prior to the appearance of deep ultraviolet light emitting diodes (UV-C LEDs), the majority of UV disinfection devices are calibrated for a λ of 253.7 nm, characteristic for the mercury gas spectrum.

Results and Conclusions

Table 1

	Wavelenght nm	*WPE* %	*k* cm²/mJ	E_3 kWh/m²
Hg Lamp	253,7	33	8,11	0,009
LED	265	0,6	8,05	0,41
LED	280	1,9	5,61	0,17

Taken from: Rattanakul (2018)

WPE at 280 nm is three times larger than at 265 nm. The kinetic inactivation constant k is only 30% less than the one at 265 nm resulting in half the energy consumption compared to the use of an LED at 265 nm. Furthermore the LED at 285 nm has a larger lifetime.

$$Fluence = I[TUV(\lambda), WPE(\lambda)] \times (Vol/Q) = k(\lambda)^{-1}\log(N/N_0) \quad (9)$$

All parameters must be referred to the same wavelength to determine an optimal Fluence value.

Wall Plug Efficiency of UV LED

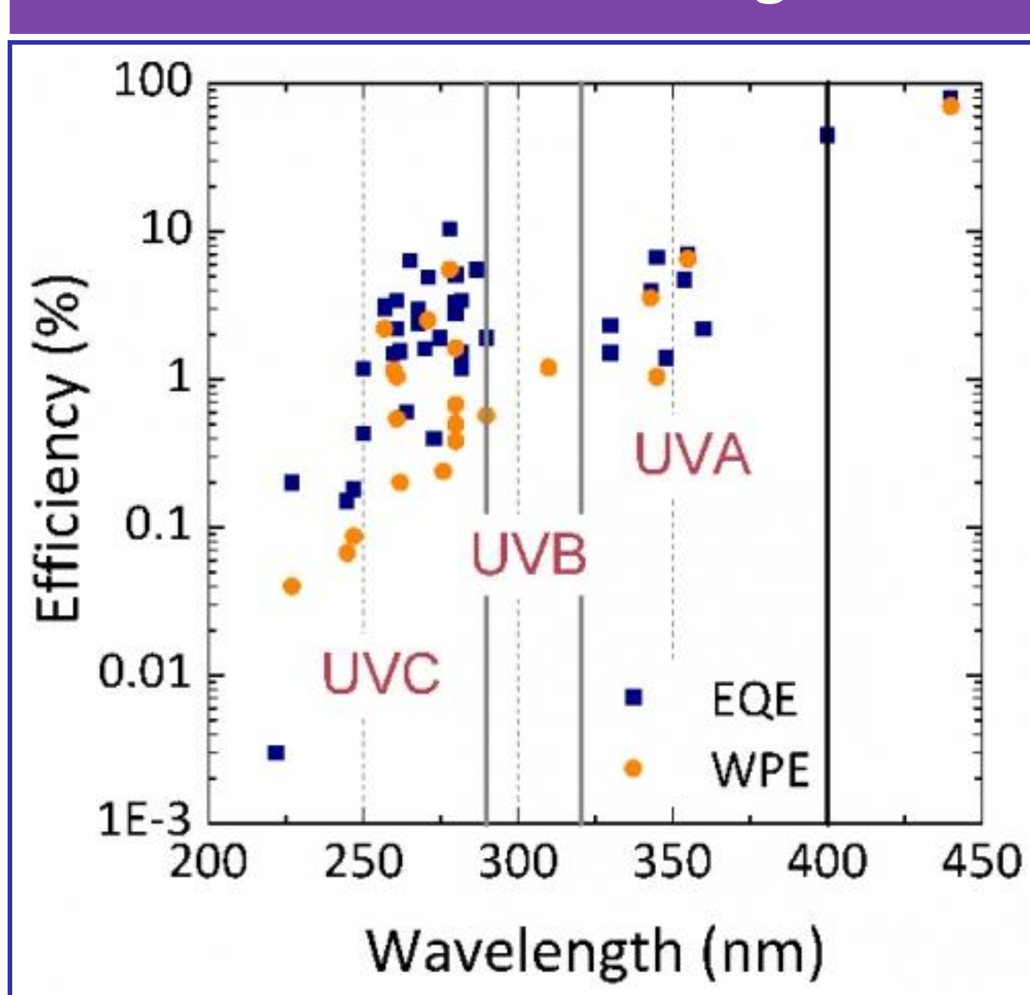


Figure 5. *WPE* and external quantum efficiency (EQE) related with λ.

The wall plug efficiency (WPE) is defined as the ratio of electrical power consumption P_{LED} and optical output power of the UV-C LED device denoted by P_{LIGHT}. Kneissl related the *WPE* with external quantum efficiency (EQE) and the rate between optical and electrical energy as shown in the next equation (Kneissl, 2019).

$$WPE = \frac{P_{LIGHT}}{P_{LED}} = \eta_{EQE}\frac{hv}{eV} \quad (8)$$

Acknowledgment

Dr. Ernesto Gramsch director of Optics and Semiconductor Lab, Univ. de Santiago de Chile, for his constant support. We also acknowledge the help of C. Lopez and F. Gatica, Hydraluvx Engineers.