Portable Sanitization Chamber

By
Robertson Beauchamp, Jacob Blackburn, Lauren Kieffer, Elliot Nation, Angel Soto, and Dangxian Zha
Team 15

Engineering Analysis

Document

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Department of Mechanical Engineering
Northern Arizona University
Flagstaff, AZ 86011

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1.0 INTRODUCTION

W.L. Gore & Associates designs products to the highest quality in their class. They are looking for a current portable sanitization device that will decrease the bioburden levels on select materials to a certain threshold. The engineering analysis examines the parameters of top contenders from the concept generation and compares their characteristics to the customer requirement driven specifications in **Appendix A**. Since each sanitizing process inherently requires certain physical containment processes, the container analysis is incorporated with each process. The concepts under analysis are chemical fogging with hydrogen peroxide (H_2O_2), Ultraviolet Germicidal Irradiation (UVGI or UV-C), and laser sanitization. Material components for each sanitizing method are analyzed for specification compatibility. These comparisons provide justification in deciding which design best satisfies the customer requirements.

2.0 CHEMICAL FOGGING ANALYSIS

This system uses a chemical fogging process of a 7% hydrogen peroxide (H_2O_2) solution. The solution is pumped into an aluminum block heat exchanger where it is vaporized. This flash of vaporization causes the gas to quickly increase in temperature and pressure. Since the heat exchanger is enclosed, vaporized H_2O_2 flows out of a nozzle at high velocity. As the vapor exits the nozzle its pressure drops dramatically, also causing a significant drop in temperature (below scalding temperatures).

This cooled vapor is contained inside of an enclosure and quickly sanitizes the materials contained within. This method is compatible for the materials in question as the chemical does not corrode or react with the materials and covers complex geometries. The cold steam is compatible with objects that are sensitive to heat, and because it is a vapor, it will not saturate materials that are affected by water.

The vaporized hydrogen peroxide must be filtered, or allowed to decompose into water and oxygen before it is safe for human exposure.

2.1 FILTERS

For the hydrogen peroxide fogging process, a filter will need to be included in the design. The filter is needed to break down the H_2O_2 solution into H_2O and O_2, so that it is safe to be released around humans.

There are three common types of air filters. These include High Efficiency Particulate Air (HEPA) purifiers, activated carbon filters, and titanium oxide (TiO_2) photocatalytic oxidation filters. HEPA filters do not break down any chemicals, eliminating them from the filter analysis.

Activated carbon filters can be used for simple chemical decomposition, such as the breakdown of some of the H_2O_2, but they must be replaced every 4-6 weeks.

Titanium oxide oxidation filtration uses a UV light photocatalytic process to break down bacteria and harmful chemicals. These filters are efficient, converting over 95% of harmful bacteria and chemicals into carbon dioxide and water, which falls well below OSHA concentration limits for hydrogen peroxide exposure [1]. Due to the effectiveness of the titanium oxide filters, it is the top choice for decomposing hydrogen peroxide. These UV filters have a regular use of breaking down chemicals in non-sanitizing applications (when in isolation) essentially requiring the hydrogen peroxide to evacuate from the sanitizing chamber before exposure to UV light. The perceived value for this design is detailed in Section 5.

2.2 ENCLOSURE MATERIALS

Materials for the enclosure and additional system components must be selected. The materials that will be included in the design must be compatible with hydrogen peroxide. A few materials were considered due to their excellent compatibility with H_2O_2 at concentrations from 10-100%. These materials include; PVC, aluminum, polycarbonate, PTFE, and titanium. All of these materials show no effective corrosion, discoloration, or degradation when exposed to H_2O_2 at a concentration of 10%. At higher concentrations, titanium shows minimal effects [4].

Because PVC, aluminum, PTFE, and polycarbonate all withstand exposure to H_2O_2, any of these materials would work well with the chemical process system. Due to the strength of the materials (comparing Modulus of Elasticity), aluminum will be used for the overall enclosure. This will also include the door, handle, hinges, rack, and any other small connecting pieces.

For additional pieces, including the H_2O_2 solution container, tubing, and nozzle; PVC and PTFE will be used [5].

In **Figure 1** below, the concept of how the potential Fogging Chamber is shown. The section that is cut out on the top is where the filter would go. The side compartment shown on the left is where the fog unit will be placed.

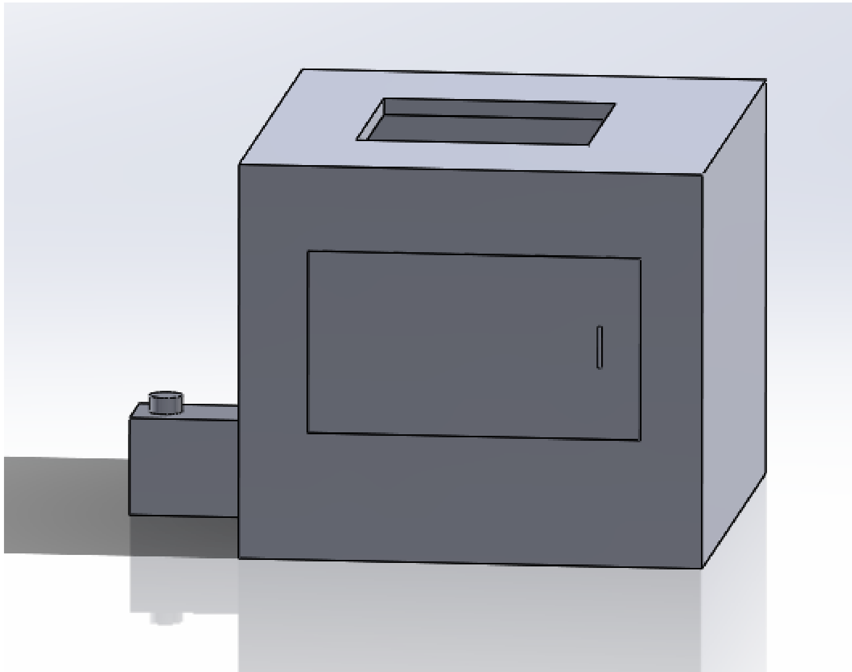


Figure 1: Fogging concept design.

3.0 UVGI DISINFECTION

Ultraviolet Germicidal Irradiation is a common method used for air, water, and surface sterilization. The UVGI process uses a 254 nm wavelength in order to inactivate microorganisms. To sanitize the surface of an object, it needs direct exposure from the lights for a given amount of time depending on the microorganism. In the case of *Bacillus atrophaeus*, to achieve a 2 log reduction, it would require a UV light exposure (Dose) of 50 mW s/cm^2 [6]. In order to determine the amount of time it takes to achieve this reduction, the specifications of the bulb is needed.

Four bulbs were chosen based on their height and power output. The specifications can be viewed in **Table 1** below.

Table 1: Ultraviolet bulb specification

Bulb Model	Life (hr)	Lamp Wattage (W)	UV-C Radiation (W)	Length (cm)	Diameter (cm)	Weight (g)
TUV PL-L 95W	9000	95	27	53.5	3.8/1.8	134
TUV 18W 1SL	9000	18	4.5	60.4	2.8	100
TUV 10W SLV	9000	10	2.5	34.5	2.8	62
G25T8 (GE-T8)	7500	25	7	45.7	2.8	N/A

Using these four bulb types, the time it takes to achieve a 2 log reduction using the known exposure of 50 mW s/cm^2 [6] can be found. The intensity can be found using **Equation 1**,

$$I = \frac{P}{A} \qquad (1)$$

where *P* is the output power of the UVC radiation and *A* is the projected area of the light. The area of each light is calculated using the length of the bulb times 1 ft in the radial direction. The intensity of each light can be seen in **Table 2**. The Dosage can be found using **Equation 2**,

$$D = I * t(s) \qquad (2)$$

Solving for time, the time it takes each bulb to achieve a 2 log reduction and 3-4 log reduction at an exposure of 4647 mWs/cm^2 [6] can be seen in **Table 2**. The time it takes for a 3-4 log reduction shows how much longer it would take to achieve a greater state of sanitization.

Table 2: Effective application of each bulb

Bulb Model	Intensity (mW/cm^2)	Time For 2log (sec)	Time For 3-4log (sec)
TUV PL-L 95W	9.28	1.25	500.93
TUV 18W 1SL	1.56	7.45	2984.78
TUV 10W SLV	1.51	7.66	3068.78
G25T8 (GE-T8)	2.86	4.06	1626.01

Based off the time it takes to achieve a 2 log reduction, the TUV PL-L 95W bulb is the most effective for the design. The full specifications of the bulb can be seen in **APPENDIX B**. Since the bulb is now known, other components such as the ballast and base, can now be selected.

Below are the concept designs for the UV chamber. Figure 2 shows the overall design and Figure 3 shows how the placement will look inside the chamber.

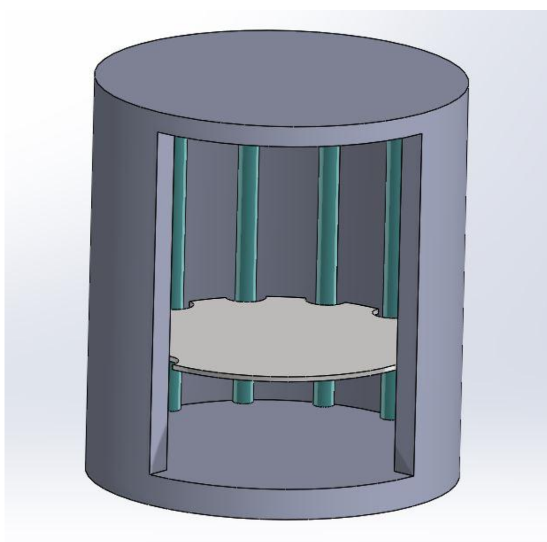


Figure 2: UV Chamber

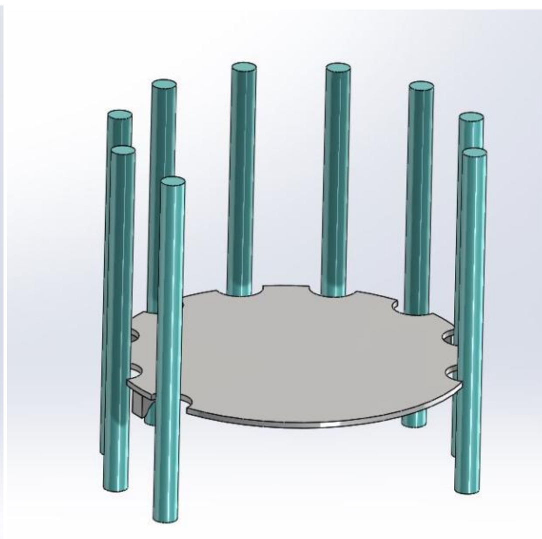


Figure 3: Inside UV Chamber

4.0 DEEP UV (UVC) LASER DISINFECTION

UV lasers are similar to the effectiveness of UVC light as they both use the same mode of disinfection. Producing lasers in the UVC wavelength is a complex process and is cost prohibitive. At this point in time, the technology is still in the early stages of development.

A study by Sharp Laboratories of Europe, Ltd. (6), demonstrated the effectiveness of the UVC laser in inactivating different bacteria and viruses, and decontaminating drinking water. They used a 205 nm through 230 nm wavelength lasers at 1 mW. In their experiments, they focused the laser to a 0.05 cm diameter dot. Assuming that they need a dosage of 50 mW s/cm^2 to reduce *Bacillus atrophaeus* spores by 2-log and 100-4,000 mW s/cm^2 to have 3-4-log reduction (7), the required time to achieve the above dosage can be found by substituting **Equation 1** into **Equation 2** while rearranging to solve for time:

$$\mathrm{t(s)} = \frac{\mathrm{DA}}{\mathrm{P}} \tag{2a}$$

Using **Equation 2a** and 1 mW laser would result:

$$t(s) = \frac{50\,\frac{\mathrm{mW \cdot s}}{\mathrm{cm^2}} \cdot 1.96\mathrm{x}10^{-3}\mathrm{cm^2}}{1\mathrm{mW}} = 0.098\ \mathrm{s}$$

for 2-log reduction and similarly 0.196 - 7.859 second pulse for 3-4-log reduction. This results in a required time for 2-log reduction over an area the size of 8.5” x 11” paper of 30,240 seconds or 8.4 hours.

At this time, the required time for just 2-log reduction is far too long to be acceptable. If the laser output could reach 100 mW for a continuous beam, the required time would be reduced to 5 mins for 2-log reduction and 10 - 403 mins (0.168 - 6.72 hrs) for 3-4-log reduction. This is far more acceptable for quick disinfection as it falls within the 20 minute goal.

Factoring in that the design to use a laser would require a mirror to scan the items, all above times would need to factor the reflectivity of the mirror. Using bare aluminum mirrors from Rocky Mountain Instrument Company, the expected reflectivity is between 90% and 93% [8]. This means that an ideal 5 minute scan would be between a 5.4 - 5.6 minute real scan. The disinfection chamber will be made of aluminum, which will reflect and stop all laser beams from reaching the user when the system is running.

5.0 COMBINED UV/H_2O_2 - PROCESS

There are many advantages in using a multi-process Ultraviolet/H_2O_2 system. A filtration system could be entirely eliminated by introducing the UV light process into the chemical fogging system. By running the UV lights immediately after the fogging, the hydrogen peroxide would be safely decomposed. Additionally, the UV light would add extra sanitization.

This two-step photocatalytic process of using H_2O_2 followed by UV light, also creates free hydroxyl radicals, OH+, that are strong oxidizing agents. These radicals degrade a variety of additional toxins such as; benzene, dichloroethylene, Freon 113, and various pesticides.

A study by Braz [3] shows that the UV/ H_2O_2 process successfully inactivates *Bacillus atrophaeus* spores.

5.1 MATERIALS SELECTION

Again, aluminum was chosen for the enclosure due to its strength and compatibility with H_2O_2. The fogging system used in the chemical process would be exactly the same, including the same material selections.

The main issue with the collaborative system is keeping the UV lights clean from the potentially corrosive H_2O_2 solution. To do this, the lights would have to be covered by some sort of transparent glass or plastic. This keeps the H_2O_2 fog from reaching the UV lights. PVC and PTFE are both found in transparent form, and are UV light resistant. Meaning, the UV rays that would be sanitizing and decomposing the H_2O_2 would not penetrate the plastics.

Borosilicate, also known by the brand name Pyrex, is a highly UV-transmitting glass. By surrounding the cylindrical enclosure with a borosilicate tube the UV lights would be protected from the hydrogen peroxide and from dust and other potential threats, while the UV light still reaches the objects in the enclosure.

6.0 MASS CALCULATION FOR COMBINED UV/H_2O_2 PROCESS CHAMBER

The group determined to use concentric cylindrical for combined UV/H_2O_2 process design. The interior cylinder is shorter than the exterior cylinder, and in this situation the enclosure cylinder can contained the whole chamber completely, see **Table 3**.

Table 3: Dimensions for the chamber

Inside Height	h(m)	0.80	h(ft)	2.62
Outside Height	h(m)	1.00	h(ft)	3.28
Inside Plastic	di(m)	0.50	di(ft)	1.64
	t(m)	0.005	t(ft)	0.016
	do(m)	0.51	do(ft)	1.67
	V(m^3)	**0.160**	V (ft^3)	**5.659**
Spacing	s(m)	0.05	s(ft)	0.16
Outside Aluminum	di(m)	0.56	di(ft)	1.82
	t(m)	0.010	t(ft)	0.030
	do(m)	0.57	do(ft)	1.85
	V(m^3)	**0.251**	V (ft^3)	**8.854**

To keep the UV lights clean from the corrosive H_2O_2, some transparent glass should be used to keep the H_2O_2 fog reaching the UV lights. The group determined to use Borosilicate as the cover material. For the enclosure material, the group determined to use aluminum since it has a proper compatibility with H_2O_2, see **Table 4**.

Table 4: Mass of the interior and exterior chamber

Inside Plastic	V (m^3)	V (ft^3)	ρ (kg/m^3)	ρ (lb/ft^3)	Mass (kg)	Mass (lb)
	0.0032	0.11	2230	139.21	**7.04**	**15.52**
Outside Aluminum	V (m^3)	V (ft^3)	ρ (kg/m^3)	ρ (lb/ft^3)	Mass (kg)	Mass (lb)
	0.0088	0.31	2700	168.56	**23.75**	**52.36**

In **Table 5** below the mass of UV, wire, and the fog machine is calculated below.

Table 5: Mass for the other material

Materials	Mass(kg)	Mass(lb)	#	Total Mass (kg)	Total Mass (lb)
UV	0.1	0.22	8	0.8	1.76
Wire	0.1	0.22	1	0.1	0.22
Fog Machine	1.0	2.20	1	1.00	2.20

The total mass of the whole chamber is approximately 33kg, which meet the requirement of portability as seen in **Table 6**.

Table 6: Total mass for entire chamber

Mass(kg)	Mass(lb)
32.69	**72.07**

7.0 CONCLUSION

After analyzing all of the concepts, chemical fogging and UV lighting would work well to meet the requirements of the client. Lasers are good at sanitizing for small applications, such as cleaning teeth during a surgery. Laser sanitization does not meet the requirements of the client since larger applications require increases in process time and mechanical complications that become safety hazards and a cost burden. There are many advantages and disadvantages to using two processes. Chemical fogging is effectively disperses into the enclosure, covering any complex geometries that require sanitizing. A filter would be needed to reduce the amount of H_2O_2. UVGI applications perform well within the time constraint, but create a maintenance burden due to the nature of wavelength penetration.

From this analysis, developing a design that combines two processes proves to be the favorable option. The ultraviolet process compliments chemical fogging and can be integrated simply by keeping the UV lights within the sanitizing chamber and running them for a given length of time after chemical decomposition is complete. Utilizing both methods provides a wider range of sanitization (since certain spores are resistant to specific methods), proving to be a more effective design than either individual process.

REFERENCES

[1]Peak Pure Air, “How TiO2 UV Photocatalytic Oxidation (PCO) Works”, 2001, https://www.peakpureair.com/how-tio2-uv-photocatalytic-oxidation-pco-works, accessed on Nov. 14, 2013.

[2]Melanie Kito, Hi Nguyen, and John Tran, “Hydrogen Peroxide and UV Treatment”, 1998, http://www.calpoly.edu/~ceenve/enve/jsczechowski/enve436/projects/Hydro-Perox/H2O2-UV-Treatment.html, accessed on Nov. 12, 2013.

[3]Braz. J. Chem. Eng. vol.30 no.3 São Paulo July/Sept. 2013, “Inactivation of Bacillus atrophaeus spores in healthcare waste by UV light coupled with H_2O_2”, 2012

[4]Cole Parmer, “Material Compatibility with Hydrogen Peroxide (H_2O_2)”, Ozone Services, http://www.ozoneservices.com/articles/004.htm, accessed on Nov. 14, 2013.

[5]Schott North America, Inc., “SCHOTT Tubing Product Selector”, 2013, http://www.us.schott.com/tubing/english/product_selector/index.html?glassid=8347, accessed on Nov. 16, 2013

[6] Owens,M., Deal,D., Shoemaker, M., Knudson, G., Meszaros, J., and Deal, J., 2005, “High-Dose Ultraviolet C Light Inactivates Spores of Bacillus Atrophaeus and Bacillus Anthracis Sterne on Nonreflective Surfaces,” Applied Biosafety, **10**(4)**,** pp. 240-247.

[7] Boardman, E., Huang, L., Robson-Hemmings, J., Smeeton, T., Hooper, S., Heffernan, J., 2012, “Deep ultraviolet (UVC) laser for sterilisation and fluorescence applications,” Sharp Laboratories of Europe, Ltd.

[8] 2013, ”Bare Aluminum (BAL)”, from http://rmico.com/coatings-specifications/metal-hybrid/bare-aluminum-bal

APPENDICES

Appendix A: Design specifications table with customer requirements and justifications

Customer Requirements	Design Specifications	Reasoning and justification	Quantity or Pass/Fail
CLEANLINESS STANDARD reduce the bioburden to less than routine final bioburden levels	Process effectively elimiantes bacterial spores (e.g. Bacillus Atropheaus)	Client specified	1 log unit reduction
SAFETY No harmful materials Users are not at risk of exposure to sanitizing source Applicable OSHA safety standards met	Physical components do not cause user harm	OSHA employee safety guidelines	pass/Fail
	Chemical concentration	Allowable substance exposure from OSHA standard	H_2O_2: 1.4 mg/m^3 No eye exposure to light
	Electrically grounded Non-pinching hinge	User electrical guidelines from OSHA standards	pass/fail
EASE OF USE Short cycle time Cycle ends automatically when complete Easily transported by one person	Duration of process	Compared to common autoclave	20 minutes
	Control System	signals automatically execute process shutdown	pass/fail
	weight*	Human lifting average	75 lbs
	width	Fits through doorways and on client countertops	1 meter
SANITIZE VARIOUS MATERIALS e.g. Tackle Box Cleanroom Notebook Hemostats	Temperature	Avoid glass transitioning temperature of common polymers (polycarbonate)	120°c
	Stresses applied	Minimum modulus of elasticity to prevent deformation	2 Gpa
	Does not saturate material	Prevents adverse function effects for pourous materials	pass/fail
	substance covers every aspect of material	Complex geometries may provide small crevices that require sanitizing	pass/fail
BUDGET	Cost to generate	Client specified	$3,000

Appendix B: UVGI lamp chosen

TUV PL-L

TUV PL-L 95W

TUV PL-L lamps are compact UVC (germicidal) lamps used in professional water and air disinfection units. The compact size of the lamp allows for a small system design and design flexibility. TUV PL-L lamps offer almost constant UV output over their complete lifetime, for maximum security of disinfection and high system efficacy. Thanks to the single-ended lamp base, lamp replacement is easy.

Product data

- General Characteristics

System Description	High Frequency
Cap-Base	2G11
Cap-Base Information	4 Pins
Bulb	2xT16
Execution	-
Main Application	Disinfection
Useful Life	9000 hr

- Light Technical Characteristics

Color Code	TUV
Color Designation (text)	-

- Electrical Characteristics

Watts	95 W
Lamp Wattage Tech-nical	90 W
Lamp Voltage	115 V
Lamp Current	0.8 A

- UV-related Characteristics

UV-C Radiation	27.0 W

- Product Dimensions

Base Face to Base Face A	505 (max) mm
Insertion Length B	530 (max) mm
Overall Length C	535 (max) mm
Diameter D	38 (max) mm
Diameter D1	18 (max) mm

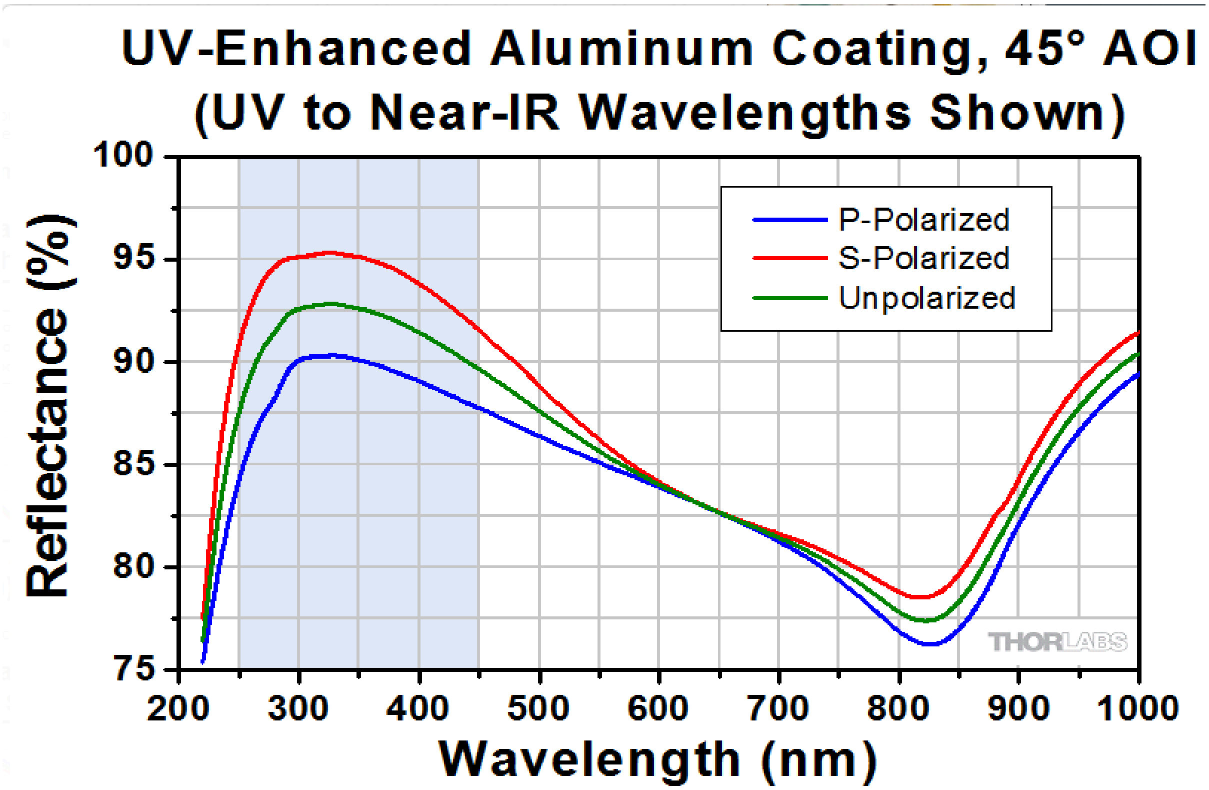
- Product Data

Product number	137257
Full product name	TUV PL-L 95W/4P HO 1CT
Short product name	TUV PL-L 95W/4P HO 1CT/25
Pieces per Sku	1
eop_pck_cfg	25
Skus/Case	25
Bar code on pack	8711500888297
Bar code on case	8711500888303
Logistics code(s)	927909804007
eop_net_weight_pp	134.000 gr

Dimensional drawing

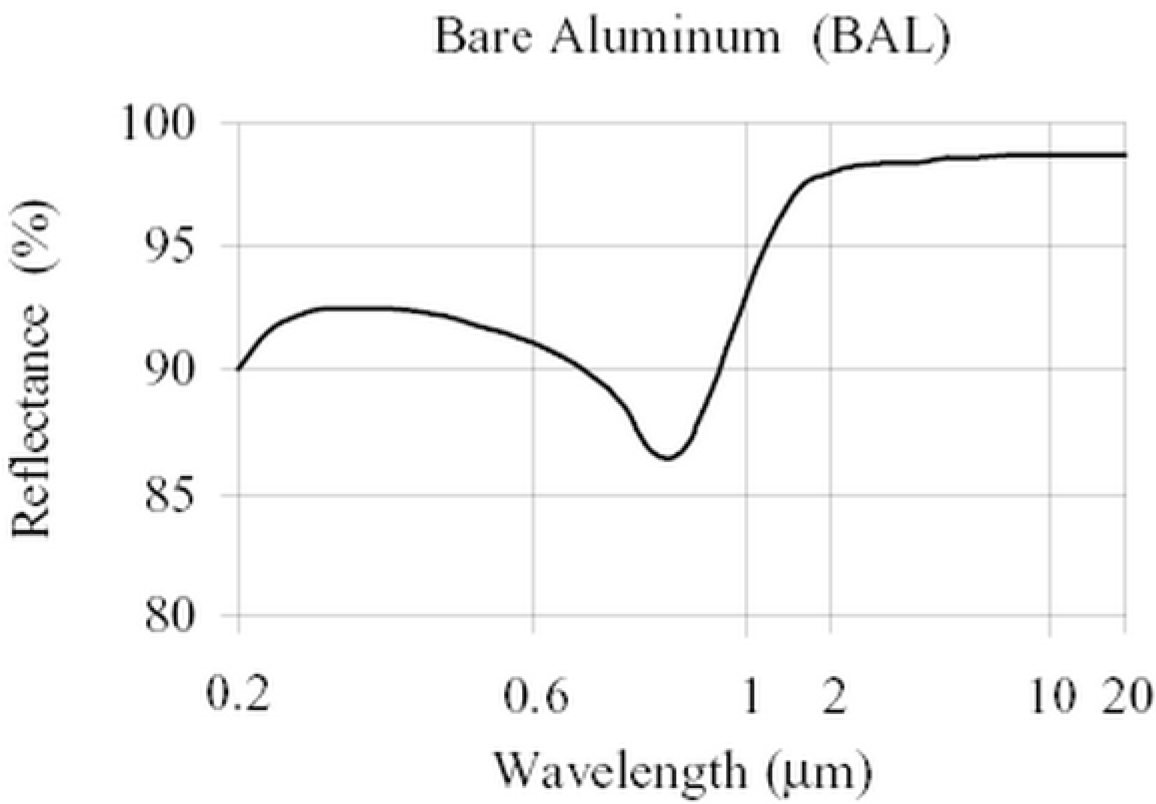
PHILIPS
sense and simplicity

Appendix C: Reflectivity of aluminum for ultraviolet design



http://www.thorlabs.us/newgrouppage9.cfm?objectgroup_id=264

Appendix C: Effective reflection of UV by Aluminum



http://rmico.com/coatings-specifications/metal-hybrid/bare-aluminum-bal

Appendix D: Material Properties

Material	**Density(kg/m^2)**
PVC	1300
Al	2700
Polycarbonate	1200
PTFE	2200
Ti	4506
Borosilicate(Pyrex)	2230

http://en.wikipedia.org/wiki/Polyvinyl_chloride
http://en.wikipedia.org/wiki/Aluminium
http://en.wikipedia.org/wiki/Polycarbonate
https://www.google.com/#q=density+of+ptfe
http://en.wikipedia.org/wiki/Titanium
http://www.camglassblowing.co.uk/gproperties.htm