DLUV267:  Modular UVC sterilizer

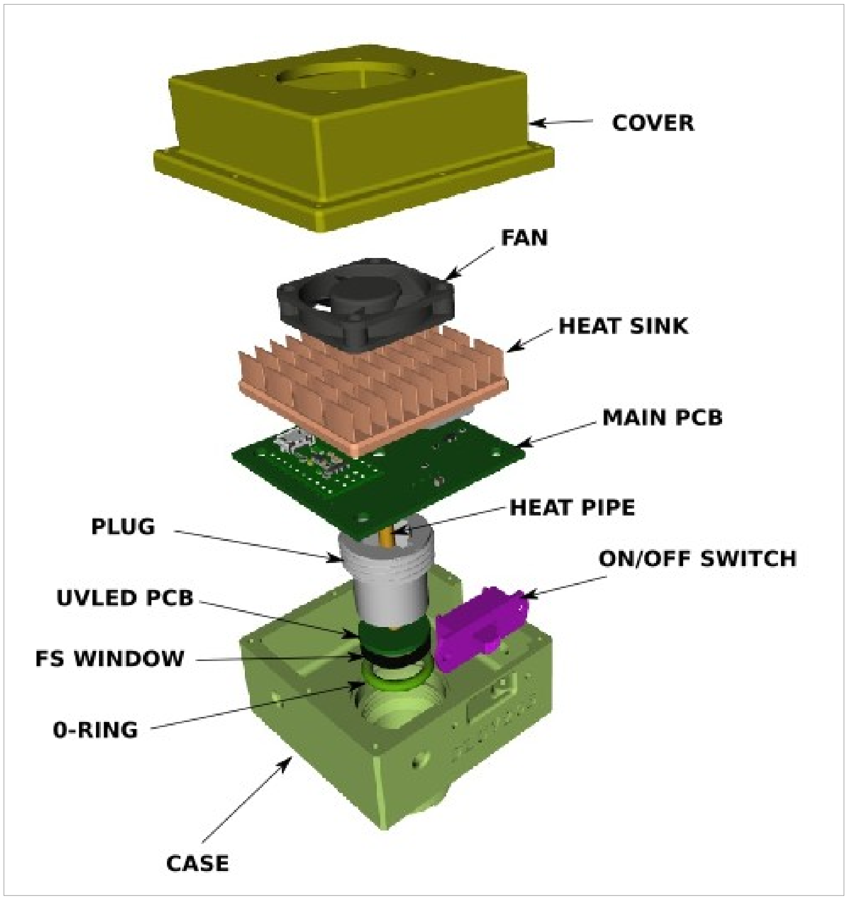
Description:

The DLUVxxx is meant to sterilize some flowing medium – liquid or gas – by means of Ultra-Violet light in the UV-C band – generated efficiently by solid state UV light-emitting-diodes.  It is meant to be modular (utilizing a common interface with pipes and/or ducts); long lived, and maintenance free.

The “xxx” in the name represents the predominate wavelength (in nanometers) of the UVC-LED used in the device.

It mounts to pipes and ducts using a male ¾ inch National Pipe Thread (NPT).

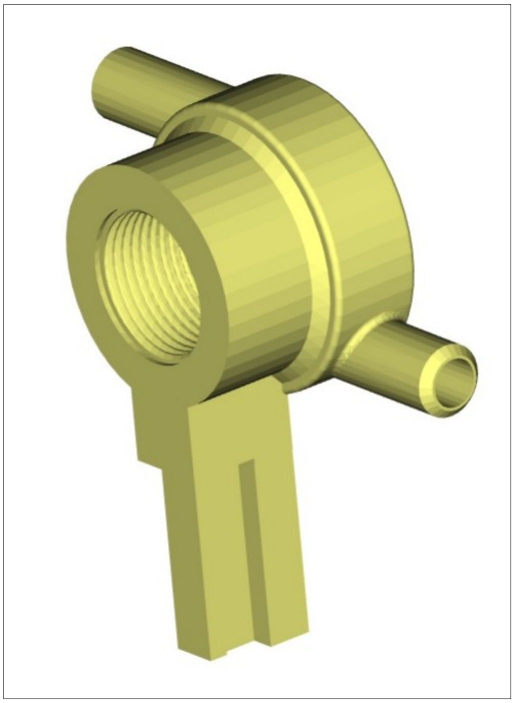
Power is provided by a 9-12 VDC barrel jack (connected to a compatible plug-in power supply).



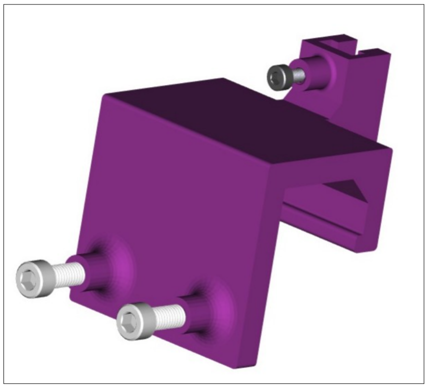

**DLUV265 COMPONENTS**

The 3/4”NPT male thread of the case threads into a corresponding female thread of the head. The type of head is unique to the fluid/gas to be sterilized.

Below we show one such head – developed to sterilize water. Water is pumped into this head ( dubbed the “Swirly” Head) through the inlet (the tangential tube at the top); swirls around the head interior space (exposure volume for the UV radiation from the UVLED); and exits through the outlet (the tangential tube at the bottom). Water exposure to UV is limited by the flow rate of the pump used. The slower the pump, the longer the UV exposure, and the more effective the sterilization.

The Swirly Head is mounted to a tank-edge bracket by sliding its mounting-channel into a mating clamp. The mating clamp attaches to the rim or side of the tank.

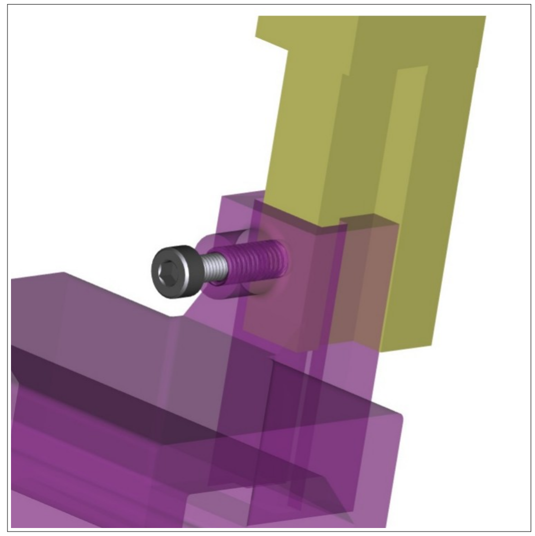


To the right we show an image of the mating clamp.

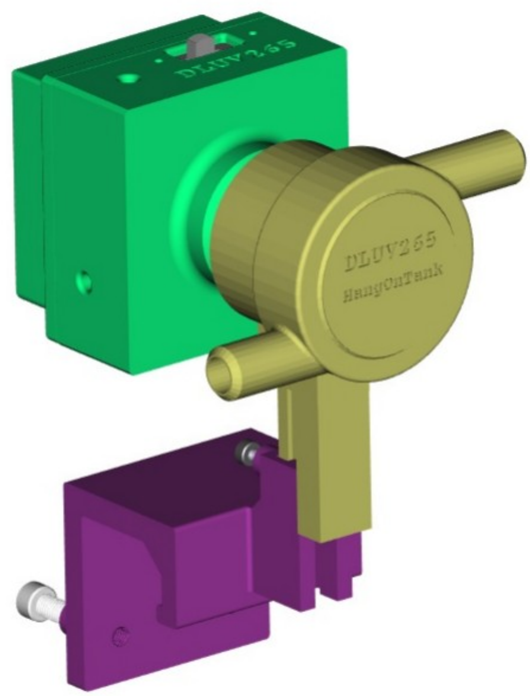
Two M5 screws (nylon or stainless) firmly clamp the device to the tank. A single M5 screw sets and holds the swirly head to the clamp.

The two pieces of the tank mounted subassembly slide into each other and lock into position via the clamp screws, as shown in the figure below and to the left:

The next figure (below right) is a detail illustrating the mating channels and set screw:



Now one can screw the UVLED module into this subassembly to complete the device, as shown to the right:

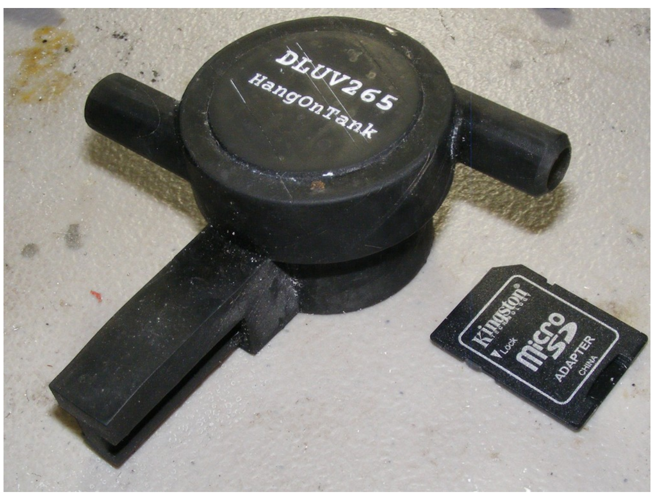


Details on UV Sterilization using DLUV265:

OK, the Dluv265 generates sterilizing UV in quantity from a compact package mountable on an aquarium tank.  Here we'll describe how we get water exposed to the UV.

The swirly chamber:

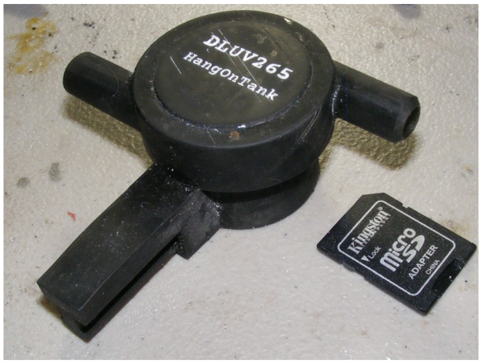
The swirly chamber is the region of the sterilizer where water is exposed to the UV.  There are two types:  tangent and right angle.  Both have a water inlet and outlet (both sized for 10mm ID tubing), but their geometry differs.  Type 1 swirly's inlet/outlet's are at tangent angles to the axis of the UVLED cone of emission (which coincides with the pipe thread axis).  Type 2 swirly's inlet/outlet form a right angle – intersecting at the axis.




Type 1 Swirly Chamber


Type 2 Swirly Chamber

Here are images of the front and back of a swirley chamber (sd card added for sense of scale):




BACK

FRONT

It doesn't matter which port is used for inlet or outlet.  The shape of the swirley promotes turbulent flow (through vorticity[1] and reversal of the port flow directions) and maximum dwell time of the water under irradiation.

Sterilization Analysis:

The UVLED emits 20 mW in a 60° cone – making the area of irradiance at a range of 10mm approximately 0.785 $cm^2$ .  This geometry, therefore, provides a UV irradiance (at the plane of the water swirl) of 20mW/0.785 $cm^2$.  This is the equivalent to 24,400 µW/$cm^2$.

The exposure to UV in the DLUV-265 is dependent (as in all aquarium UV sterilizers) on the dwell time of the water in the sterilizer's UV irradiance.  This is dependent upon two things:  (1) mass flow rate of the water going through the sterilizer, and (2) subsequent exposure time to the UV light.

These items are dependent upon the pump used for the sterilizer and the physical dimensions of the sterilizer.  Prototype DLUV-265 sterilizers have tube fittings for 10mm I.D. tubing (which provides a cross-sectional area of approximately of 0.785 $cm^2$).  The linear velocity of water through this tube is given by:

$$\text{Volumetric flow/cross-sectional area} = V_L$$

1 https://en.wikipedia.org/wiki/Vortex

… as an example, a pump with a flow rate of 600 L/hr (0.167 L/sec, or 167 $cm^3$/sec) would go through the 10mm tube at 213 cm/sec. The physical path of the water in the UV exposed area of the DLUV-265 is approximately 39.25 cm. The resulting exposure time is:

Path Length/VL = exposure time

or, for this example: (39.25cm)/(213 cm/sec) = 0.184 seconds.

If one multiplies this exposure time to the UV irradiance ( 24,400 µW/$cm^2$ ) we arrive at a zap dose of approximately 4,500 µW-sec/$cm^2$.

Lower pump flow rates increase the zap dose. A 300 L/hr pump, for instance, provides a dose of 9,000 µW-sec/$cm^2$ .

Below[2] are some typical zap dosages for some fishery pathogens. Note that this chart is for a UV wavelength of 254 nm[3] (254 is slightly better at sterilization than 265 nm):

MINIMUM REPORTED ULTRAVIOLET DOSAGE
FOR INACTIVATING FISH PATHOGENS
(micro-watt seconds per square centimeter @ 254 nm)
[Adapted from Chart 2 from Rodriguez and Gregg 1993]

| Pathogen | Dose (µW sec/$cm^2$) | Reference |
|---|---|---|
| Virus: | | |
| CCV | 20,000 | Yoshimizu, Takizawa, Kimura |
| CSV | 100,000 | Yoshimizu, Takizawa, Kimura |
| IHNV (CHAB) | 20,000 | Yoshimizu, Takizawa, Kimura |
| IHNV (RTTO) | 30,000 | Yoshimizu, Takizawa, Kimura |
| IPNV (Buhl) | 150,000 | Yoshimizu, Takizawa, Kimura |
| OMV (00-7812) | 20,000 | Yoshimizu, Takizawa, Kimura |
| Bacteria: | | |
| *Aeromonas salmonicida* | 3,620 | Nomandeau |
| *Bacilus subtilus* spores | 22,000 | Nagy |
| Fungi: | | |
| *Saprolegnia* hyphae | 10,000 | Normandeau |
| *Saprolegnia* zoospores | 39,600 | Normandeau |
| Parasite: | | |
| *Ceratomyxa shasta* | 30,000 | Bedell |
| *Costia necatrix* | 318,000 | Vlasenko |
| *Ichthyophthirius* tomites | 100,000 | Hoffman |
| *Myxosoma cerebralis* | 35,000 | Hoffman |
| *Sarcina lutea* | 26,400 | Nagy |
| *Trichodina* sp. | 35,000 | Hoffman |
| *Trichodina nigra* | 159,000 | Vlasenko |

Where:
CCV = Channel catfish virus; CSV = Chum salmon virus; IHNV = infectious hematopoietic necrosis virus (CHAB, RTTO and Buhl are strain types); OMV = *Oncorhynchus masou* virus; and IPNV = Infectious pancreatic necrosis virus.

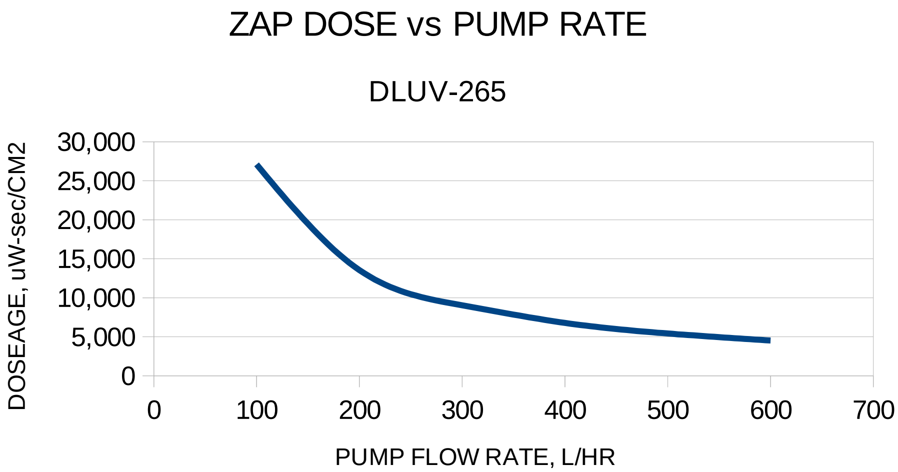
2 Roy P.E. Yanong, "Fish Health Management Considerations in Recirculating Aquaculture Systems – Part 2: Pathogens", Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Original publication date December 2003. Visit the EDIS Web site at http://edis.ifas.ufl.edu.

3 https://www.lenntech.com/library/uv/will1.htm

… and here is a chart from American Air and Water showing dosages to kill commonly found pathogens

| Bacteria | 90% (1 log reductio | 99% (2 log reductio |
|---|---|---|
| Bacillus anthracis - Anthrax | 4520 | 8700 |
| Bacillus anthracis spores - Anthrax spores | 24320 | 46200 |
| Bacillus magaterium sp. (spores) | 2730 | 5200 |
| Bacillus magaterium sp. (veg.) | 1300 | 2500 |
| Bacillus paratyphusus | 3200 | 6100 |
| Bacillus subtilis spores | 11600 | 22000 |
| Bacillus subtilis | 5800 | 11000 |
| Clostridium tetani | 13000 | 22000 |
| Corynebacterium diphtheriae | 3370 | 6510 |
| Ebertelia typhosa | 2140 | 4100 |
| Escherichia coli | 3000 | 6600 |
| Leptospiracanicola - infectious Jaundice | 3150 | 6000 |
| Micrococcus candidus | 6050 | 12300 |
| Micrococcus sphaeroides | 1000 | 15400 |
| Mycobacterium tuberculosis | 6200 | 10000 |
| Neisseria catarrhalis | 4400 | 8500 |
| Phytomonas tumefaciens | 4400 | 8000 |
| Proteus vulgaris | 3000 | 6600 |
| Pseudomonas aeruginosa | 5500 | 10500 |
| Pseudomonas fluorescens | 3500 | 6600 |
| Salmonella enteritidis | 4000 | 7600 |
| Salmonela paratyphi - Enteric fever | 3200 | 6100 |
| Salmonella typhosa - Typhoid fever | 2150 | 4100 |
| Salmonella typhimurium | 8000 | 15200 |
| Sarcina lutea | 19700 | 26400 |
| Serratia marcescens | 2420 | 6160 |
| Shigella dyseteriae - Dysentery | 2200 | 4200 |
| Shigella flexneri - Dysentery | 1700 | 3400 |
| Shigella paradysenteriae | 1680 | 3400 |
| Spirillum rubrum | 4400 | 6160 |
| Staphylococcus albus | 1840 | 5720 |
| Staphylococcus aureus | 2600 | 6600 |
| Staphylococcus hemolyticus | 2160 | 5500 |
| Staphylococcus lactis | 6150 | 8800 |
| Streptococcus viridans | 2000 | 3800 |
| Vibrio comma - Cholera | 3375 | 6500 |
| Molds | 90% | 99% |
| Aspergillius flavus | 60000 | 99000 |
| Aspergillius glaucus | 44000 | 88000 |
| Aspergillius niger | 132000 | 330000 |
| Mucor racemosus A | 17000 | 35200 |
| Mucor racemosus B | 17000 | 35200 |
| Oospora lactis | 5000 | 11000 |
| Penicillium expansum | 13000 | 22000 |
| Penicillium roqueforti | 13000 | 26400 |
| Penicillium digitatum | 44000 | 88000 |
| Rhisopus nigricans | 111000 | 220000 |
| Protozoa | 90% | 99% |
| Chlorella Vulgaris | 13000 | 22000 |
| Nematode Eggs | 45000 | 92000 |
| Paramecium | 11000 | 20000 |
| Virus | 90% | 99% |
| Bacteriopfage - E. Coli | 2600 | 6600 |
| Infectious Hepatitis | 5800 | 8000 |
| Influenza | 3400 | 6600 |
| Poliovirus - Poliomyelitis | 3150 | 6600 |
| Tobacco mosaic | 240000 | 440000 |
| Yeast | 90% | 99% |
| Brewers yeast | 3300 | 6600 |
| Common yeast cake | 6000 | 13200 |
| Saccharomyces carevisiae | 6000 | 13200 |
| Saccharomyces ellipsoideus | 6000 | 13200 |
| Saccharomyces spores | 8000 | 17600 |

Here we present a chart of UV dosage versus pump rate for the DLUV-265 as described:




The DLUV-265 has a means of cooling (a fan) independent of water flow through the device. Therefore, there is no minimum flow rate required for dependable operation (as long as there is *any* water flow at all). Cheaper, lower-flow pumps increase its disinfection performance by increasing the exposure time.

Note, however, that supply tubes smaller than 10mm diameter increase linear velocity (shortening exposure times) and head loss (shortening pump life).

LONG TERM OPERATION IN A MARINE TANK:

Mounting:

We have had our prototype running for the last 2 years on a 200L/55 gallon marine tank. The tank has a deep sand bed (with about a 25 mm anoxic water layer between bottom and sand layer); maybe 15 Kg of live rock, snails, and a cheap zoanthid coral. There is a heater (tank is maintained at 34ºC/75ºF). Originally there was a protein skimmer, but that broke 18 months ago. The tank is lit with three 75W LED bulbs (6300K) each with reflector. Lights are on a timer providing a 12hr/12hr lighting cycle.

**The only filtration after the first year was the DLUV265 UV sterilizer**. The ***only*** maintenance has been topping with fresh water to make up for evaporation.

Note the green and reddish-brown patch on the inside of the glass at the bottom-left of the image on the right. That is where the water exiting from the DLUV265 impinges on the glass (the water flow rate is around 550-600 liters/hr).

This "patch" is shown in the following image:

One can see the 15 mm exit tube (10mm ID) from the sterilizer.  Just below it is a snail on the inside of the glass.  The white blurs on the left are bubbles from the flow (breaking the surface – picture taken as I was making up evaporation in the tank.  Notice the obviously-green algae forming a crescent above the impingement area, while reddish-brown algae (or, maybe, tholins) form the majority of the impingement ellipse.

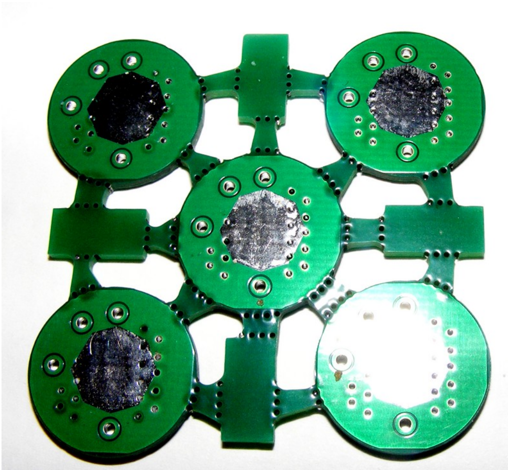
I'd like help from viewers in determining just what's happening here.   … any spectroscopists out there? …. My speculation is that the flow conditions are such that the green crescent is the result of higher oxygen content/mixed flow, while the red/brown area gets lighter carbohydrates – resulting in either tholins, or a different algae species.

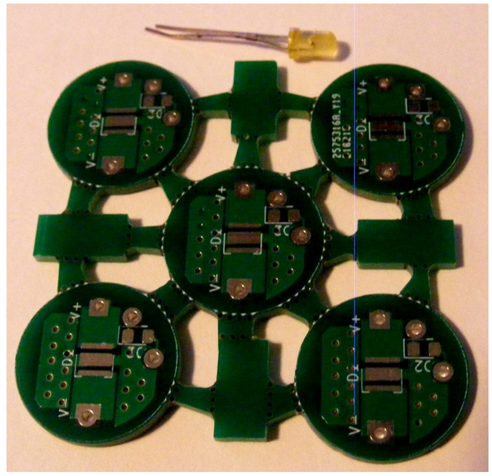
The coral really seems to like the setup – having increased significantly in size from the original frag (with 3 polyps … it was only $20 … a mundane brown with no UV illumination … a mundane orange/brown without near UV illumination):

APPENDIX:  CONSTRUCTION DETAILS

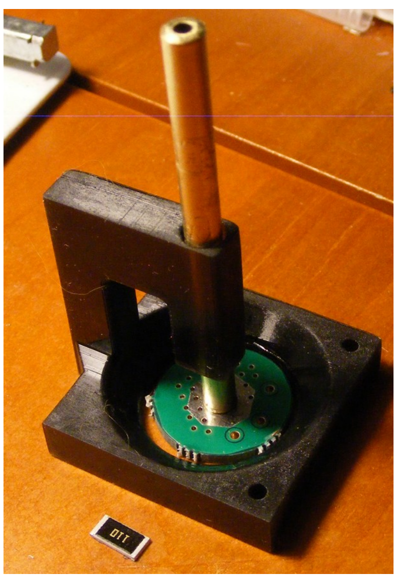
Construction:

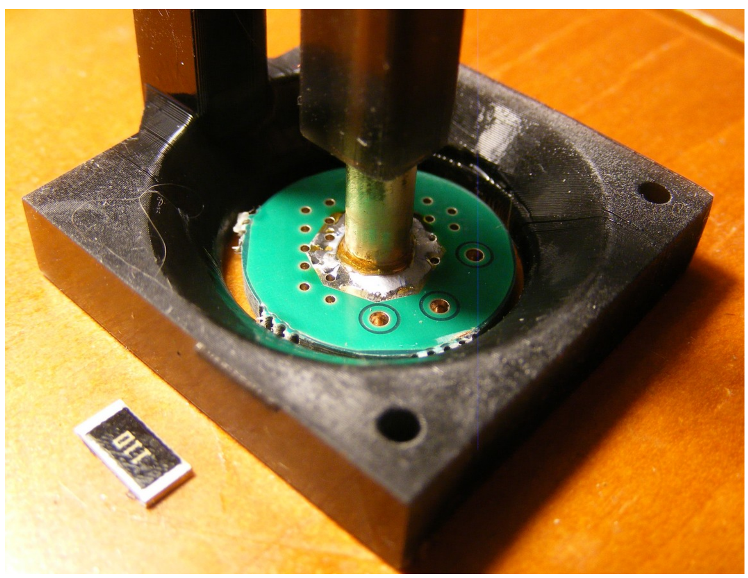
palatalized UVLED PCB (left: heat sink side)       (right: LED side – 3mm LED for comparison)





UVLED PCB, brass tube, and soldering jig (left); close up of heat pipe solder joint on UVLED PCB (right)





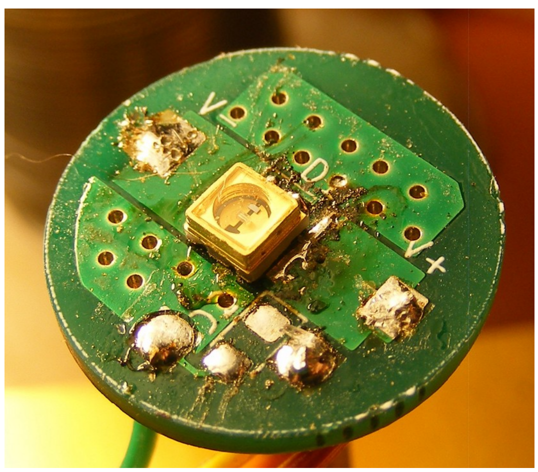
LED Chips for this board:

For trial purposes, I found some UVLEDs on Banggood (of dubious origins). Advertised at 275 nm, but, they were the right size and footprint, and, hey, they were cheap – $6.60 for 5!

I really need to build a UV monochrometer to verify LED wavelengths, but that's another project … so many things to do….

Anyway, when these came, there was no markings to distinguish anode from cathode. So, I attached a 5V wall brick to the board (the Banggood page had absolutely dismal info on the chips, and the received items bore little resemblance to the pictures on their website), then moved the chip around with tweezers until the LED glowed violet dimly. Not recommended for the eyes, but the turn on V is listed at 6V, so the output was barely visible with 5V applied.

Then, for reference I took this image with the chip in turn-on orientation on this board:

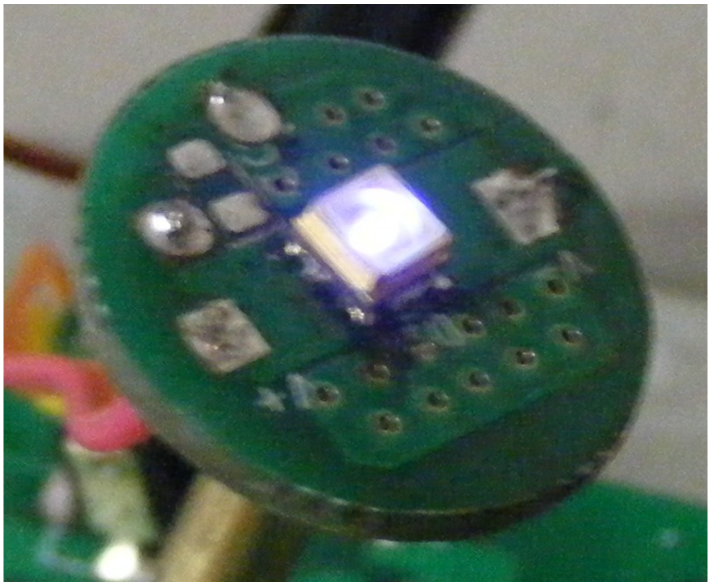



Yes, I know, a dirty, yucky assembly – I cleaned it up after the image was taken.

I assume the dark rectangle between anode and cathode is the zener in the LED package. In the correct orientation, the zener is down, anode to right, cathode to left (the enemy's gate is always down, Ender…).

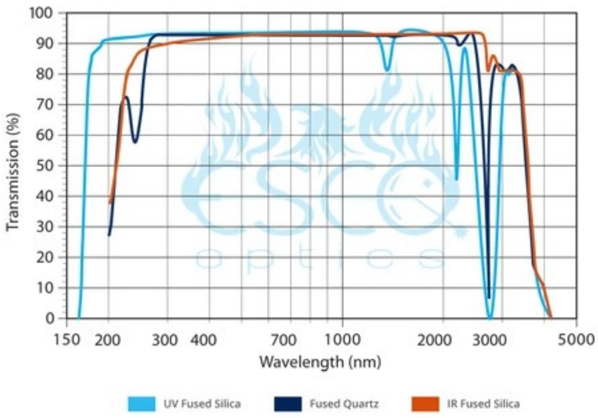
These are rated (by Banggood, anyway) at 2.5 to 5 mW output at 275nm.

Here it is operating:



FUSED SILICA WINDOW & O-RINGS:

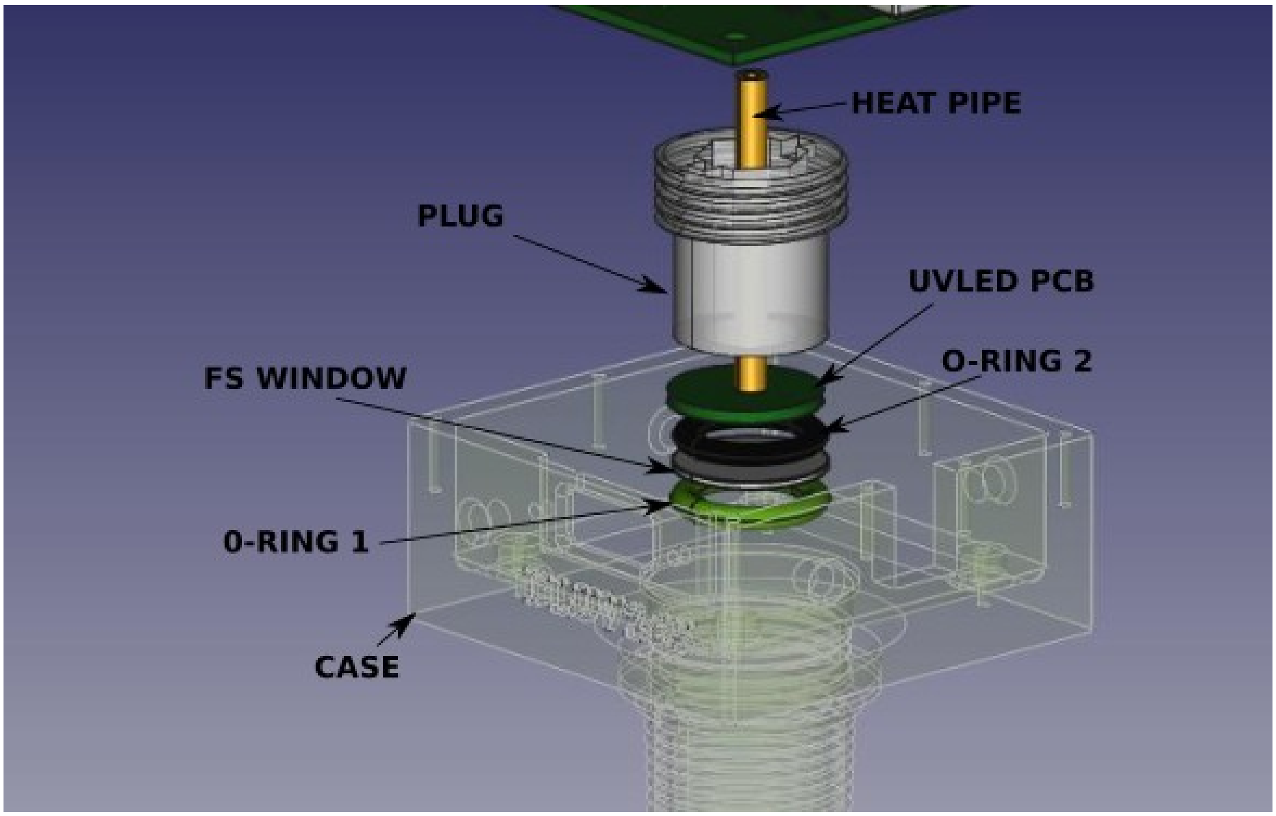
A UV-grade fused silica window provides means for the UVLED output to get into the medium to be irradiated.  The transmissions spectrum of UVFS is:

The window is from Esco Optics … as shown here. Dimensions are: 19.05 mm Diameter by 1.0 mm thick. … at 265 nm its transmission is over 90%.

Two Viton O-rings (RING1 & RING2) seal the window and the DLUV265 case from the irradiated environment. Viton has much better resistance to UV than does Buna-N rubber.

The case plug, when screwed into the case, buts pressure on the o-rings/window stack. We’ve pressure-tested this seal to 60 psi (differential) with no leakage.



PRESSURE TEST:

We rigged a pressure test apparatus out of some PVC pipe, a regulator, and an air compressor.

In the image, red pipe contains water, while white pipe contains air. The DLUV265 is screwed into the bottom of the water column. Threads were sealed using teflon tape.

The air compressor supplied 90 psi air to the regulator – which allowed us to put 10-90 psi (70-620 kPa) on the water column at will.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We stopped after holding an hour at 60 psi (400 kPa) with no leakage apparent.