Design Description Document

Exhibit Design

Rochester Museum and Science Center

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Document Number 00006

Revisions	Level	Date
	H	05-04-2017

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Revision History

Rev	Description	Date
A	Initial DDD	01/25/2017
B	Added Sig Fit, minor spec updates	02/07/2017
C	CAD, Empirical Results, Budget update	02/24/2017
D	Added proof of concept pictures	02/28/2017
E	Updated Schedule & Budget	04/05/2017
F	Minor corrections, added construction	04/26/2017
G	Revisions in response to Customer comments	04/30/2017
H	Final Modifications	05/04/2017

Table of Contents

Vision

Our goal is to create an interactive exhibit that engages kids of all ages and can teach fundamentals about some optical phenomenon. Accompanying the exhibit will be a plaque elaborating on the phenomenon demonstrated. The plaque will explain the physical phenomenon at the level of technical sophistication which a child can understand, or at least which a non-technically educated adult can understand and engage with.

A plaque at the RMSC, or "copy," is formatted in 3 tiers, each with smaller font and more technical depth than the last. The first tier explains how to use the exhibit and what is going on at the most fundamental level. The second tier is slightly more sophisticated, but very short. The third tier reaches the science reading level of an 8^{th} grader which is the recognized science reading level of the general public. All 3 levels combined add to about 100 words.

Project Scope

- Physically testing planned designs with museum visitors for usability and durability.
- Designing and building one (1) final-stage exhibit prototype.
- Writing a concise explanation of the optical phenomenon for the layman visitor to understand.
- Detailed list of all materials used and vendors to get them from.
- Instruction manual for construction.

We are not responsible for:

- Installing the exhibit into the floor of the museum.
- Making it impossible for someone who is trying to hurt themselves with the exhibit to do so.

Construction Restrictions & Safety Constraints

While on display, our deliverable product is constantly consuming power. Subsequent modifications for integration into the museum floor may change this, but that is outside the scope of this project.

The light source is powered by a standard wall outlet. This was not a hard constraint on our design, but a desired quality.

The panel is functional when stepped on with unclean shoes throughout a typical day of use. The top surface can be easily cleaned with standard cleaning tools.

This product does not have the ability to harm an unaccompanied child through reasonable use or misuse.

This product cannot be harmed without the intentional malicious action of an adult.

Background

Certain materials exhibit birefringence when put under mechanical stress. This means that depending on the polarization of incoming light, the material will cause the light to slow down at different rates. As a consequence, for any incoming polarized light, the polarization is warped in a way representative of the spatial pattern of stress on the material. If you place the material between two polarizers with an external light source, the first polarizer will assert linear polarization on the light, the material will potentially modify the asserted polarization depending on the stress on the location of the object, and the second polarizer will block the component of light polarized in the direction of the first polarizer. If the material does not modify the polarization in a region do to a lack of internal stress, the light will be blocked and the region will appear dark. Thus, the light which shines through the system can be viewed as a map of the stress on a material.

<u>Qualitative Proof of Concept</u>
We tested the viability of stress-induced birefringence of plexiglass under body weight to produce noticeable contrast by placing a piece of plexiglass between two polarizers. The plate was supported on two parallel edges and illuminated from below by a fluorescent bulb. The images were taken when the plate was either free standing or under vertical stress from a foot, to demonstrate contrast, and with either fully crossed (angled at 90 degrees) or partially crossed (angled at 60 degrees) polarizers. Stress was introduced by stepping on the plate with partial body weight. The results, as shown in Figure 1, show that the effect is noticeable and viable as a museum exhibit. We chose the fully crossed orientation because of its more dramatic contrast between stressed and unstressed.

Unstressed | Stressed

Fully Crossed Polarizers

Partially Crossed Polarizers

Figure 1
The above table shows experimental images of plexiglass between two polarizers.

Design

Our first priority was to develop an exhibit which demonstrates stress-induced birefringence in an interactive and exciting way. Specifically, we had to develop a stress plate which, when stepped on, would exhibit a non-uniform intensity distribution as a consequence of birefringence. This was achieved (using the configuration shown in figures 2 through 5) by placing a uniform light source under a sheet, which is in turn between two crossed polarizers. The sheet had to be constructed of a material that exhibits significant stress-induced birefringence under the weight of a small child. Significant birefringence is defined here to mean “sufficient to produce an effect you don’t have to be looking for to see.” We chose to use a polycarbonate sheet as our active medium. Additionally, the structure had to function and not break under the weight of an adult. As such, our design supports the weight of the user with a thick sheet of tempered glass. The light source must be reasonably uniform and bright enough so that patterns induced by the material are clearly visible. The plate would ideally be of uniform brightness or darkness when no pressure is applied and only display complex patterns when stepped on.

For prototyping purposes, the entire optical apparatus we will deliver is about 2 ft. square in area and 1 ft. tall. Upon full integration into the museum, dimensions may change, but it is outside the scope of this project.

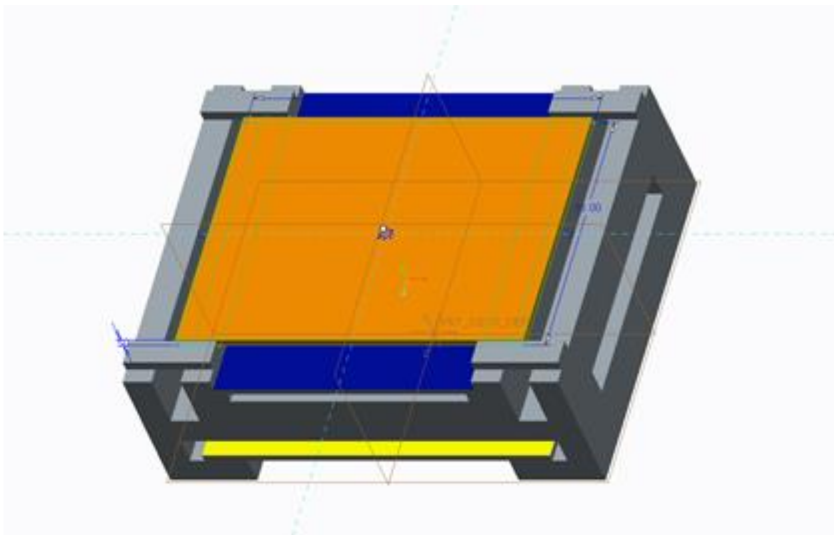

Figure 2

This is our build for the interior of the design. It supports the various pieces of glass with 2x4s such that there is nothing blocking the light from being transmitted and there is no weight being placed on the light source. The light source is suspended as to allow room for the electronics (see Figure 6). The grey material is wood; the yellow is the light source; the blue is the tempered glass and the first polarizer; the orange is the upper layer. A detailed description of how we put this together will be delivered as part of the final project.

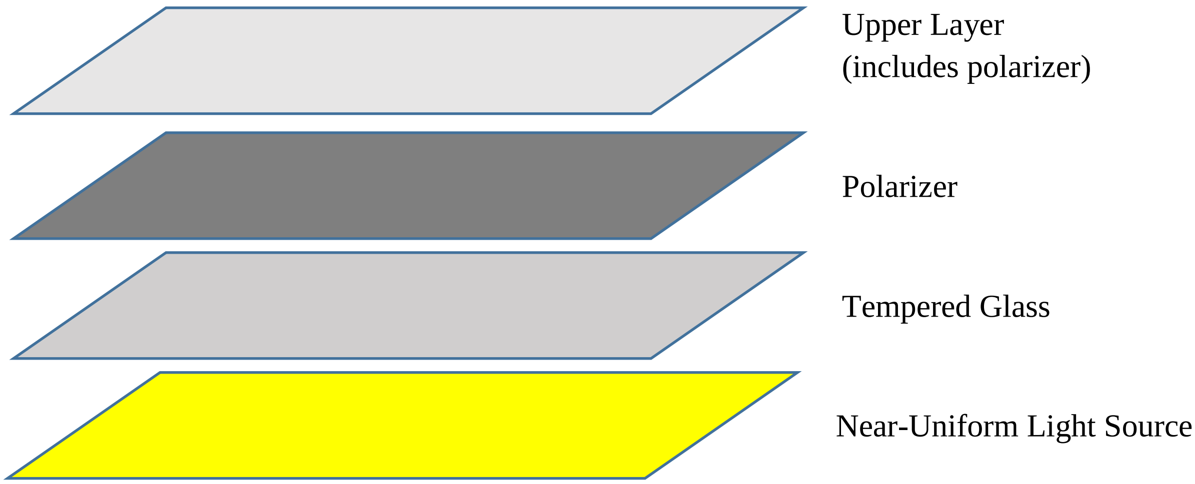

Figure 3

This is a representation of our final product unpackaged. At the base there is a light source. The light emitted will travel through a tempered glass sheet which serves to stop the upper layer from bending too far. It will then pass through one polarizing film, becoming polarized. Finally, it will pass through the upper layer, which has a series of sub-sheets outlined in Figure 5.

Frame

After receiving wood provided by the museum and ordering the polarizer, glass, and light source online, we constructed the exhibit using the campus fabrication studio. Slight modifications to the original design were necessary to accommodate the power supply on the underside of the light source.

Figure 4

The intermediate structure of our framework before the addition of polarizers and plywood covering.

Upper Layer

The optically active medium, which displays the stress induced birefringence, is split into two sheets, one on top of the other. Between these sheets, we placed objects, such as a pen, to create a more complex and visible stress pattern. For the birefringent medium, we found the most visible response for polycarbonate sheets. Above the upper active sheet, the second polarizer is placed, oriented orthogonal to the lower polarizer on the tempered glass. Above this is a protective sheet. We used a thin sheet (0.25 inch) of acrylic, but the material need only be easy to clean, durable, and transmissive.

In place of polycarbonate sheets, we tried acrylic plexiglass, which proved to have a negligible effect. Traditional high-end optical glasses were avoided as they are designed to have little birefringence (See Appendix A).

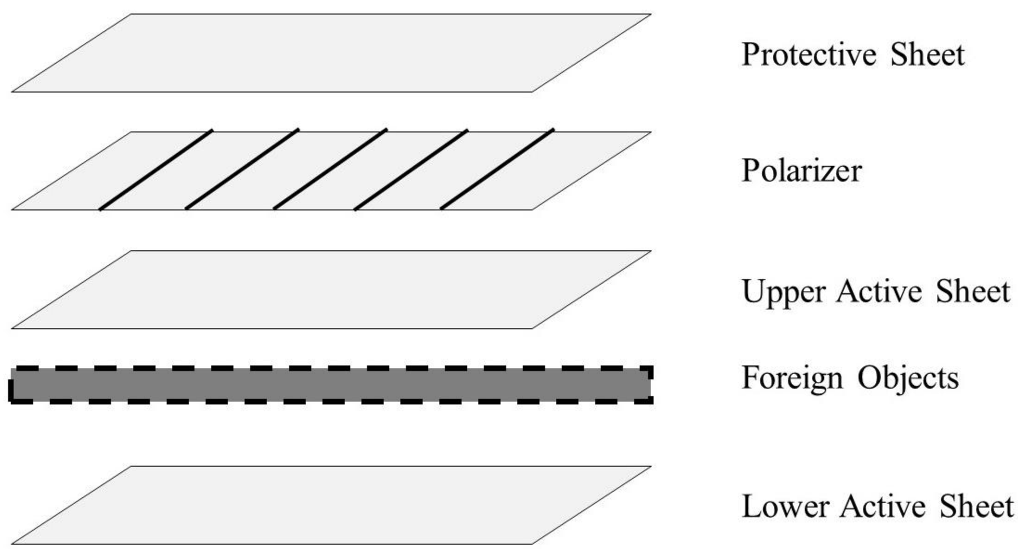

Figure 5

The upper layer of the design, which responds optically to stress, has multiple layers to maximize the visibility of the effect and provide durability under standard museum conditions.

Tempered Glass

This level of our structure serves three purposes. The first and most important purpose is that it prevents the structure from breaking under both proper use and misuse. The manufacture's specification for this half inch thick glass states that it can hold over 1000 lbs. As a second purpose it serves as a full stop for the upper layer, which would sag under an adult weight to below this location. Sagging too low could harm the exhibit, most notably the light source which is not meant to take weight. Lastly it is used as a place to hold one of the polarizers.

Light Source

For the light source, we used a 2’ by 2’ dimmable LED panel, shown in Figure 6. A cavity exists at the bottom of the exhibit enclosure which holds the panel level with the ground while leaving room for the power supply on the underside of the panel. The box accepts 120V AC current, so we connected the power supply to a standard outlet by soldering the appropriate connections on the underside to a standard NEMA grounded cord and plug.

Figure 6

2’x2’ dimmable LED panel from Green Light Depot. ~0.5” thick. It is takes the output of a normal plug to operate. A link to this product can be found in the appendix.

Augmentations to Initial Design

Foreign Objects

Although we see some stress-induced birefringence as we put weight on the plates, the change of pattern corresponding to different amounts and directions of stress is not as visible as we expected, as can be seen in the first row of Figure 9. As a solution, we inserted foreign objects, like pens, pennies, and small slices of silicone, between the two active stress-plates. When we apply stress on the plate, the foreign objects are also pressed against the plate, preventing it from sagging to its minimal-stress location. This non-uniform topology allows for the user’s weight to apply localized areas of high stress to the plate in turn making the effect easily visible. We found that inserting a pen produces the desired dramatic effect and appreciate that it is something all museum goers can recognize.

Silicone

We explored silicone as a modification to the birefringent plate between the polarizers. The results are shown in Figure 7. We squeezed transparent silicone sealant onto a plexiglass plate, placed a second plexiglass plate on the free side of the silicone, and placed polarizers on either side of the resulting compound plate. The plate was supported on two parallel edges and illuminated from below by a fluorescent bulb. The images were taken with the plate either free standing or under vertical stress from a foot, to demonstrate contrast. Stress was placed by stepping on the plate with partial body weight. We noted that due to some form of innate birefringence or polarization scattering within the silicone, the plate was not fully dark when not under pressure. As a result, the color change under pressure was much more noticeable than the intensity contrast.

Unstressed Stressed

Figure 7

The experimental images of translucent silicone sealant placed between two pieces of plexiglass and two polarizers.

Additional experimentation with the silicon was done by spreading a flat layer of standard silicone sealant over an acrylic sheet. The resulting sheet is shown in Figure 8. We then used this sheet as the lower optically active layer of the plate that the visitor stands on. The results are shown in Figure 9. In general, the pattern was less visible due to lower contrast, while the undisturbed state of the plate was brighter. The silicon gave the unstressed region a green-blue hue, while stressed regions displayed warmer colors.

Figure 8
The silicone covered sheet used when testing different configurations of the plate. Three tubes of silicone were applied with a caulk gun before being spread with a paint stick to produce an even surface.

Summary of Object and Silicone Augmentations

The birefringent effect is most noticeable to all viewers with the pen between the active sheets and without the silicone, as can be seen in the second row of Figure 9. As such, this configuration is our choice of final design.

	Primary Perspective	Primary Perspective Stressed	Bystander Perspective	Bystander Perspective Stressed
Standard Sheet				
Standard Sheet with Pen				
Silicone Sheet				
Silicone Sheet with Pen				

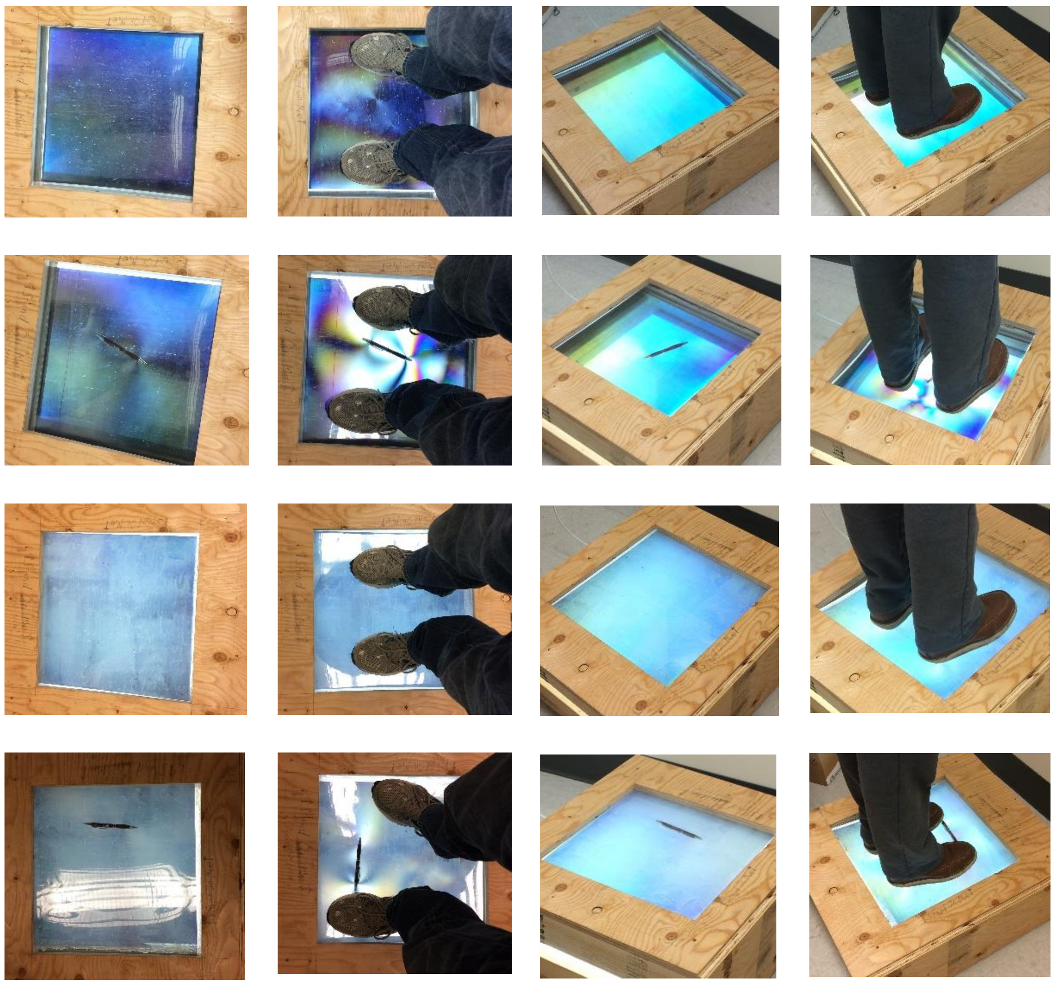

Figure 9

A comparison table showing the result of a lower plate with silicon plate compared with a standard plexiglass plate. The two are shown with and without an object between the optically active plates, with and without stress, and from the perspective of the primary user compared with the perspective of bystanders.

<u>3D Glasses</u>

We also experimented with using 3D glasses to add another dimension to our exhibit. To use the exhibit in this manner, we remove the top polarizer from the box and supply the user with 3D glasses or linear polarizers. When visitors are using the polarizers, visitors can see the patterns the exhibit creates, but when they are looking at the exhibit directly, i.e. without looking through the polarizer, they do not see the pattern. The pattern will also change based on how the polarizer is being held. If the visitor spins the polarizer, they see the pattern shift.

Figure 10

The panel of light with the top polarizer removed. The 3D glasses are held in place to demonstrate that the effect is visible only to people who are using a polarizer.

Budget

			Estimated Cost	**Actual Cost**
Product	Quantity	Size	Price/Unit	Price/Unit
Polarizers	1	6’ x 17”	$229.50	$229.50
LED Panel	1	2’ x 2’	$41.99	$41.99
Tempered Glass	1	30”x18”x1/2”	$203.96	$203.96
Plexiglass (Polycarbonate, 1/4")	1	18” x 24”	-	$21.38
Plexiglass (Acrylic, 1/4")	1	18” x 24”	$20	$20
Plexiglass (Acrylic, 1/2")	1	18” x 24”	$12	$12
Silicone	3	10.1 oz.	-	$5
Plywood*	4	2’ x 4’ x 1/2”	$11.45	$0*
Whitewood*	3	96” x 2” x 4”	$2.82	$0*
Total			$561.71	**$543.83**

* Supplied by the RMSC

Appendix A: Computer Modeling of Design

To add technical depth to our project and more easily determine the sizes and materials needed, we modeled our intended design. To do this, we first used a finite element model software, Patran, followed by analysis using SigFit. These tools are capable of modeling the stress induced by any weight we instruct it to; the change in index of refraction due to this stress; and the portion of light that will pass through both polarizers.

Initial testing indicated we would face difficulty if we used glasses often used in optical instruments such as BK7. Because BK7 is designed to be used in optical systems, it is designed to have lower stress-induced birefringence than plexiglass. Plexiglass on the other hand is made without controlling for birefringence and as such, we have successfully used it to produce an easily noticeable effect.

We also modeled a bonded piece of BK7 with SF57 in an effort to mitigate reversal of the birefringence, resulting in a factor of 1000 improvement on our system. However, due to cost benefits of using plexiglass and that our proof of concept and further work using plexiglass has worked, we did not look further into this.

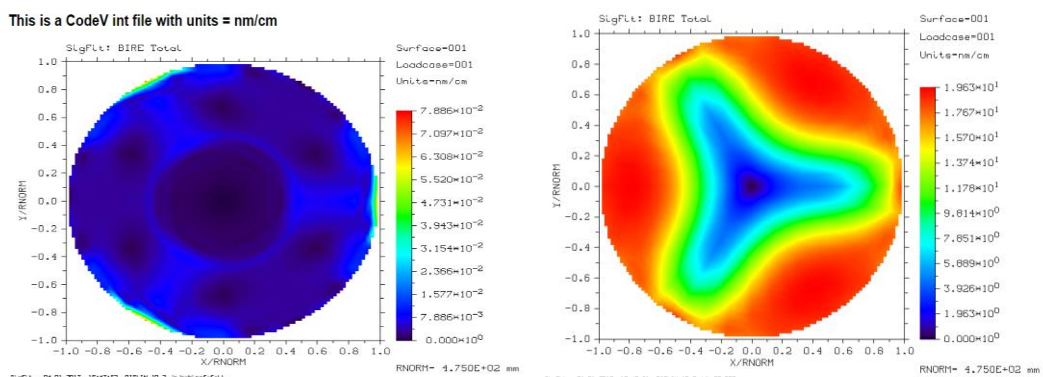

Figure 11

The results of our computer simulation. In each of these figures, what is being measured is the amount of birefringence as exhibited in a circular plate supported by 3 points. The units of these measurements is nm of birefringence per cm of plate thickness given a 12 mm thick disk. On the left is the amount of birefringence in a purely BK7 plate. On the right is the bonded BK7 and SF57 plate. Note that in both cases, the birefringence is much smaller than a wave of light (~500 nm), but the fused plate had almost 250 times more of an effect than the BK7 plate.

We did not model with plexiglass because of the lack of information regarding its birefringent properties.

Because this modeling was used specifically for proof of concept, the final design (the rectangle supported along opposite edges) was not modeled.

After doing the finite element modeling above, we modeled how various light sources work with the polarizers and stress plates. This was necessary so that we do not purchase a light source that will not work with our product.

Appendix B: Initial Light Source Design

Before settling on the current light source, we designed a fluorescent source using a scattering sheet, reflective sides, and parabolic reflectors below the linear fluorescent bulbs, for sufficiently uniform light distribution. At a later phase in the design process, we discovered an LED source with superior performance, lesser size, and limited increased cost which we transitioned towards as our primary illumination (see Figure 6). The dimensions of our final design of the fluorescent source before changing approaches are shown in Figure 12. We modeled this source in LightTools and found light distribution simulations shown in Figure 13.

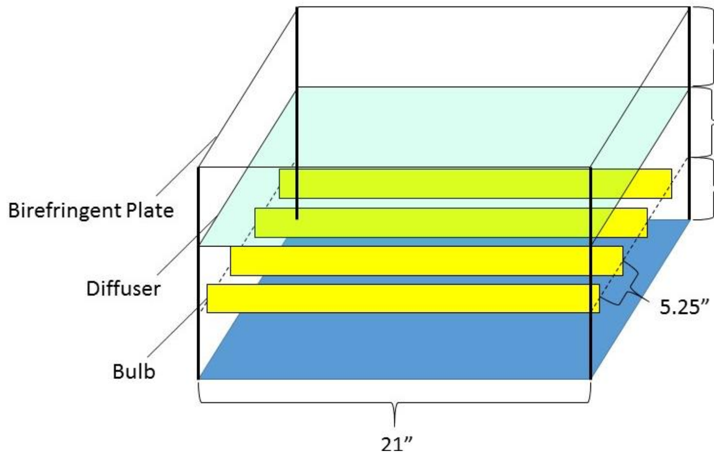

Figure 12
The above diagram gives the dimensions used for the design and simulation of the uniform fluorescent light source.

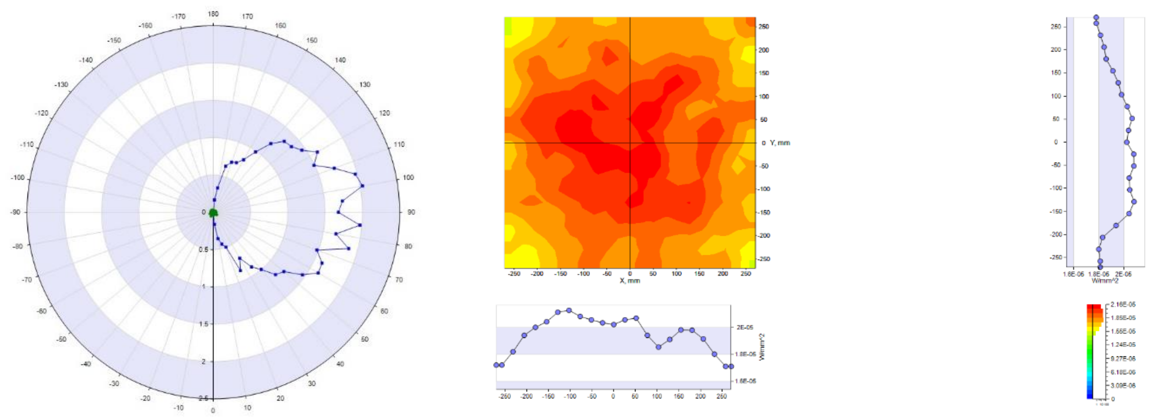

Figure 13
The intensity slice (left) graph shows the angular distribution of light leave the source. The luminescence plot (right) gives the irradiance distribution of light at the location of the birefringent plate.

Appendix C: Links to Product Pieces

Light Source (LED Panel):
https://greenlightdepot.com/products/2-x-2-40w-led-panel-light-ul-dlc-dimmable-premium-dlc?variant=33642680964
Company: GreenTek Energy Systems
Product: 2'x2' 40W LED Panel Light (UL+DLC)
Size: 24in x 24in x .5in
Lifespan: 50,000 hour

Polarizers:
http://polarization.com/polarshop/product_info.php?cPath=21&products_id=30
Company: Polarization.com
Product: PF030
Size: Width – 17'', Thickness – 0.03''

Tempered Glass:
https://www.dullesglassandmirror.com/tempered-glass.asp
Company: Dulles Glass & Mirror
Product: Rectangle Tempered Glass
Size: 18'' x 24'' x ½''