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KURIOS-XL1/M - June 26, 2024

Item # KURIOS-XL1/M was discontinued on June 26, 2024. For informational purposes, this is a copy of the website content at that time and is valid only for the stated product.

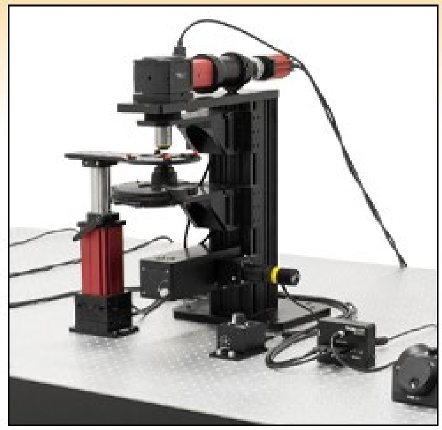
LIQUID CRYSTAL TUNABLE BANDPASS FILTERS

- **Tunable Bandpass Filters for Visible Ranges**
- **Ideal for Multispectral and Hyperspectral Imaging**

Kurios® Controller
Included with Each Model

KURIOS-WL1
Fixed Bandwidth,
Ø35 mm CA

KURIOS-XL1/M
Fixed Narrow Bandwidth. Ø35 mm CA



Application Idea
This DIY hyperspectral imaging system includes the previous-generation KURIOS-VB1 tunable filter and Cerna® microscopy platform (see the *Application Ideas* tab for details).

OVERVIEW

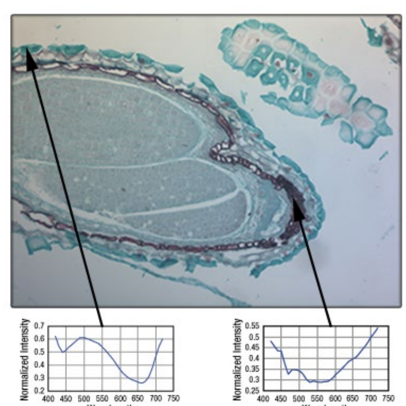
Features

Kurios®

- Tunable Optical Filters with Fully Programmable Sequences
- Included Controller Provides Local Control via the Front Panel and Remote Control via BNC and USB
- Software and SDK Included (See *Software* Tab for Details)
- Temperature-Controlled Head for Long-Term Stability
- Ø20 mm or Ø35 mm Clear Aperture
- Several Mounting Options
    - Three 8-32 (M4) Tapped Holes for Post Mounting
    - Internal SM1 (1.035"-40) or SM2 (2.035"-40) Threads on Both Sides
    - 4-40 Tapped Holes on Both Sides for 30 mm or 60 mm Cage Systems

Kurios® Liquid Crystal Tunable Bandpass Filters provide a continuously tunable center wavelength (CWL) in the 420 - 730 nm or 430 - 730 nm range. Currently available Kurios models have a fixed bandwidth for any given center wavelength.

With an included controller that provides Trigger In, Trigger Out, and Analog In functionality, these tunable optical bandpass filters are ideal for applications that perform multispectral or hyperspectral imaging, as demonstrated in the image to the right. For example, they can be used in conjunction with a monochrome scientific CMOS camera to obtain images with a much higher accuracy for color representation than using a color CMOS camera with a Bayer mosaic. This technique produces true spectral imaging and can thus show spectral features that would otherwise be impossible to detect. Thorlabs' Kurios tunable filters and CMOS cameras are also compatible with our modular Cerna® microscopy platform that supports customizable microscopy solutions.



Click to Enlarge
A hyperspectral image of a root cell taken using the previous-generation
KURIOS-WB1. Two sample spectrums at the regions indicated are also shown. More details on this measurement are available in the *Application Ideas* tab.

Click to Enlarge
The front of the filter head contains internal SM1 or SM2 threads, four 4-40 taps for cage systems, and an engraving for the transmission axis.

Click to Enlarge
The back of the filter head contains the same mounting features as the front. The output polarization is rotated by 90° with respect to the input polarization.

Similar in construction to Lyot and Solc filters, Kurios filters consist primarily of liquid crystal cells that are sandwiched between polarizing elements. Their integrated design enables quick and vibrationless tuning. For added operational stability, a closed-loop temperature control servo is used to maintain the filter head's operating temperature. An LED on the filter head displays red when the head is warming up and green when it is ready to be used.

Wavelength Control with Included Controller
The controller's front panel provides manual control of the center wavelength and enables programmable switching sequences, as described in the *Control* tab. In addition, the controller offers three BNC connectors (Trigger In, Trigger Out, and Analog In) that allow Kurios to be synchronized with a wide range of other devices, such as scientific cameras and motion control stages. Each Kurios is factory calibrated and ships with a switching time map so that the user may optimize their system for the specific filter.

Click to Enlarge
[APPLIST]
[APPLIST]
The SLS401 Xenon Arc Light Source coupled using a liquid light guide to our KURIOS-WL1/M Tunable Filter. The Ø35 mm clear aperture within the SM2-threaded housing is visible.

The Trigger In connector allows Kurios to be controlled by another device via a TTL signal. It can be used, for instance, to synchronize Kurios with a scientific camera, such that every time the camera captures an image, the filter is immediately advanced to the next wavelength in the sequence. Kurios triggers on the falling edge of the 5 V TTL signal.

The Trigger Out connector outputs a TTL signal that has the same duration as the calibrated switching time of the filter. This signal can be used, for example, to monitor the switching time and to cause events to coincide with or follow the switching event, such as imaging or shuttering.

The Analog In connector allows the center wavelength to be set by a 0 to 5 V signal from an external voltage source and changed by an internal or external trigger. 0 V corresponds to the minimum wavelength of 420 nm or 430 nm, while 5 V corresponds to the maximum wavelength of 730 nm. For details, see the *Control* tab.

Kurios' sequence preload function, which is accessible from the front panel, the included GUI, and a command-line interface, permits the user to define a sequence of wavelengths (up to 1024 values). Providing an internal or external trigger switches the wavelength to the next value in the sequence. This function can be used, for example, in combination with the Trigger Out and Trigger In connectors to trigger a camera at the completion of each wavelength switch and then accept a trigger from the camera once the image is obtained. This sequence is stored within the controller's non-volatile memory, enabling the user to close the software GUI or unplug the USB cable without loss of the preloaded sequence. However, powering off the controller will cause the non-volatile memory to reset.

For the currently available models, the Bandwidth button on the front of the controller toggles between the filter throughput at the bandwidth corresponding to the given model and beam-blocking mode ("Black").

Transmission and Polarization
The liquid crystal optics in Kurios filters are not sensitive to the direction of propagation, allowing the filter to be used in either direction. The first element in the filter head is a linear polarizer and each face is marked with a white line (see the images to the right) that indicates the transmitted polarization direction. For maximum transmission, the input beam should be linearly polarized and aligned with this polarization axis. Please note that since Kurios is structured like Lyot and Solc filters, the polarization axis rotates by 90° through the filter head. To obtain the specified attenuation of out-of-band wavelengths, the input beam should be well collimated, since the filter head's field of view is ±6°.

A lens-tube-mounted premium 750 nm shortpass filter is included with our KURIOS-WB1/M, KURIOS-WL1(/M), and KURIOS-XL1(/M) Tunable Filters for visible wavelengths. Use of this filter is recommended to protect the filter head components from excessive IR illumination.

Mounting Options
These tunable filters are post mountable via three 8-32 (M4) taps on the sides of the housing. In addition, four 4-40 tapped holes on the front and back faces provide compatibility with our 30 mm or 60 mm cage systems, depending on the model. The front and back faces of the housing are internally SM1- (1.035"-40) or SM2- (2.035"-40) threaded. These threads accommodate Ø1" and Ø2" lens tubes, respectively. To connect the KURIOS-WB1/M filter to a camera, use our SM1A39 SM1-to-C-Mount thread adapter together with an appropriate tube lens.

SPECS

Fixed Bandwidth Tunable Filters			
Item #	**KURIOS-WB1/M**	**KURIOS-WL1(/M)**	**KURIOS-XL1(/M)**
Wavelength Range	420 - 730 nm		430 - 730 nm
Bandwidth (FWHM)[a]	35 nm at 550 nm		10 nm at 550 nm
Switching Speed[b]	<40 ms	<50 ms	<70 ms
Clear Aperture	Ø20 mm	Ø35 mm	Ø35 mm
Polarized Transmission[c]	45% at 550 nm		17% at 550 nm
Out-of-Band Blocking	OD > 2		
Minimum Incremental Step Size	1 nm		
Tuning Accuracy	±FWHM/10		
Angle of Incidence (Field of View)	±6°		
Wavelength Uniformity	FWHM/8 over Clear Aperture	FWHM/4 over Clear Aperture	
Damage Threshold – **Pulsed (ns)**	0.1 J/cm^2		
Damage Threshold – **Pulsed (fs)**	0.02 J/cm^2 (532 nm, 76 Hz, 100 fs, Ø162 µm)		
Damage Threshold – **CW**	0.8 W/cm[d] (532 nm, Ø0.471 mm)		
Filter Head Dimensions	52.6 mm x 52.6 mm x 48.5 mm (2.07" x 2.07" x 1.91")	79.0 mm x 79.0 mm x 39.5 mm (3.11" x 3.11" x 1.56")	79.0 mm x 79.0 mm x 60.5 mm (3.11" x 3.11" x 2.38")
Filter Head Front/Rear Threading	SM1 (1.035"-40) Internal Threads	SM2 (2.035"-40) Internal Threads	
Filter Head Mounting Options	M4 Tap for Post Mounting (3 Places) 4-40 Taps for Cage System	8-32 (M4) Tap for Post Mounting (3 Places) 4-40 Taps for Cage System	
Operating Temperature	0 to 40 °C		
Storage Temperature	-15 to 65 °C		

a. The bandpass width increases linearly with wavelength. See the Performance Plots below for details.
b. The switching speed depends upon the initial and final wavelength. See the Performance Plots below for details.
c. Typical transmission for input light polarized parallel to the filter's transmission axis.
d. The power density of your beam should be calculated in terms of W/cm. Please see the *Damage Thresholds* tab for details.

CONTROL

Kurios® tunable bandpass filters have three operating modes for control of the center wavelength: Manual, Sequenced, and Analog. They also provide a beam blocking mode ("black mode"). Full details on the operation are available from the manual.

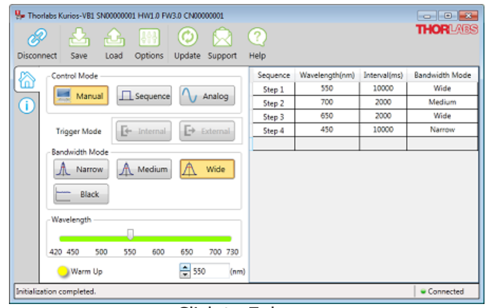
Manual Mode
In manual mode, the center wavelength is immediately set when a command is issued. This command can be issued in several ways:

- Turn the wavelength knob on the Kurios front panel (pictured to the right)
- Use the wavelength slider in the software interface (shown in the screenshot below)
- Type the desired wavelength into the software interface
- Issue the serial command

Click to Enlarge
The front panel of the KURIOS-WB1/M controller while it is set to manual mode.

The Kurios controller defaults to the manual mode when it is powered on. If the controller is not in manual mode, it can be activated through any of the following methods:

- Press the Mode button on the controller repeatedly, until "MANUAL" is shown on the front panel (as pictured to the right)
- Press Manual in the software interface (shown in the screenshot below)



Click to Enlarge
The main window of the software when the previous-generation model KURIOS-VB1 Selectable Bandpass Tunable Filter is connected. (When using the KURIOS-WB1/M or KURIOS-WL1(/M), the Narrow and Medium buttons are grayed out. For the KURIOS-XL1(/M), the Medium and Wide buttons are grayed out.)

- Issue the serial command

Sequenced Mode
In sequenced mode, Kurios stores a series of center wavelengths that it sends to the optical head whenever an internal or external trigger is received. The maximum number of wavelengths that can be stored in the sequence is 1024; at the end of the sequence, the controller loops back to the beginning and starts over again. This sequence is stored within the controller's non-volatile memory, enabling the user to close the software GUI or unplug with USB cable without loss of the preloaded sequence. However, powering off the controller will cause the non-volatile memory to reset. The software is used to input the sequence of wavelengths desired. Sequenced mode can be activated using any of the following methods:

- Press the Mode button on the controller repeatedly, until either "SEQ.INT" or "SEQ.EXT" is shown on the front panel
- Press Sequence in the software interface (shown in the screenshot to the right)
- Issue the proper serial commands

Analog Mode
In analog mode, the center wavelength is directly controlled by a 0 to 5 V signal connected to the Analog In connector on the Kurios front panel. 0 V corresponds to the shortest wavelength and 5 V to the longest. When an internal or external trigger is received, the center wavelength is updated to the value determined by the Analog In voltage; at all other times, the Analog In voltage is ignored. Analog mode can be accessed using any of the following methods:

- Press the Mode button on the controller repeatedly, until either "ANA.INT" or "ANA.EXT" is shown on the front panel
- Press Analog in the software interface (shown in the screenshot to the right)
- Issue the proper serial commands

Internal and External Triggering
In both sequenced and analog modes, an internal or external trigger is needed to update the center wavelength. Otherwise, the wavelength remains unchanged.

For internal triggering, the signal is provided by a clock within the controller and has a user-specified interval between triggers from 1 ms to 60 s. Moreover, when in sequenced mode, each wavelength in the sequence can have its own interval time. In contrast, when in analog mode, the controller updates the wavelength according to the analog input signal at the interval time set by the user.

For external triggering, the 5 V TTL signal is provided through the Trigger In BNC connector on the front panel. Kurios triggers on the falling edge of the 5 V TTL signal.

Beam Blocking Mode
In beam blocking mode ("black mode"), the transmission is set to a minimum value, ignoring the center wavelength setting. This mode can be activated through any of the following methods:

- Press the Bandwidth button on the controller repeatedly, until "BLACK" is shown on the front panel
- Press Black in the software interface (shown in the screenshot above)
- Issue the proper serial command

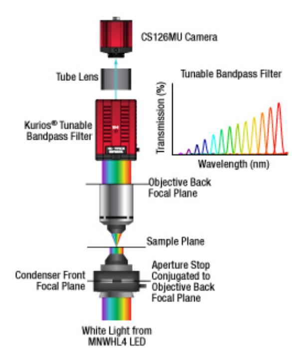
APPLICATION IDEAS

Hyperspectral Imaging

In hyperspectral imaging, a stack of wavelength-separated, two-dimensional images is acquired. This technique is frequently used in microscopy, biomedical imaging, and machine vision, as it allows quick sample identification and analysis.

Hyperspectral imaging obtains images with significantly better spectral resolution than that provided by standalone color cameras. Color cameras represent the


Click for Details
This DIY hyperspectral imaging system is built on Thorlabs' Cerna Microscopy Platform. Key components include the previous-generation KURIOS-VB1 Tunable Bandpass Filter, the CS126MU Monochrome Scientific Camera, and



Click to Enlarge

entire spectral range of an image by using three relatively wide spectral channels-

our MNWHL4 Neutral White Mounted LED.

Schematic of the Hyperspectral Imaging Microscope

red, green, and blue. In contrast, hyperspectral imaging systems incorporate optical elements such as liquid crystal tunable bandpass filters or diffraction gratings, which create spectral channels with significantly narrower bandwidths.

Example Image Stacks

The data in the images and video below demonstrate the hyperspectral imaging technique. Figure 1 depicts two images of a mature *capsella bursa-pastoris* embryo (also known as shepherd's-purse) taken with the tunable filter set to center wavelengths of 500 nm and 650 nm. These two images show that an entire field of view is acquired at each spectral channel. Figure 2 is a video containing 31 images of the same sample, taken at center wavelengths from 420 nm to 730 nm in 10 nm steps. (10 nm is not the spectral resolution; the spectral resolution is set by the FWHM bandwidth at each wavelength.) In Figure 3, images from each spectral channel are used to determine the color of each pixel and assemble a color image. Figure 3 also demonstrates that a broadband spectrum is acquired at each pixel, permitting spectroscopic identification of different sample features within the field of view.

Kurios tunable filters offer a number of advantages for hyperspectral imaging. Unlike approaches that rely upon angle-tunable filters or manual filter swapping, Kurios filters use no moving parts, enabling vibrationless wavelength switching on millisecond timescales. Because the filter is not moved or exchanged during the measurement, the data is not subject to "pixel shift" image registration issues. Our filters also include software and a benchtop controller with external triggers, making them easy to integrate with data acquisition and analysis programs.

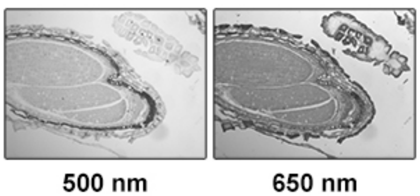


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Figure 1: Two images of a mature *capsella bursa-pastoris* embryo taken at different center wavelengths. The entire field of view is acquired for each spectral channel.

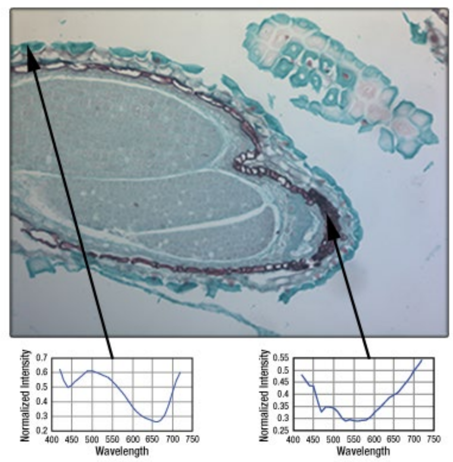

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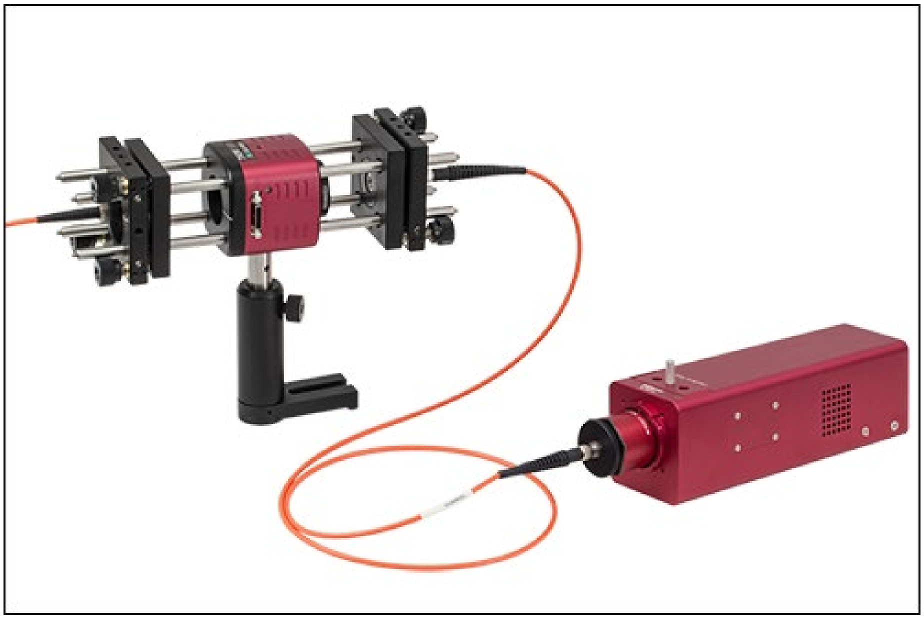
Figure 3: A color image of the mature *capsella bursa-pastoris* embryo, assembled using the entire field of view acquired in each spectral channel, as shown in Figure 1. By acquiring across multiple channels, a spectrum for each pixel in the image is obtained.

Tunable-Wavelength Illumination Sources

The system below uses a Kurios tunable filter and a broadband illumination source to provide millisecond-timescale tuning between visible wavelengths (420 - 730 nm). The following tables correspond with either the imperial or metric list of components used in the application photograph.



Click to Enlarge

Previous-Generation KURIOS-WB1 Used to Construct a Tunable Illumination Source for Visible Wavelengths

SOFTWARE

Kurios® Software Package

GUI Interface

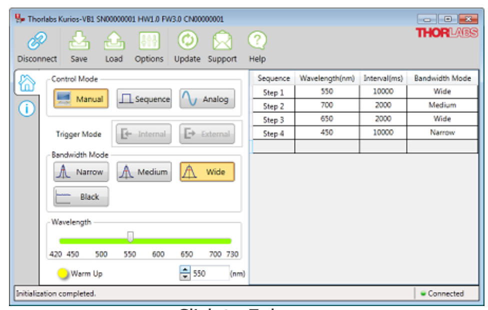
The Kurios software package allows the user to select between the Manual, Sequence, and Analog Modes for determining the center wavelength of the filter head. (These modes are discussed in detail in the *Control* tab.) In manual mode, the wavelength slider is enabled, which lets the user choose any center wavelength within the 420 - 730 nm, 430 - 730 nm, or 650 - 1100 nm range. For sequence and analog modes, either internal or external triggering can be chosen; triggers are needed to update the center wavelength.

Software

Version 1.6.3

Includes a GUI for control of Kurios, as well as the required device drivers, C/C++ code examples, and LabVIEW VIs. To download, click the button below.

Software



Click to Enlarge

The main window of the software when the previous-generation KURIOS-VB1/M Selectable Bandpass Tunable Filter is connected. (When using the KURIOS-WB1/M or KURIOS-WL1(/M), the Narrow and Medium buttons are grayed out. For the KURIOS-XL1(M/), the Medium and Wide buttons are grayed out.)

In sequence and analog modes, the user may define sequences of up to 1024 wavelengths to be cycled through by the controller. Each step in the sequence has its own wavelength and duration (1 ms to 60 s). Sequences can be saved and loaded in CSV format using the "Save Profile" and "Load Profile" buttons.

Custom Software Development

We also provide C/C++ and LabVIEW software development kits for controlling Kurios with other instruments through the USB port on the controller. Sample C++ code and LabVIEW programs help to illustrate how the C commands and LabVIEW VIs can be utilized.

DAMAGE THRESHOLDS

Damage Threshold Data for Kurios® Tunable Bandpass Filters

The specifications to the right are measured data for Thorlabs' Kurios Tunable Filters.

Damage Threshold Specifications		
Item # Suffix	**Laser Type**	**Damage Threshold**
-WB1/M **-WL1(/M)** **-XL1(/M)**	**Pulsed (ns)**	0.1 J/cm^2
	Pulsed (fs)	0.02 J/cm^2 (532 nm, 76 Hz, 100 fs, Ø162 µm)

	CW[a]	0.8 W/cm (532 nm, Ø0.471 mm)

a. The power density of your beam should be calculated in terms of W/cm. For an explanation of why the linear power density provides the best metric for long pulse and CW sources, please see the "Continuous Wave and Long-Pulse Lasers" section below.

Laser Induced Damage Threshold Tutorial

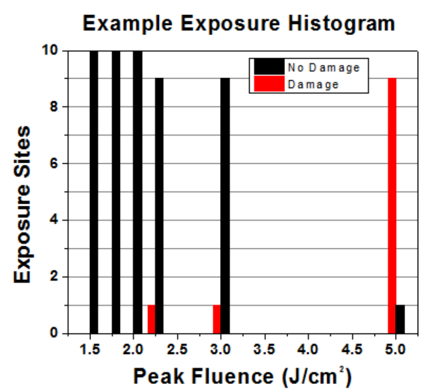
The following is a general overview of how laser induced damage thresholds are measured and how the values may be utilized in determining the appropriateness of an optic for a given application. When choosing optics, it is important to understand the Laser Induced Damage Threshold (LIDT) of the optics being used. The LIDT for an optic greatly depends on the type of laser you are using. Continuous wave (CW) lasers typically cause damage from thermal effects (absorption either in the coating or in the substrate). Pulsed lasers, on the other hand, often strip electrons from the lattice structure of an optic before causing thermal damage. Note that the guideline presented here assumes room temperature operation and optics in new condition (i.e., within scratch-dig spec, surface free of contamination, etc.). Because dust or other particles on the surface of an optic can cause damage at lower thresholds, we recommend keeping surfaces clean and free of debris. For more information on cleaning optics, please see our *Optics Cleaning* tutorial.

Testing Method

Thorlabs' LIDT testing is done in compliance with ISO/DIS 11254 and ISO 21254 specifications.

First, a low-power/energy beam is directed to the optic under test. The optic is exposed in 10 locations to this laser beam for 30 seconds (CW) or for a number of pulses (pulse repetition frequency specified). After exposure, the optic is examined by a microscope (~100X magnification) for any visible damage. The number of locations that are damaged at a particular power/energy level is recorded. Next, the power/energy is either increased or decreased and the optic is exposed at 10 new locations. This process is repeated until damage is observed. The damage threshold is then assigned to be the highest power/energy that the optic can withstand without causing damage. A histogram such as that below represents the testing of one BB1-E02 mirror.

The photograph above is a protected aluminum-coated mirror after LIDT testing. In this particular test, it handled 0.43 J/cm^2 (1064 nm, 10 ns pulse, 10 Hz, Ø1.000 mm) before damage.



Example Test Data			
Fluence	# of Tested Locations	Locations with Damage	Locations Without Damage
1.50 J/cm^2	10	0	10
1.75 J/cm^2	10	0	10
2.00 J/cm^2	10	0	10
2.25 J/cm^2	10	1	9
3.00 J/cm^2	10	1	9
5.00 J/cm^2	10	9	1

According to the test, the damage threshold of the mirror was 2.00 J/cm^2 (532 nm, 10 ns pulse, 10 Hz, Ø0.803 mm). Please keep in mind that these tests are performed on clean optics, as dirt and contamination can significantly lower the damage threshold of a component. While the test results are only representative of one coating run, Thorlabs specifies damage threshold values that account for coating variances.

Continuous Wave and Long-Pulse Lasers

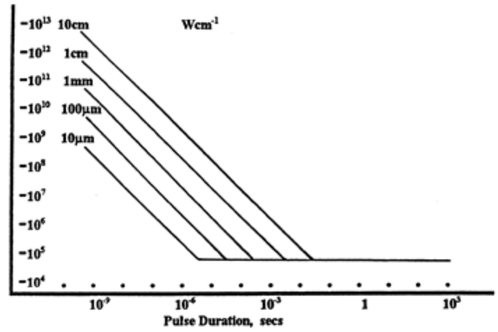
When an optic is damaged by a continuous wave (CW) laser, it is usually due to the melting of the surface as a result of absorbing the laser's energy or damage to the optical coating (antireflection) [1]. Pulsed lasers with pulse lengths longer than 1 µs can be treated as CW lasers for LIDT discussions.

When pulse lengths are between 1 ns and 1 µs, laser-induced damage can occur either because of absorption or a dielectric breakdown (therefore, a user must check both CW and pulsed LIDT). Absorption is either due to an intrinsic property of the optic or due to surface irregularities; thus LIDT values are only valid for optics meeting or exceeding the surface quality specifications given by a manufacturer. While many optics can handle high power CW lasers, cemented (e.g., achromatic doublets) or highly absorptive (e.g., ND filters) optics tend to have lower CW damage thresholds. These lower thresholds are due to absorption or scattering in the cement or metal coating.

Pulsed lasers with high pulse repetition frequencies (PRF) may behave similarly to CW beams. Unfortunately, this is highly dependent on factors such as absorption and thermal diffusivity, so there is no reliable method for determining when a high PRF laser will damage an optic due to thermal effects. For beams with a high PRF both the average and peak powers must be compared to the equivalent CW power. Additionally, for highly transparent materials, there is little to no drop in the LIDT with increasing PRF.

In order to use the specified CW damage threshold of an optic, it is necessary to know the following:

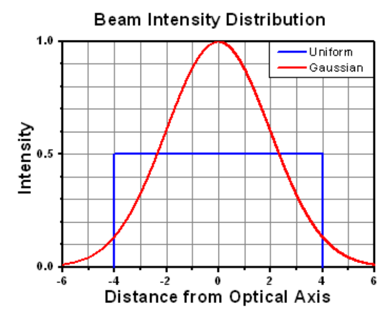
1. Wavelength of your laser
2. Beam diameter of your beam ($1/e^2$)
3. Approximate intensity profile of your beam (e.g., Gaussian)
4. Linear power density of your beam (total power divided by $1/e^2$ beam diameter)



LIDT in linear power density vs. pulse length and spot size. For long pulses to CW, linear power density becomes a constant with spot size. This graph was obtained from [1].

Thorlabs expresses LIDT for CW lasers as a linear power density measured in W/cm. In this regime, the LIDT given as a linear power density can be applied to any beam diameter; one does not need to compute an adjusted LIDT to adjust for changes in spot size, as demonstrated by the graph to the right. Average linear power density can be calculated using the equation below.

$$\text{Linear Power Density} = \frac{\text{Power}}{\text{Beam Diameter}}$$



The calculation above assumes a uniform beam intensity profile. You must now consider hotspots in the beam or other non-uniform intensity profiles and roughly calculate a maximum power density. For reference, a Gaussian beam typically has a maximum power density that is twice that of the uniform beam (see lower right).

Now compare the maximum power density to that which is specified as the LIDT for the optic. If the optic was tested at a wavelength other than your operating wavelength, the damage threshold must be scaled appropriately. A good rule of thumb is that the damage threshold has a linear relationship with wavelength such that as you move to shorter wavelengths, the damage threshold decreases (i.e., a LIDT of 10 W/cm at 1310 nm scales to 5 W/cm at 655 nm):

$$\text{Adjusted LIDT} = \text{LIDT Power}\left(\frac{\text{Your Wavelength}}{\text{LIDT Wavelength}}\right)$$

While this rule of thumb provides a general trend, it is not a quantitative analysis of LIDT vs wavelength. In CW applications, for instance, damage scales more strongly with absorption in the coating and substrate, which does not necessarily scale well with wavelength. While the above procedure provides a good rule of thumb for LIDT values, please contact Tech Support if your wavelength is different from the specified LIDT wavelength. If your power density is less than the adjusted LIDT of the optic, then the optic should work for your application.

Please note that we have a buffer built in between the specified damage thresholds online and the tests which we have done, which accommodates variation between batches. Upon request, we can provide individual test information and a testing certificate. The damage analysis will be carried out on a similar optic (customer's optic will not be damaged). Testing may result in additional costs or lead times. Contact Tech Support for more information.

Pulsed Lasers

As previously stated, pulsed lasers typically induce a different type of damage to the optic than CW lasers. Pulsed lasers often do not heat the optic enough to damage it; instead, pulsed lasers produce strong electric fields capable of inducing dielectric breakdown in the material. Unfortunately, it can be very difficult to compare the LIDT specification of an optic to your laser. There are multiple regimes in which a pulsed laser can damage an optic and this is based on the laser's pulse length. The highlighted columns in the table below outline the relevant pulse lengths for our specified LIDT values.

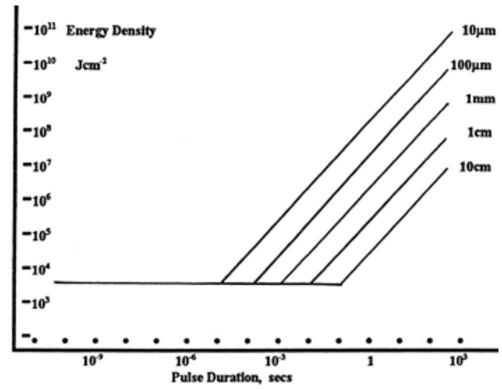
Pulses shorter than 10^{-9} s cannot be compared to our specified LIDT values with much reliability. In this ultra-short-pulse regime various mechanics, such as multiphoton-avalanche ionization, take over as the predominate damage mechanism [2]. In contrast, pulses between 10^{-7} s and 10^{-4} s may cause damage to an optic either because of dielectric breakdown or thermal effects. This means that both CW and pulsed damage thresholds must be compared to the laser beam to determine whether the optic is suitable for your application.

Pulse Duration	$t < 10^{-9}$ s	$10^{-9} < t < 10^{-7}$ s	$10^{-7} < t < 10^{-4}$ s	$t > 10^{-4}$ s
Damage Mechanism	Avalanche Ionization	Dielectric Breakdown	Dielectric Breakdown or Thermal	Thermal

Relevant Damage Specification	No Comparison (See Above)	Pulsed	Pulsed and CW	CW

When comparing an LIDT specified for a pulsed laser to your laser, it is essential to know the following:

1. Wavelength of your laser
2. Energy density of your beam (total energy divided by $1/e^2$ area)
3. Pulse length of your laser
4. Pulse repetition frequency (prf) of your laser
5. Beam diameter of your laser ($1/e^2$)
6. Approximate intensity profile of your beam (e.g., Gaussian)



LIDT in energy density vs. pulse length and spot size. For short pulses, energy density becomes a constant with spot size. This graph was obtained from [1].

The energy density of your beam should be calculated in terms of J/cm^2. The graph to the right shows why expressing the LIDT as an energy density provides the best metric for short pulse sources. In this regime, the LIDT given as an energy density can be applied to any beam diameter; one does not need to compute an adjusted LIDT to adjust for changes in spot size. This calculation assumes a uniform beam intensity profile. You must now adjust this energy density to account for hotspots or other nonuniform intensity profiles and roughly calculate a maximum energy density. For reference a Gaussian beam typically has a maximum energy density that is twice that of the $1/e^2$ beam.

Now compare the maximum energy density to that which is specified as the LIDT for the optic. If the optic was tested at a wavelength other than your operating wavelength, the damage threshold must be scaled appropriately [3]. A good rule of thumb is that the damage threshold has an inverse square root relationship with wavelength such that as you move to shorter wavelengths, the damage threshold decreases (i.e., a LIDT of 1 J/cm^2 at 1064 nm scales to 0.7 J/cm^2 at 532 nm):

$$Adjusted\ LIDT = LIDT\ Energy \sqrt{\frac{Your\ Wavelength}{LIDT\ Wavelength}}$$

You now have a wavelength-adjusted energy density, which you will use in the following step.

Beam diameter is also important to know when comparing damage thresholds. While the LIDT, when expressed in units of J/cm², scales independently of spot size; large beam sizes are more likely to illuminate a larger number of defects which can lead to greater variances in the LIDT [4]. For data presented here, a <1 mm beam size was used to measure the LIDT. For beams sizes greater than 5 mm, the LIDT (J/cm2) will not scale independently of beam diameter due to the larger size beam exposing more defects.

The pulse length must now be compensated for. The longer the pulse duration, the more energy the optic can handle. For pulse widths between 1 - 100 ns, an approximation is as follows:

$$Adjusted\ LIDT = LIDT\ Energy \sqrt{\frac{Your\ Pulse\ Length}{LIDT\ Pulse\ Length}}$$

Use this formula to calculate the Adjusted LIDT for an optic based on your pulse length. If your maximum energy density is less than this adjusted LIDT maximum energy density, then the optic should be suitable for your application. Keep in mind that this calculation is only used for pulses between 10^{-9} s and 10^{-7} s. For pulses between 10^{-7} s and 10^{-4} s, the CW LIDT must also be checked before deeming the optic appropriate for your application.

Please note that we have a buffer built in between the specified damage thresholds online and the tests which we have done, which accommodates variation between batches. Upon request, we can provide individual test information and a testing certificate. Contact Tech Support for more information.

[1] R. M. Wood, Optics and Laser Tech. **29**, 517 (1998).
[2] Roger M. Wood, *Laser-Induced Damage of Optical Materials* (Institute of Physics Publishing, Philadelphia, PA, 2003).
[3] C. W. Carr *et al.*, Phys. Rev. Lett. **91**, 127402 (2003).
[4] N. Bloembergen, Appl. Opt. **12**, 661 (1973).

LIDT CALCULATIONS

LIDT Calculator

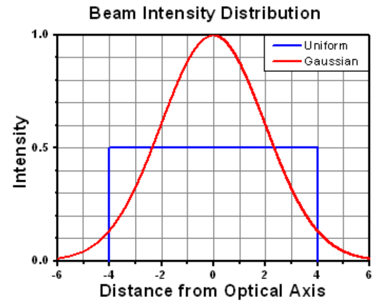
In order to illustrate the process of determining whether a given laser system will damage an optic, a number of example calculations of laser induced damage threshold are given below. For assistance with performing similar calculations, we provide a spreadsheet calculator that can be downloaded by clicking the button to the right. To use the calculator, enter the specified LIDT value of the optic under consideration and the relevant parameters of your laser system in the green boxes. The spreadsheet will then calculate a linear power density for CW and pulsed systems, as well as an energy density value for pulsed systems. These values are used to calculate adjusted, scaled LIDT values for the optics based on accepted scaling laws. This calculator assumes a Gaussian beam profile, so a correction factor must be introduced for other beam shapes (uniform, etc.). The LIDT scaling laws are determined from empirical relationships; their accuracy is not guaranteed. Remember that absorption by optics or coatings can significantly reduce LIDT in some spectral regions. These LIDT values are not valid for ultrashort pulses less than one nanosecond in duration.

CW Laser Example

Suppose that a CW laser system at 1319 nm produces a 0.5 W Gaussian beam that has a 1/e^2 diameter of 10 mm. A naive calculation of the average linear power density of this beam would yield a value of 0.5 W/cm, given by the total power divided by the beam diameter:

$$\text{Linear Power Density} = \frac{\text{Power}}{\text{Beam Diameter}}$$

However, the maximum power density of a Gaussian beam is about twice the maximum power density of a uniform beam, as shown in the graph to the right. Therefore, a more accurate determination of the maximum linear power density of the system is 1 W/cm.



A Gaussian beam profile has about twice the maximum intensity of a uniform beam profile.

An AC127-030-C achromatic doublet lens has a specified CW LIDT of 350 W/cm, as tested at 1550 nm. CW damage threshold values typically scale directly with the wavelength of the laser source, so this yields an adjusted LIDT value:

$$\text{Adjusted LIDT} = \text{LIDT Power}\left(\frac{\text{Your Wavelength}}{\text{LIDT Wavelength}}\right)$$

The adjusted LIDT value of 350 W/cm x (1319 nm / 1550 nm) = 298 W/cm is significantly higher than the calculated maximum linear power density of the laser system, so it would be safe to use this doublet lens for this application.

Pulsed Nanosecond Laser Example: Scaling for Different Pulse Durations

Suppose that a pulsed Nd:YAG laser system is frequency tripled to produce a 10 Hz output, consisting of 2 ns output pulses at 355 nm, each with 1 J of energy, in a Gaussian beam with a 1.9 cm beam diameter (1/e^2). The average energy density of each pulse is found by dividing the pulse energy by the beam area:

$$\text{Energy Density} = \frac{\text{Pulse Energy}}{\text{Beam Area}}$$

As described above, the maximum energy density of a Gaussian beam is about twice the average energy density. So, the maximum energy density of this beam is ~0.7 J/cm^2.

The energy density of the beam can be compared to the LIDT values of 1 J/cm^2 and 3.5 J/cm^2 for a BB1-E01 broadband dielectric mirror and an NB1-K08 Nd:YAG laser line mirror, respectively. Both of these LIDT values, while measured at 355 nm, were determined with a 10 ns pulsed laser at 10 Hz. Therefore, an adjustment must be applied for the shorter pulse duration of the system under consideration. As described on the previous tab, LIDT values in the nanosecond pulse regime scale with the square root of the laser pulse duration:

$$\text{Adjusted LIDT} = \text{LIDT Energy}\sqrt{\frac{\text{Your Pulse Length}}{\text{LIDT Pulse Length}}}$$

This adjustment factor results in LIDT values of 0.45 J/cm^2 for the BB1-E01 broadband mirror and 1.6 J/cm^2 for the Nd:YAG laser line mirror, which are to be compared with the 0.7 J/cm^2 maximum energy density of the beam. While the broadband mirror would likely be damaged by the laser, the more specialized laser line mirror is appropriate for use with this system.

Pulsed Nanosecond Laser Example: Scaling for Different Wavelengths

Suppose that a pulsed laser system emits 10 ns pulses at 2.5 Hz, each with 100 mJ of energy at 1064 nm in a 16 mm diameter beam ($1/e^2$) that must be attenuated with a neutral density filter. For a Gaussian output, these specifications result in a maximum energy density of 0.1 J/cm^2. The damage threshold of an NDUV10A Ø25 mm, OD 1.0, reflective neutral density filter is 0.05 J/cm^2 for 10 ns pulses at 355 nm, while the damage threshold of the similar NE10A absorptive filter is 10 J/cm^2 for 10 ns pulses at 532 nm. As described on the previous tab, the LIDT value of an optic scales with the square root of the wavelength in the nanosecond pulse regime:

$$\text{Adjusted LIDT} = \text{LIDT Energy}\sqrt{\frac{\text{Your Wavelength}}{\text{LIDT Wavelength}}}$$

This scaling gives adjusted LIDT values of 0.08 J/cm^2 for the reflective filter and 14 J/cm^2 for the absorptive filter. In this case, the absorptive filter is the best choice in order to avoid optical damage.

Pulsed Microsecond Laser Example

Consider a laser system that produces 1 µs pulses, each containing 150 µJ of energy at a repetition rate of 50 kHz, resulting in a relatively high duty cycle of 5%. This system falls somewhere between the regimes of CW and pulsed laser induced damage, and could potentially damage an optic by mechanisms associated with either regime. As a result, both CW and pulsed LIDT values must be compared to the properties of the laser system to ensure safe operation.

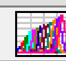
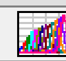
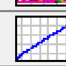
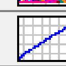
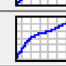
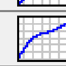
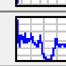
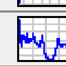
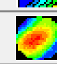
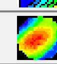
If this relatively long-pulse laser emits a Gaussian 12.7 mm diameter beam ($1/e^2$) at 980 nm, then the resulting output has a linear power density of 5.9 W/cm and an energy density of 1.2 x 10^{-4} J/cm^2 per pulse. This can be compared to the LIDT values for a WPQ10E-980 polymer zero-order quarter-wave plate, which are 5 W/cm for CW radiation at 810 nm and 5 J/cm^2 for a 10 ns pulse at 810 nm. As before, the CW LIDT of the optic scales linearly with the laser wavelength, resulting in an adjusted CW value of 6 W/cm at 980 nm. On the other hand, the pulsed LIDT scales with the square root of the laser wavelength and the square root of the pulse duration, resulting in an adjusted value of 55 J/cm^2 for a 1 µs pulse at 980 nm. The pulsed LIDT of the optic is significantly greater than the energy density of the laser pulse, so individual pulses will not damage the wave plate. However, the large average linear power density of the laser system may cause thermal damage to the optic, much like a high-power CW beam.

Liquid Crystal Tunable Filters, Fixed Wide Bandwidth, Visible Wavelengths

- Wavelength Range: 420 - 730 nm
- Bandwidth at λ = 550 nm: 35 nm FWHM
- Switching Time: <50 ms
- Polarized Transmission at λ = 550 nm: 45%
- See the Table to the Right and the *Specs* Tab Above for More Details

Limited STOCK

These items will be retired when stock is depleted. If you require these parts for line production, please contact our OEM Team.

Performance Plots (Click for Plot)		
Item #	**KURIOS-WB1/M**	**KURIOS-WL1(/M)**
Transmission Spectrum[a]		
Bandwidth[b]		
Transmission at Center Wavelength[a]		
Optical Density, CWL = 625 nm		
Switching Time[c]		
Uniformity,[d] **CWL = 550 nm**		
Raw Data for All Plots	KURIOS-WB1/M	KURIOS-WL1(/M)

a. For input light polarized parallel to the filter's transmission axis.
b. The bandwidth increases linearly with the center wavelength.
c. This plot gives the switching time as a function of the initial wavelength (on the Y axis) and the final wavelength (on the X axis). The plot is not symmetric because liquid crystal optics respond faster to voltage increases than voltage decreases.
d. Uniformity is defined as the center wavelength shift divided by the FWHM bandwidth at the specified wavelength setting.

KURIOS-WB1/M and KURIOS-WL1(/M) are fixed wide-bandpass versions of our Kurios tunable bandpass filters. The center wavelength (CWL) is tunable from 420 nm to 730 nm. In general, the transmission and the width of the bandpass region increase with the CWL. The plots in the table to the right contain more details.

To eliminate transmission in the near-IR and IR wavelength range, each of these tunable filters includes a premium shortpass filter with a 750 nm cut-off wavelength in an SM-threaded housing. This filter is recommended for use at the incident side of the filter head to protect the internal components from excessive IR exposure. The KURIOS-WB1/M includes the FESH0750 filter and the KURIOS-WL1(/M) includes a Ø2" version of the FESH0750 filter with the same optical properties. The filter also blocks UV light (<385 nm) and may be used to reduce UV intensity in the incident beam.

The fixed bandpass tunable filters provide switching times that vary depending upon the initial and final wavelengths. As shown in the contour plots in the table to the right, for small changes in the CWL (Δλ ≤ 30 nm), the switching time will be ≤5 ms. For greater changes in the CWL, the switching time will increase, reaching a maximum of 40 ms when switching from 420 nm to 730 nm.

The KURIOS-WB1/M has a clear aperture of Ø20 mm. The housing has internal SM1 (1.035"-40) threading and is compatible with our 30 mm cage systems.

Alternatively, the KURIOS-WL1(/M) has a clear aperture of Ø35 mm. Its housing has internal SM2 (2.035"-40) threading and is compatible with our 60 mm cage systems.

Each Kurios tunable filter is factory calibrated and ships with a switching time map so that users may optimize their system for the specific filter. The map can be saved to disk through the included Windows® software.

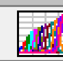
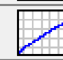
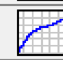
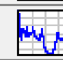
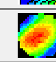
Part Number	Description	Price	Availability
KURIOS-WB1/M	**Tunable Filter, Fixed Wide Bandpass, Ø20 mm CA, 420 - 730 nm, M4 Taps**	**$6,068.30**	**Today**
KURIOS-WL1/M	**Tunable Filter, Fixed Wide Bandpass, Ø35 mm CA, 420 - 730 nm, M4 Taps**	**$8,087.77**	**Today**
KURIOS-WL1	**Tunable Filter, Fixed Wide Bandpass, Ø35 mm CA, 420 - 730 nm, 8-32 Taps**	**$8,087.77**	**Today**

Liquid Crystal Tunable Filter, Fixed Narrow Bandwidth, Visible Wavelengths

- Wavelength Range: 430 - 730 nm
- Bandwidth at λ = 550 nm: 10 nm FWHM
- Switching Time: <70 ms
- Polarized Transmission at λ = 550 nm: 17%
- See the Table to the Right and the *Specs* Tab Above for More Details

Limited STOCK

These items will be retired when stock is depleted. If you require these parts for line production, please contact our OEM Team.

KURIOS-XL1 Performance Plots (Click for Plot)	
Transmission Spectrum[a]	
Bandwidth[b]	
Transmission at Center Wavelength[a]	
Optical Density, CWL = 625 nm	
Switching Time[c]	
Uniformity,[d] CWL = 550 nm	
Raw Data for All Plots	

a. For input light polarized parallel to the filter's transmission axis.
b. The bandwidth increases linearly with the center wavelength.
c. This plot gives the switching time as a function of the initial wavelength (on the Y axis) and the final wavelength (on the X axis). The plot is not symmetric because liquid crystal optics respond faster to voltage increases than voltage decreases.
d. Uniformity is defined as the center wavelength shift divided by the FWHM bandwidth at the specified wavelength setting.

KURIOS-XL1(/M) is a fixed narrow-bandpass version of our Kurios tunable bandpass filters. The center wavelength (CWL) is tunable from 430 nm to 730 nm. In general, the transmission and the width of the bandpass region increase with the CWL. The plots in the table to the right contain more details.

To eliminate transmission in the near-IR and IR wavelength range, this tunable filter includes a Ø2" version of the FESH0750 premium shortpass filter with a 750 nm cut-off wavelength in an SM2-threaded housing. This filter is recommended for use at the incident side of the filter head to protect the internal components from excessive IR exposure. The filter also blocks UV light (<385 nm) and may be used to reduce UV intensity in the incident beam.

The fixed narrow bandpass tunable filter provides switching times that vary depending upon the initial and final wavelengths. As shown in the contour plot in the table to the right, for small changes in the CWL (Δλ ≤ 30 nm), the switching time will be ≤10 ms. For greater changes in the CWL, the switching time will increase, reaching a maximum of 70 ms when switching from 425 nm to 725 nm.

The KURIOS-XL1(/M) has a clear aperture of Ø35 mm. Its housing has internal SM2 (2.035"-40) threading and is compatible with our 60 mm cage systems.

Each Kurios tunable filter is factory calibrated and ships with a switching time map so that users may optimize their system for the specific filter. The map can be saved to disk through the included Windows® software.

Part Number	Description	Price	Availability
KURIOS-XL1/M	**Customer Inspired! Tunable Filter, Fixed Narrow Bandpass, Ø35 mm CA, 430 - 730 nm, M4 Taps**	**$10,977.75**	**Today**
KURIOS-XL1	**Customer Inspired! Tunable Filter, Fixed Narrow Bandpass, Ø35 mm CA, 430 - 730 nm, 8-32 Taps**	**$10,977.75**	**Today**