

Saturation Limits, Damage Thresholds, and Attenuation Selection

Introduction

Attenuation is used to prevent sensor saturation and sensor damage. Sometimes the attenuation options themselves are at risk of damage, so it is important to choose attenuation with sufficient damage handling for a given application's beam parameters. The difference between sensor saturation limit and damage threshold of components will be discussed in this application note. Also, a guide to selecting the proper attenuation is provided.

Saturation Limit

DataRay offers a variety of different technologies for beam profiling measurements, but something they all have in common is the use of a detector or detector array to convert energy to an electrical signal that is eventually read by software as values in digital units. Whether it is a CCD, CMOS, microbolometer, Si photodetector, InGaAs or other, they all have a saturation limit that determines the useful range for energy measurements. Above the saturation limit, the detector is no longer useful for measurements because it no longer responds linearly to light. The DataRay software displays the maximum digital value read by a pixel or detector as the ADC Peak %. When the detector is saturated, the ADC Peak % will be >95% and the software will color the value **Orange** to indicate invalid measurements.

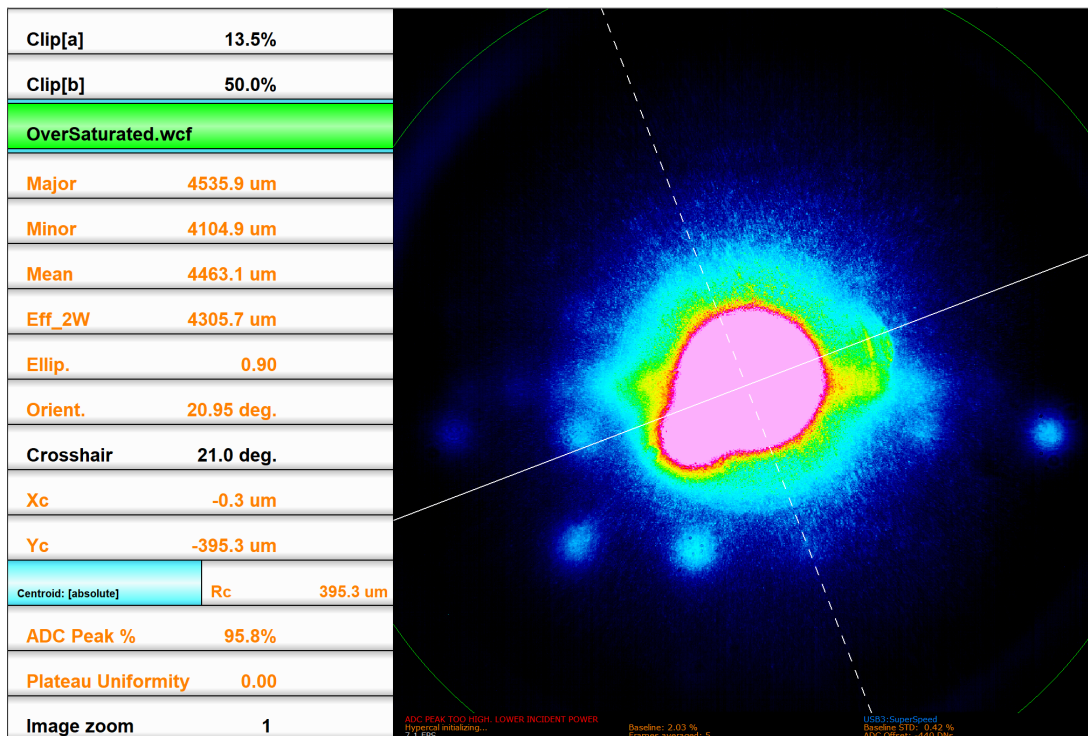


Figure 1: This screenshot shows the software during a saturated measurement. The results are invalid and it is recommended to lower incident power.

Damage Threshold

Measurements are invalid above the *saturation limit*, but the detector is not at risk of being permanently damaged until the beam's irradiance is above the *damage threshold*. The damage threshold defines the irradiance or fluence at which permanent damage may occur and is measured in W/cm^2 for CW lasers or J/cm^2 for pulsed lasers. For CW lasers, sometimes the damage threshold is given as a linear power density in W/mm . This is because the CW irradiance limit varies with beam diameter, while the linear power density limit does not. The damage threshold for most sensors is much higher than the saturation threshold; for CCD and CMOS detectors it can be $\sim 1000X$ the saturation limit. So, when choosing the proper amount of attenuation to ensure the sensor is below the saturation limit, it follows that the sensor will also be well below the damage threshold. However, the attenuation products that reflect and/or absorb the excess power have a damage threshold of their own that is important to observe.

**More care is required for the WinCamD-IR-BB which has a saturation range close to its damage threshold.

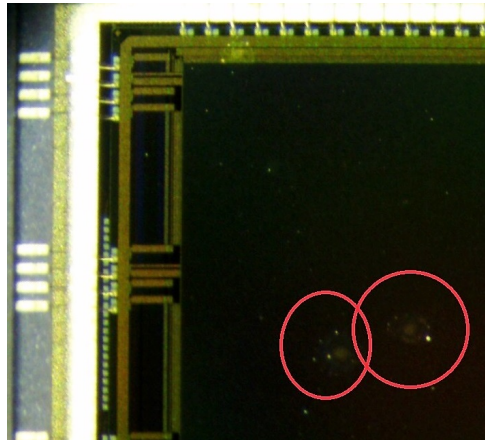


Figure 2: This WinCamD-LCM sensor was damaged by a laser well above the damage threshold.

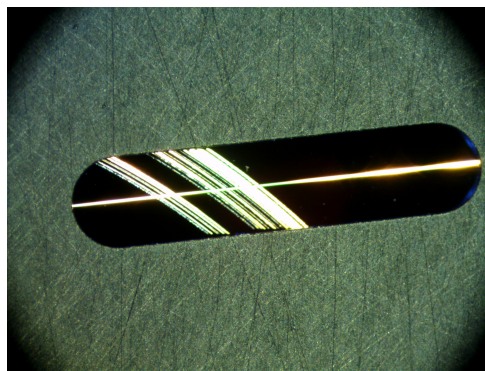


Figure 3: This slit used in our Beam'R2 and BeamMap2 products is damaged by a laser that was above the damage threshold. As the puck holding the slits rotated and the beam was moved, multiple arcs were burned in the substrate coating.

Laser Induced Damage Threshold Testing

Laser-induced damage threshold (LIDT) testing is performed on our high-power beam sampler and other attenuation products to provide the maximum allowable irradiance or fluence in accordance with ISO 21254. LIDT testing involves subjecting a sample to an increasing fluence or irradiance in multiple areas to determine when damage may occur. LIDT is defined at specific wavelengths and pulse widths. Because it is not feasible to measure LIDT for every laser configuration, estimations must be made to scale for wavelength and pulse width. The rule of thumb is to scale by λ/λ_{spec} and $\sqrt{\tau/\tau_{spec}}$.

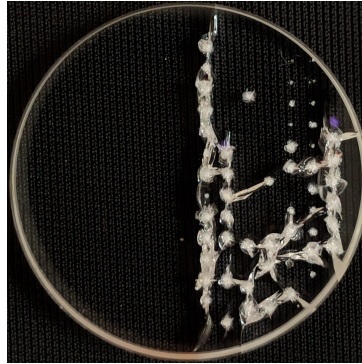


Figure 4: Damaged glass wedge after damage threshold testing. This UVFS glass wedge is used in our Polarization Preserving Beam Sampler (PPBS-UVFS).

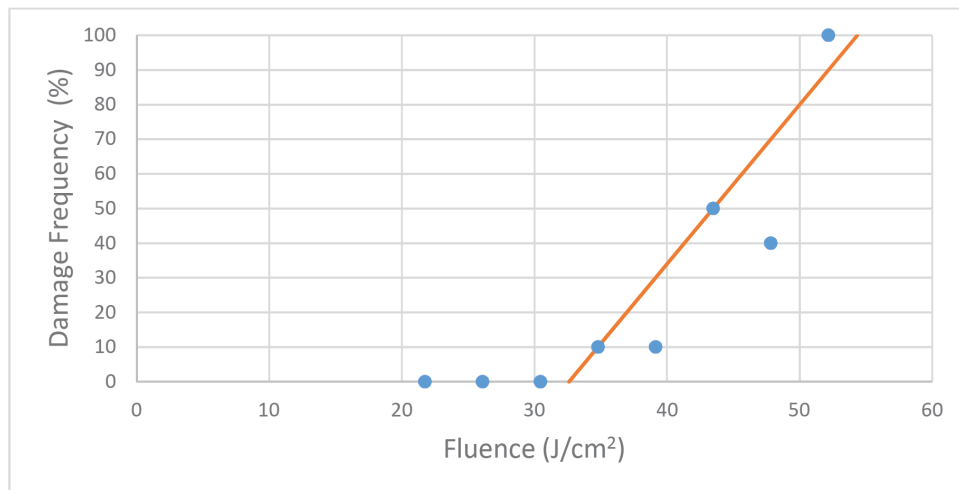


Figure 5: LIDT testing for the PPBS-UVFS at 532 nm and 5.2 ns pulse width. In this case, the damage threshold is 30 J/cm^2 .

Attenuation Accessories

Attenuation accessories are selected to lower the power/energy of a beam so that it can be measured by the detector without exceeding the saturation limits. Every attenuation option has its own damage threshold that must be observed. This means that once the required amount of attenuation is determined, the products that provide this attenuation (ND filters, beam samplers etc.) must be chosen such that they themselves are not at risk of damage. ND filters have a relatively low damage threshold, and reflective beam samplers have a high damage threshold.

Product	Wavelength (nm)	LIDT Specification	
PPBS-UVFS	193	1.4 J/cm ²	(193 nm, 13 ns, 20 Hz, Ø1.33 mm)
	266	6.4 J/cm ²	(266 nm, 7.52 ns, 20 Hz, Ø0.31 mm)
	355	30 J/cm ²	(355 nm, 6.2 ns, 20 Hz, Ø0.216 mm)
	532	30 J/cm ²	(532 nm, 5.4 ns, 20 Hz, Ø0.241 mm)
	1064	100 J/cm ²	(1064 nm, 16 ns, 20 Hz, Ø0.405 mm)
	532, CW	>11.1 W/mm*	(532 nm, CW 10 s, Ø0.504 mm)
	1064, CW	>350 W/mm*	(1064 nm, CW 10 s, Ø0.053 mm)
PPBS-BF	2940	100 J/cm ²	(2940 nm, 300 µs, 2 Hz, Ø0.27 mm)
	10600	>10.36 J/cm ² *	(10600 nm, 74 ns, 4 Hz, Ø1.06 mm)
PPBS-CF	193	0.19 J/cm ²	(193 nm, 13 ns, 20 Hz, Ø1.33 mm)
	266	18 J/cm ²	(266 nm, 7.52 ns, 20 Hz, Ø0.24 mm)
	2940	70 J/cm ²	(2940 nm, 300 µs, 2 Hz, Ø0.27 mm)
PPBS-ZnSe	2940	500 J/cm ²	(2940 nm, 300 µs, 2 Hz, Ø0.27 mm)
	10600	6 J/cm ²	(10600 nm, 74 ns, 4 Hz, Ø1.06 mm)
NDL-Ge	2940	30 J/cm ²	(2940 nm, 300 µs, 2 Hz, Ø0.27 mm)
	10600	1.5 J/cm ²	(10600 nm, 74 ns, 4 Hz, Ø1.06 mm)
CBS	355	1 J/cm ²	(355 nm, 10 ns)
	532	2 J/cm ²	(532 nm, 10 ns)
	1064	6 J/cm ²	(1064 nm, 10 ns)
2.5 µm Sapphire Slit	355	0.075 J/cm ²	(355 nm, 5.2 ns, 20 Hz, Ø0.506 mm)
	1540	0.2 J/cm ²	(1540 nm, 14.8 ns, 20 Hz, Ø0.28 mm)
	1064, CW	8 mW/µm (linear power density)	(1064 nm, CW 10 s, Ø0.042 mm)
ND-5	532	20 J/cm ²	(532 nm, 4.4 ns, 20 Hz, Ø0.25 mm)
	1064, CW	15 W/mm (linear power density)	(1064 nm, CW 10 s, Ø0.042 mm)
ND-3-UV	355	0.05 J/cm ²	(355 nm, 5.2 ns, 20 Hz, Ø0.506 mm)
LBPS-TS-200	532	9.75 J/cm ²	(532 nm, 21.7 ns, 20 Hz, Ø0.48 mm)
	1064	12 J/cm ²	(1064 nm, 14.4 ns, 20 Hz, Ø0.41 mm)
*Max irradiance/fluence of test laser, no damage			

Figure 6: LIDT results for various attenuation accessories. The standard test method was substantially in agreement with ISO 11254.

Attenuation Calculator

The Attenuation Calculator is an Excel spreadsheet compatible with Excel 2007 or later that estimates the effects of selected attenuation options for user-provided beam parameters. The goal is to advise the user of saturation limits and damage thresholds.

The Attenuation Calculator serves as a guide to prevent damage and provide a good starting point for measurements. All numbers are estimates and assume Gaussian beams; results vary depending on the beam. Further adjustments in attenuation may be necessary.

1. Determine the saturation threshold for your given beam profiler and beam parameters. The wavelength, beam size, and power must be considered. For pulsed lasers the pulse energy, pulse width, and repetition rate must also be considered.

- (a) Enter your beam parameters in the **User Inputs** section

User Inputs	
Wavelength (nm)	675
Laser Output Power (mW)	5000
First Attenuation Optic	None
Second Attenuation Optic	None
Third Attenuation Optic	None
Gaussian Waist Diameter (um)	1000
Flat Beam Diameter (um)	707.1
Pulsed?	No

Figure 7: Attenuation Spreadsheet User Inputs

- (b) Choose a combination of standard ND filters that results in an output that is within the sensor saturation limits. This is done by ensuring the relevant cell in the **Saturation Limits** section is *not* highlighted **red**. Ideally it will be highlighted **green**.

User Inputs	
Wavelength (nm)	675
Laser Output Power (mW)	5000
First Attenuation Optic	ND-2
Second Attenuation Optic	ND-2
Third Attenuation Optic	ND-4
Gaussian Waist Diameter (um)	1000

Estimated CW Exposure Time (ms)
1.29

Figure 8: Standard ND filter(s) are selected to reduce the sensor irradiance to within saturation limits.

2. Ensure no elements are above their damage threshold.

- (a) Check the CW Measurement section to observe whether any element is highlighted in red which indicates it is above its damage threshold (Figure 9).

CW Measurement					
Element	Irradiance (mW/cm ²)	Power (W)	Damage Threshold (mW/cm ²)	Power Limit (W)	Diameter (um)
ND-2	1272295.192	5	449991	1.768422888	707.37
ND-2	12739.58553	0.050052076	450051	1.768188105	707.28
ND-4	127.5549406	0.000501042	450098	1.768005108	707.20
S-WCD-LCM Sensor	0.012715723	4.99345E-08	10	3.92699E-05	707.11

Figure 9: The first ND filter is expected to be damaged, so a higher power-handling option must be chosen instead.

- (b) If an element is above its damage threshold, a different attenuation option with higher power handling must be chosen instead as the first element. The PPBS or CBS attenuation products have the highest damage thresholds available.

CW Measurement					
Element	Irradiance (mW/cm ²)	Power (W)	Damage Threshold (mW/cm ²)	Power Limit (W)	Diameter (um)
PPBS-FS	1270855.113	5	398245683	1566.841408	707.77
ND-2	691.5109749	0.002716851	450051	1.768188105	707.28
ND-4	6.923744975	2.71968E-05	450098	1.768005108	707.20
S-WCD-LCM Sensor	0.000690216	2.71047E-09	10	3.92699E-05	707.11

Figure 10: The PPBS-FS beam sampler has a higher damage threshold to safely replace the first ND filter.

- Ensure that the relevant box in the Saturation Limit section is still highlighted Green (Figure 11). If it is red, then the second and third attenuation options should be changed. Ideally standard ND filters can be chosen for these options.
- Your attenuation option(s) are now satisfactory if none of the results are highlighted red. Be sure that you have the available working distance necessary for the chosen attenuation option(s), and that the options are appropriate for your wavelength.
- Setup the beam profiling system with the selected attenuation options and begin a measurement.
 - Following all relevant safety procedures, begin a measurement with the chosen attenuation and beam profiler.
 - Ideally, the selected attenuation will provide good measurements.
 - If the exposure time is at a minimum and the sensor is saturated, additional attenuation should be added. If the exposure time is at a maximum and the sensor is not receiving enough signal, attenuation should be lowered in the smallest steps available until signal level is adequate. The ND-filters included with every standard camera purchase allow, through various combinations, nominal OD values of 1 to 6 in steps of 1.

Estimated CW Exposure Time (ms)
23.68

Figure 11: The PPBS-FS beam sampler provides more attenuation than the ND-2 it replaced, so the estimated exposure time increases but the sensor is still within the recommended saturation limits.

Special Cases

Pulsed Lasers

The steps are the same for pulsed lasers, but now *both* CW and Pulse damage thresholds must be satisfied. Also, depending on the repetition rate and application it must be decided whether the beam will be measured as quasi-CW (average of several pulses) or as single pulses. This will determine which box is relevant in the **Saturation Limits** section.

Pulse widths shorter than 1 ns cannot be reliably predicted using our LIDT data because these ultra-short pulses can have damage mechanisms not present in our LIDT testing. The spreadsheet will still scale the LIDT accordingly, but the accuracy of the prediction may decrease with the results highlighted yellow as a warning.

Scanning Slit Profilers (Beam'R2/BeamMap2)

Scanning slit profilers are unique because the beam focus is on the slit rather than the detector. Only a fraction of the beam passes through the slit at a time. The detector has a very wide Gain range that is adjusted automatically, with high sensitivity at high gain. This usually results in the maximum saturation threshold of the sensor being higher than the damage threshold of the slits. In this case, the **Saturation Limits** section can be ignored and only damage thresholds need to be considered.

WinCamD-IR-BB

The WinCamD-IR-BB has a saturation threshold and measurement range that is close to the sensor's damage threshold. It is therefore very important to stay below the saturation threshold to avoid damage. Because the attenuation calculations are estimates, it is best to start with more attenuation as a precaution. It is also recommended to walk the beam on the sensor from the edge. The physical shutter will automatically close when saturation is reached in an attempt to prevent sensor damage.

Additional Notes

Beam Diameter

Beam diameter is important because irradiance and fluence scale quadratically with beam size. The beam diameters used in the spreadsheet calculations are automatically scaled by a factor of $\sqrt{2}/2$ because the irradiance calculation assumes a flat circular profile. The irradiance of a Gaussian beam is approximately twice the irradiance of an equivalent diameter flat circular beam, so the scaled beam diameter results in an equivalent irradiance flat circular beam. In ISO standard 21254, this is known as the *effective beam diameter*.

The beam diameter is not constant as the beam propagates, so the spreadsheet calculates the diameter in accordance with known Gaussian propagation properties assuming the beam waist is located on the measurement plane.