SO0001

LASER-INDUCED DAMAGE THRESHOLD (LIDT) MEASUREMENT REPORT

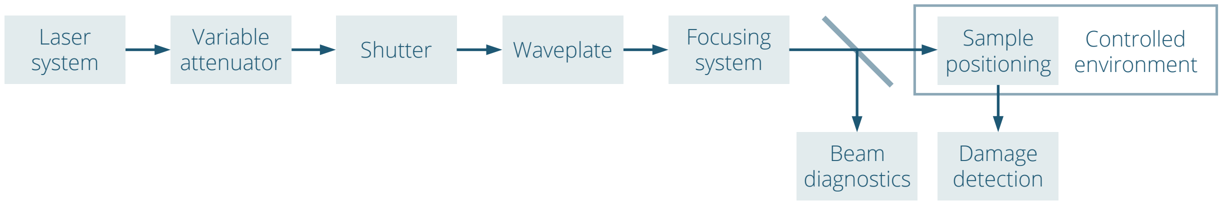
CLASSICAL LIFETIME TEST BASED ON S-ON-1 (INTERVALS) PROCEDURE

SAMPLE: SAMPLE

Request from	
Address	Company Address Line 1 Address Line 2 Country
Contact person	Name Surname
Inquiry ID	0001
Purchase order	-
Testing institute	
Address	UAB Lidaris Saulėtekio al. 10 10223 Vilnius Lithuania
Tester	Name Surname
Test date	01/07/2023
Sale order	SO0001
Test ID	-
Specimen	
Name	Sample
Type	HR Dielectric Coating
Dimensions	Ø20.0 x 5.0 mm
Packaging	Plastic box

TEST EQUIPMENT

Test setup

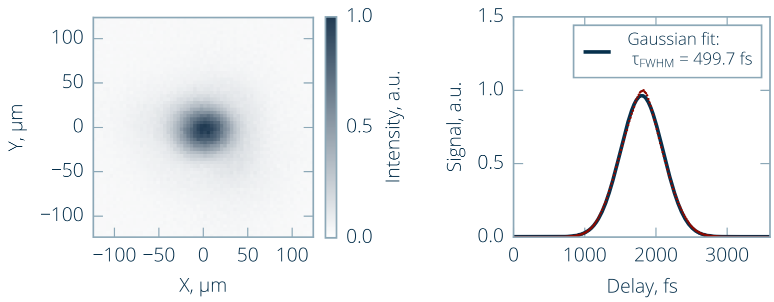


Laser and its parameters

Type	Mode-locked Yb:KGW
Manufacturer	Light Conversion
Model	Pharos SP
Central wavelength	343.0 nm
Angle of incidence	45.0 deg
Polarization state	Linear S
Pulse repetition frequency	20 kHz
Spatial beam profile in target plane	TEM00
Beam diameter in target plane ($1/e^2$)	(93.8 ± 1.0) µm
Longitudinal pulse profile	Kerr-lens mode-locked
Pulse duration (FWHM)	499.7 fs (assuming Gaussian pulse shape)
Pulse to pulse energy stability (SD)	0.4 %

Energy/power meter

Manufacturer	Ophir
Model	12A-P
Calibration due date	2024-12



(a) Beam profile (b) Pulse profile

Figure 1. Laser parameters used for measurements.

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TEST SPECIFICATION

Definitions and test description

Laser-induced damage (LID) is defined as any permanent laser radiation induced change in the characteristics of the surface/bulk of the specimen which can be observed by an inspection technique and at a sensitivity related to the intended operation of the product concerned. Laser-induced damage threshold (LIDT) is defined as the highest quantity of laser radiation incident upon the optical component for which the extrapolated probability of damage is zero. [1]

LID of the sample is investigated by performing a standardized S-on-1 test procedure.[2] LIDT value is determined by taking the average of the highest fluence value before which no damage was observed and the lowest fluence value at which damage was first observed.

Test sites

Number of sites	350
Arrangement of sites	Hexagonal
Minimum distance between sites	390 μm
Maximum pulses per site	1000000

Analysis information

Online detection	Scattered light diode
Offline detection	Nomarski microscope
Software version	b9b713f1

Test environment

Environment	Air
Cleanroom class (ISO 14644-1)	ISO7
Pressure	1 bar
Temperature	22.2 - 22.3 C
Humidity	36.9 - 37.1 %

Sample preparation

Storage before test	Normal laboratory conditions
Dust blow-off	Canned air
Cleaning	None

[1] ISO 21254-1:2011: Lasers and laser-related equipment - Test methods for laser-induced damage threshold - Part 1: Definitions and general principles, International Organization for Standardization, Geneva, Switzerland (2011)

[2] ISO 21254-2:2011: Lasers and laser-related equipment - Test methods for laser-induced damage threshold - Part 2: Threshold determination, International Organization for Standardization, Geneva, Switzerland (2011)

LIDT TEST RESULTS

LIDT VALUE

10^6-on-1	$0.0782^{+0.0098}_{-0.0093}$ J/cm^2

CHARACTERISTIC DAMAGE CURVE

Table 1: Estimated LIDTs from fiting model for sample Sample.

Test mode	Threshold (Catastrophic)	Threshold (Color mode)
1-on-1	$0.612^{+0.038}_{-0.037}$ J/cm^2	$0.4741^{+0.0321}_{-0.0311}$ J/cm^2
10-on-1	$0.548^{+0.032}_{-0.031}$ J/cm^2	$0.4533^{+0.0293}_{-0.0285}$ J/cm^2
10^2-on-1	$0.530^{+0.027}_{-0.027}$ J/cm^2	$0.4231^{+0.0274}_{-0.0267}$ J/cm^2
10^3-on-1	$0.519^{+0.032}_{-0.032}$ J/cm^2	$0.4078^{+0.0265}_{-0.0258}$ J/cm^2
10^4-on-1	$0.511^{+0.030}_{-0.029}$ J/cm^2	$0.3136^{+0.0211}_{-0.0205}$ J/cm^2
10^5-on-1	$0.511^{+0.029}_{-0.029}$ J/cm^2	$0.1893^{+0.0153}_{-0.0147}$ J/cm^2
10^6-on-1	$0.511^{+0.029}_{-0.029}$ J/cm^2	$0.0782^{+0.0098}_{-0.0093}$ J/cm^2

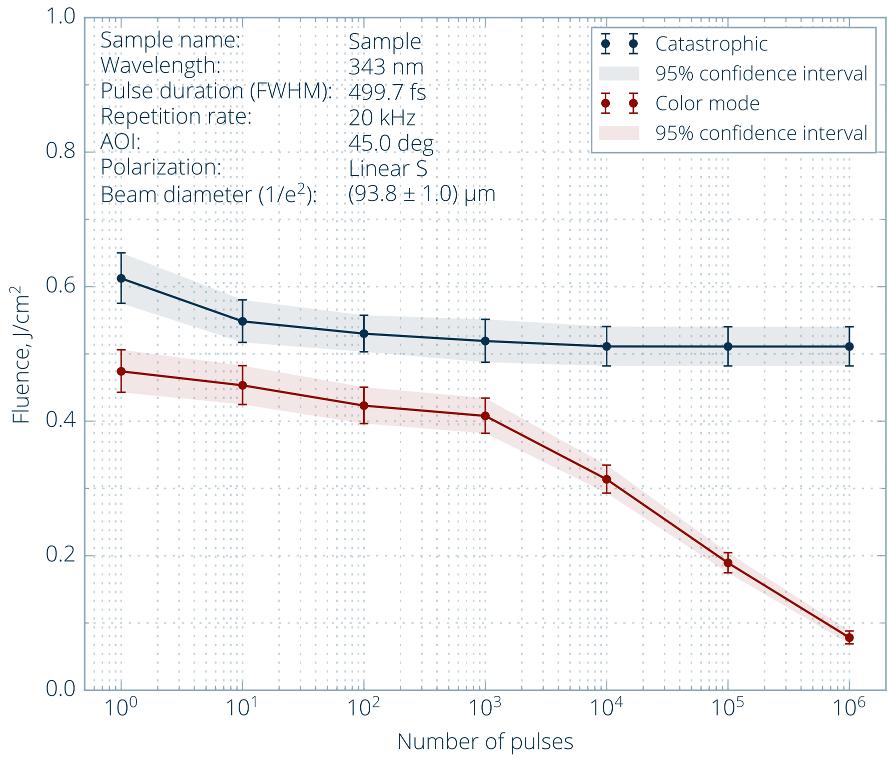
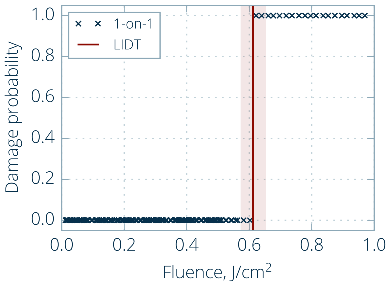
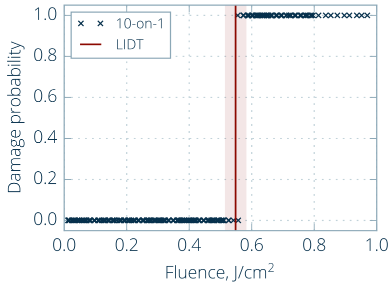


Figure 2. Characteristic damage curve.

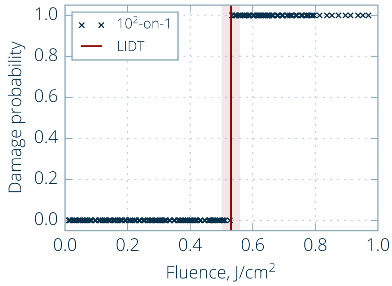
DAMAGE PROBABILITY (CATASTROPHIC)



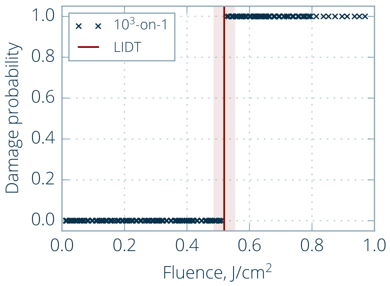
(a) 1-on-1



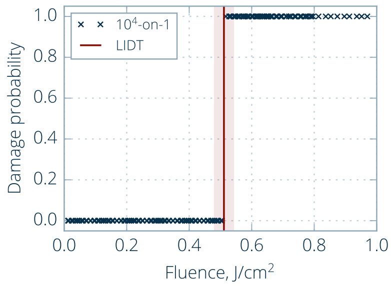
(b) 10-on-1



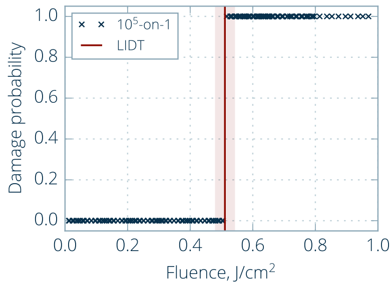
(c) 10^2-on-1



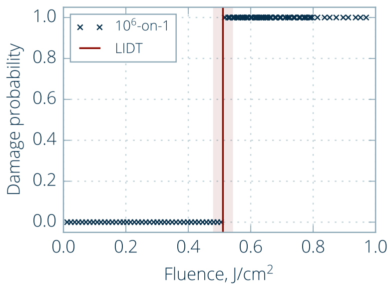
(d) 10^3-on-1



(e) 10^4-on-1



(f) 10^5-on-1



(g) 10^6-on-1

Figure 3. Damage probability plots.

TYPICAL DAMAGE MORPHOLOGY (CATASTROPHIC)

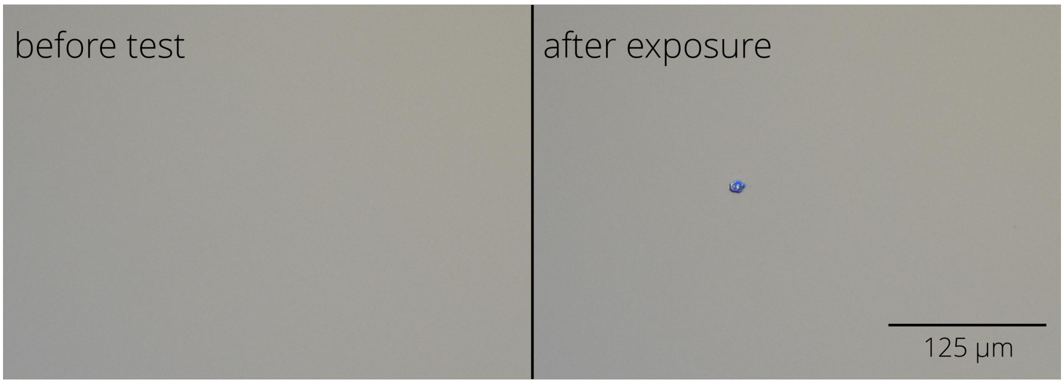


Figure 4. Typical damage morphology: fluence 0.753 J/cm^2, damage after 11 pulse(s).

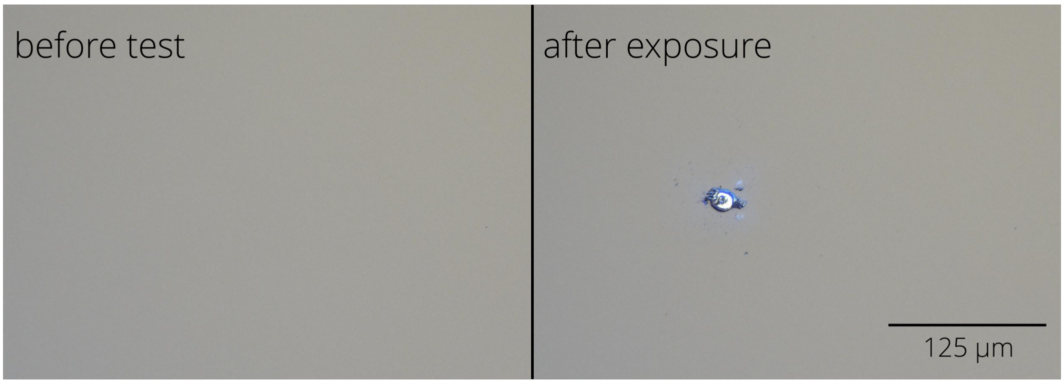
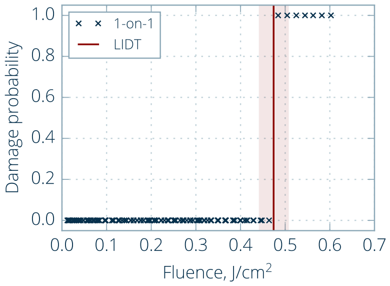
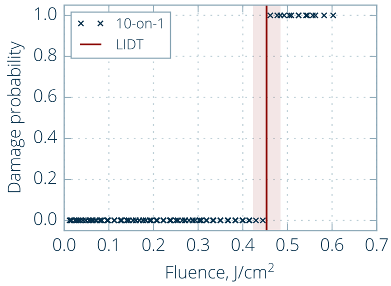


Figure 5. Typical damage morphology: fluence 0.802 J/cm^2, damage after 3 pulse(s).

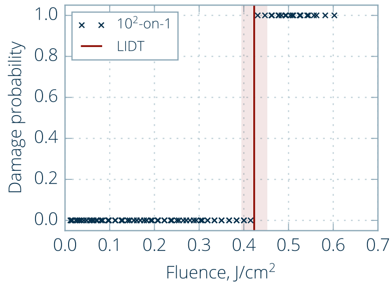
DAMAGE PROBABILITY (COLOR MODE)



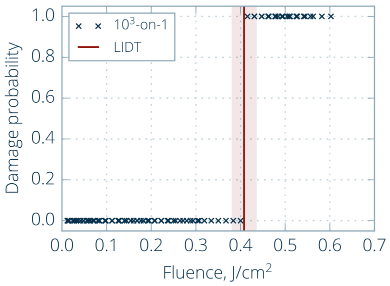
(a) 1-on-1



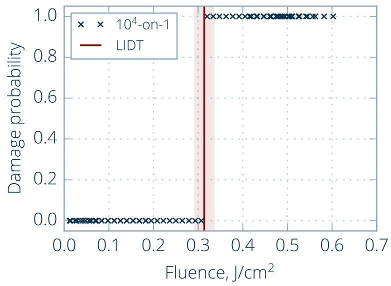
(b) 10-on-1



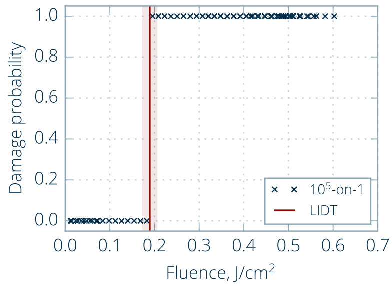
(c) 10^2-on-1



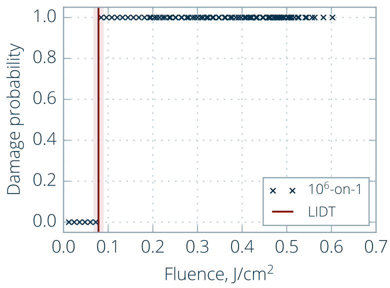
(d) 10^3-on-1



(e) 10^4-on-1



(f) 10^5-on-1



(g) 10^6-on-1

Figure 6. Damage probability plots.

TYPICAL DAMAGE MORPHOLOGY (COLOR MODE)

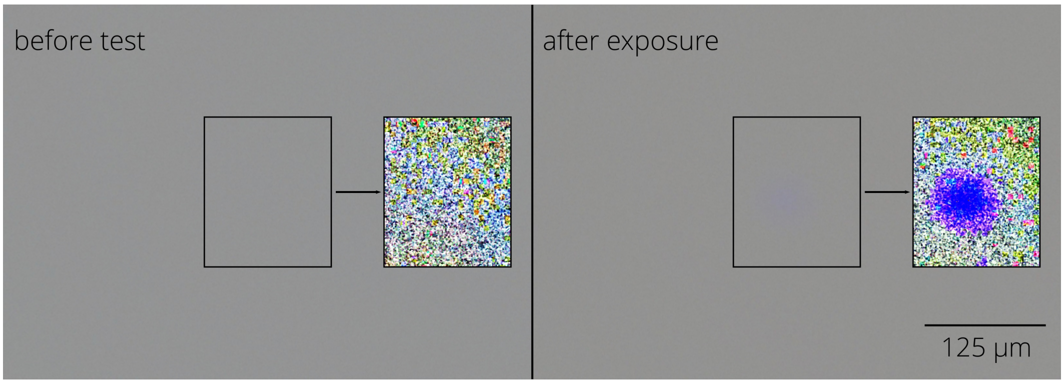


Figure 7. Typical damage morphology: fluence 0.141 J/cm^2, damage after 1000000 pulse(s). High contrast image.

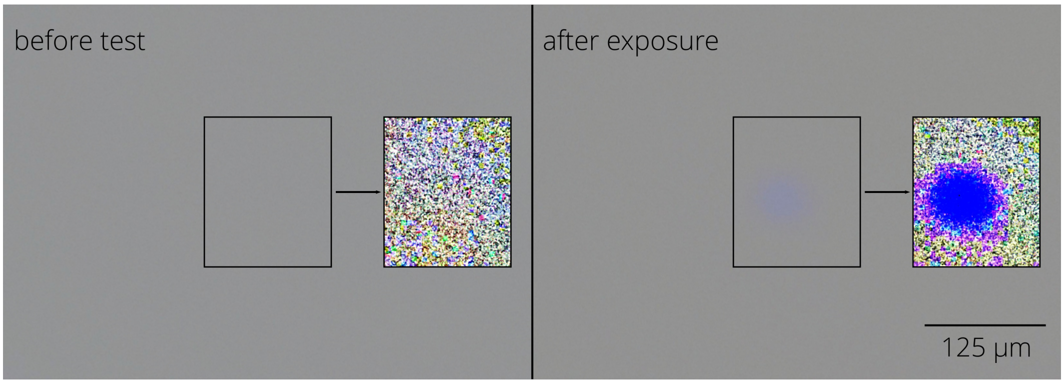


Figure 8. Typical damage morphology: fluence 0.220 J/cm^2, damage after 1000000 pulse(s). High contrast image.

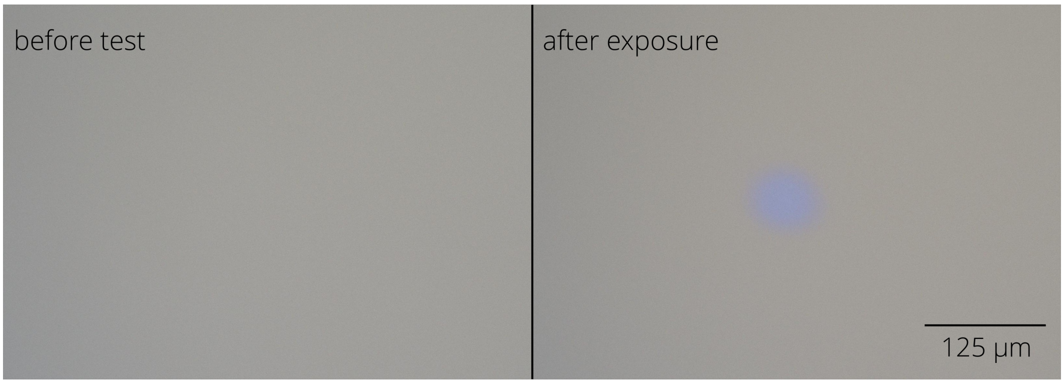


Figure 9. Typical damage morphology: fluence 0.402 J/cm^2, damage after 1000000 pulse(s).

LIFETIME EXTRAPOLATION

Lifetime of optical component is estimated by constructing a model that combines a stress-life relationship (fatigue relationship) together with lifetime distribution at a single stress (fluence – *F*) level [3]. Point estimate of the model is evaluated by performing maximum a posteriori probability estimation while the credible intervals for each of the parameters are determined using Markov chain Monte Carlo (MCMC) technique.

Lifetime distribution is assumed to follow log-normal distribution. Probability density function Φ of log-normal distribution is expressed as:

$$\Phi(t,\mu,\sigma) = \frac{1}{\sigma t}\frac{1}{\sqrt{2\pi}}\exp\left(-\frac{\left(\frac{\log(t)-\mu}{\sigma}\right)^2}{2}\right)$$

where t – irradiation time, μ – log-location parameter, σ – log-scale parameter.

SUMMARY OF LIFETIME EVALUATION

Catastrophic fatigue limit (F_0)	$0.5130\,^{+0.0039}_{-0.0193}\,J/cm^2$

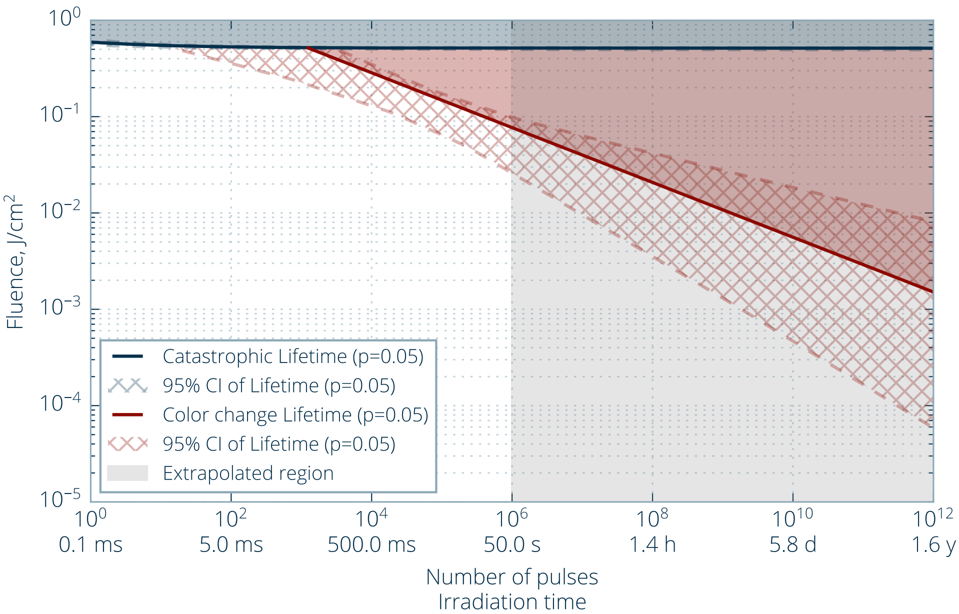


Figure 10. Summary of lifetime evaluation.

[3] Linas Smalakys and Andrius Melninkaitis, Predicting lifetime of optical components with Bayesian inference, Opt. Express 29, 903-915 (2021)

CATASTROPHIC LIFETIME EVALUATION

Stress-life relationship (fatigue relationship) for Catastrophic damages is assumed to follow an inverse power relationship (parameters $y_{0,\mu}$ and $y_{1,\mu}$) with fatigue limit F_0 while the log-scale parameter of log-normal distribution is assumed to be constant (parameter $y_{0,\sigma}$):

$$\mu(F) = y_{0,\mu} - y_{1,\mu} \log(F - F_0)$$

$$\sigma(F) = y_{0,\sigma}$$

Catastrophic fatigue limit (F_0)	$0.5130\ ^{+0.0039}_{-0.0193}\ J/cm^2$

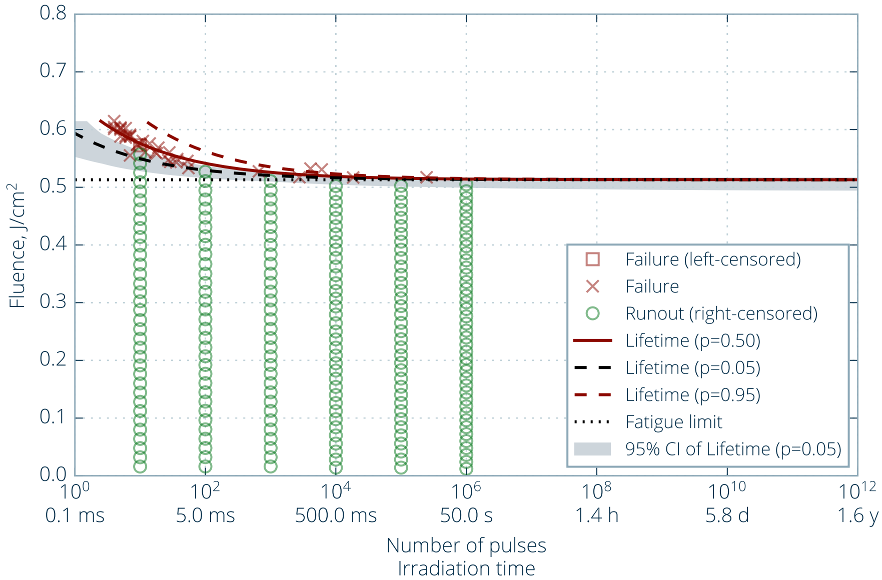


Figure 11. Lifetime extrapolation for Catastrophic damages.

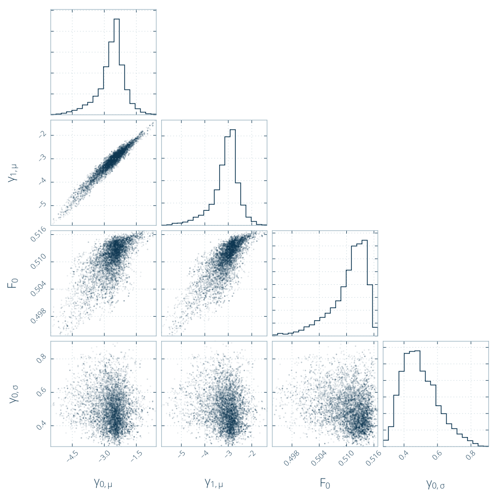


Figure 12. Corner plot of MCMC samples for Catastrophic damages.

COLOR MODE LIFETIME EVALUATION

Stress-life relationship (fatigue relationship) for Color mode damages is assumed to follow an inverse power relationship (parameters $y_{0,\mu}$ and $y_{1,\mu}$) while the log-scale parameter of log-normal distribution is assumed to be constant (parameter $y_{0,\sigma}$):

$$\mu(F) = y_{0,\mu} - y_{1,\mu} \log(F)$$

$$\sigma(F) = y_{0,\sigma}$$

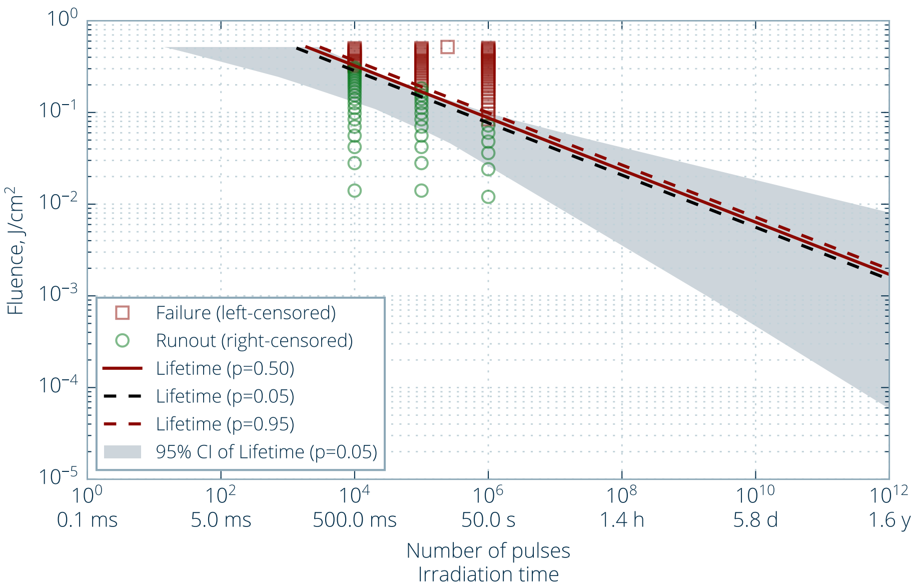


Figure 13. Lifetime extrapolation for Color mode damages.

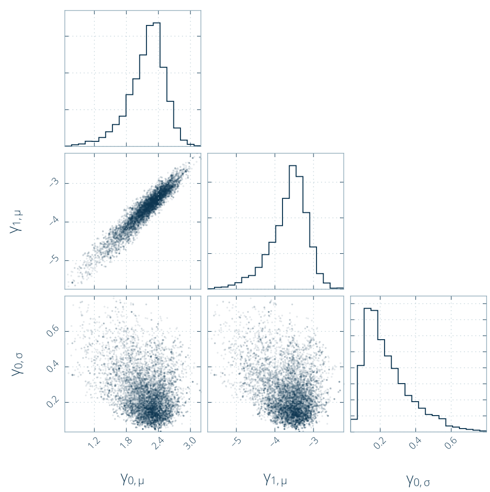


Figure 14. Corner plot of MCMC samples for Color mode damages.

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TECHNICAL NOTES

TECHNICAL NOTE 1: Oblique incidence

According to the ISO 21254-2:2011 standard, for spatial beam profiling perpendicular to the direction of beam propagation and angles of incidence differing from 0 degrees, the cosine of the angle of incidence is included in the calculation of the effective area, which leads to correct evaluation of laser fluence at different angles of incidence (Figure 15).

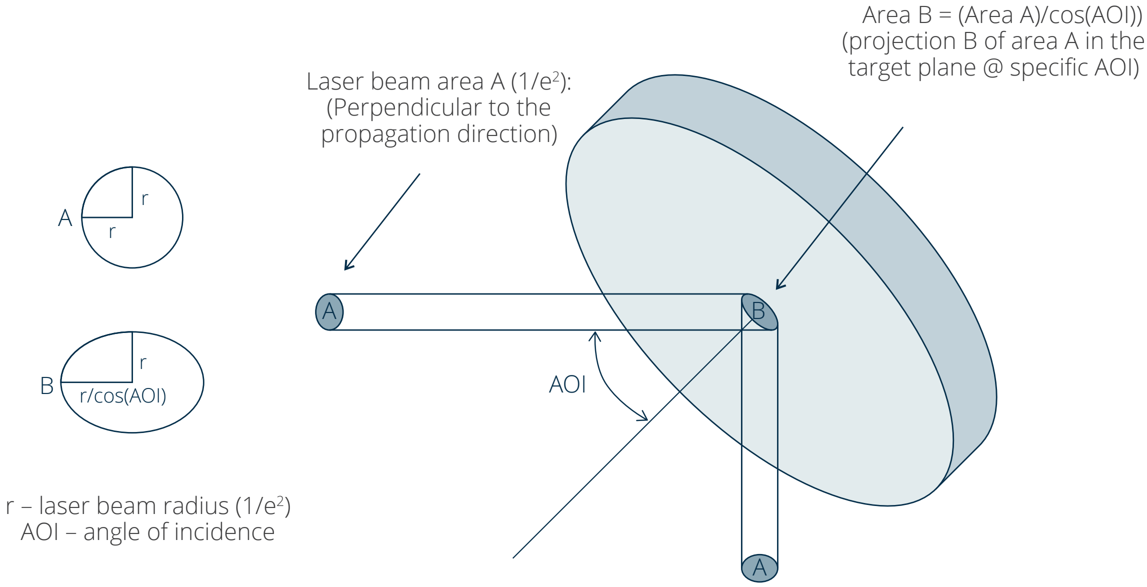

Figure 15. Oblique incidence.