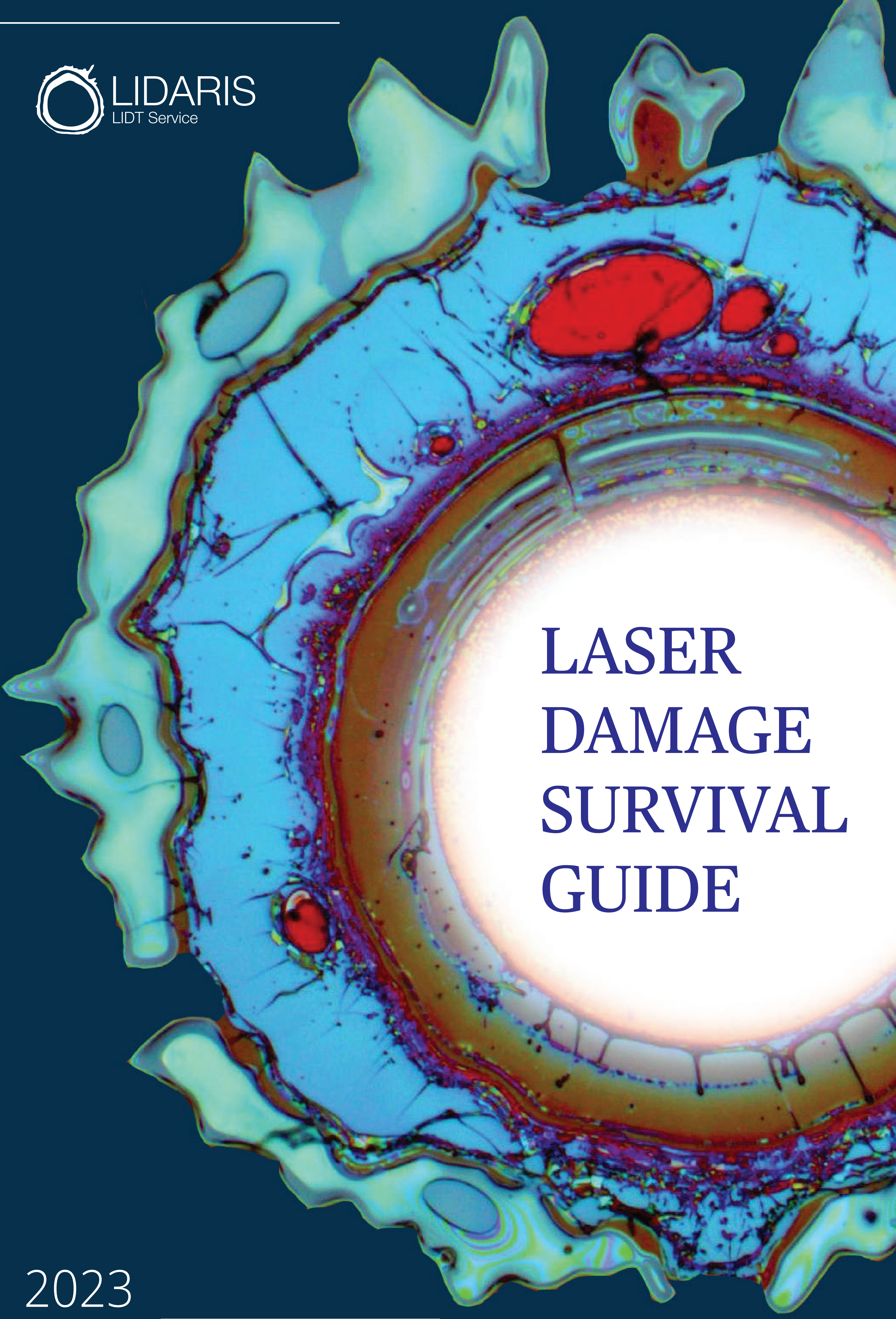
LIDARIS
LIDT Service



LASER DAMAGE SURVIVAL GUIDE

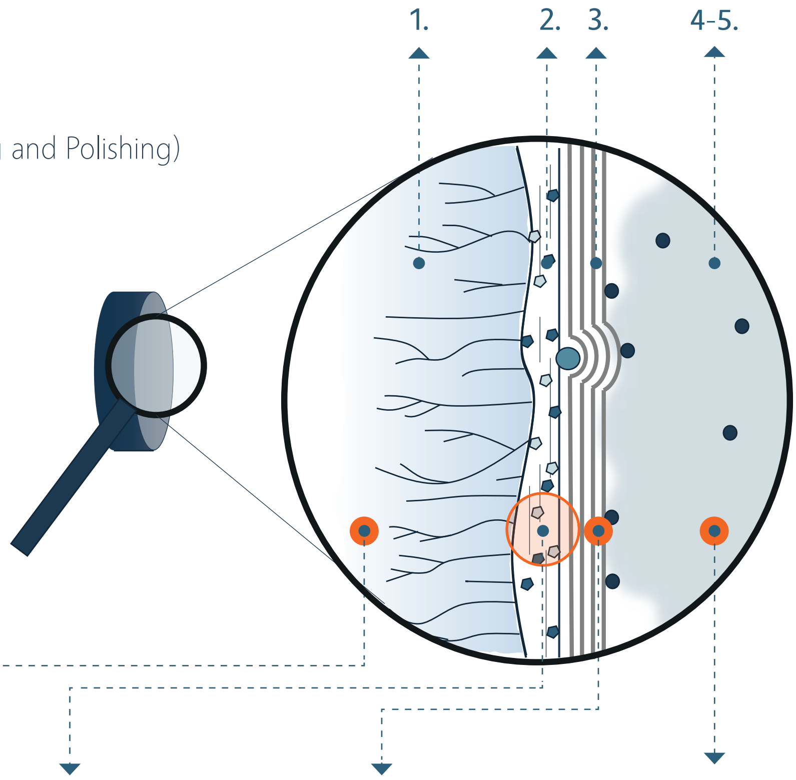
2023

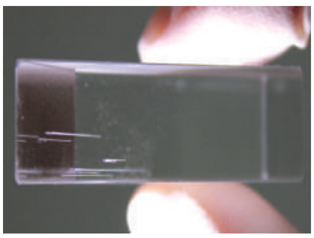
WHAT CAUSES LASER DAMAGE IN OPTICS?

Optical elements produced in classical way consist of multiple hidden layers. When the element is exposed to intense laser irradiation, each of its layers can fail due to different physical mechanisms (failure modes).

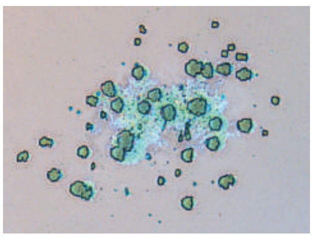
1. Sub-Surface Damage (Grinding and Polishing)
2. Polishing (Beilby) Layer
3. Nodular Defects
4. Airborne Particles & Organics
5. Laser-Induced Contamination

Get an even more detailed explanation of the defects found in your optics by booking a meeting with the expert team at Lidaris



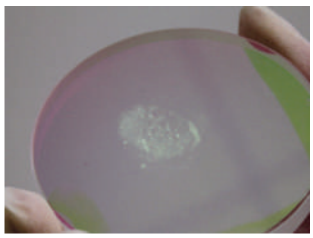


Bulk Damage
Failure Mode:
Self Focusing



Surface Damage
Failure Mode:
Subsurface
& Nodular Defects

Surface Damage
Failure Mode:
Light Absorptance
& Fatigue



Surface Damage
Failure Mode:
Contaminations

In the high-power laser market, it's not a question of "if", but rather a question of "when" optical elements will get damaged!

Often laser-induced damage can not be avoided, but it can be properly managed. This can be achieved by either measuring LIDT - **Laser-Induced Damage Threshold**, predicting Optic's Lifetime or Certification "pass" or "fail" testing. LIDT is a critical peak power or peak fluence of laser irradiation causing irreversible changes in material's structure.

HOW CAN I SURVIVE LASER DAMAGE

IF

I produce laser optics?

- develop optics of high LIDT
- ensure repeatability and quality of each batch
- figure out "what went wrong" if optics get returned as "damaged"

I distribute or sell laser optics?

- guarantee that sold optics will not break at various irradiation conditions
- find who provides good optics
- know if LIDT can be used as a unique selling point.

I integrate optics to laser systems?

- avoid bad quality optics in my system
- understand laser damage
- perform custom tests of optic's functional performance
- find trusted optics vendors

LIDARIS
LIDT Service
can help with:

- Partnership in optics R&D projects
- Quality checking of production batches
- Root cause analysis of Optics Failure
- Education in Laser Damage Metrology

- LIDT testing/certification
  - CW-NS-PS-FS
  - From IR to UV
  - Air, vacuum
- Benchmark:
  - Vendors
  - Competitors
  - Batches/items
- Education in Laser Damage Metrology

- ISO based and custom LIDT tests for high throughput screening of bad optics
- Optics lifetime testing
- Low-loss absorption
- Thermovision
- Wavefront sensing
- Education in Laser Damage Metrology

WHAT'S NEW AT LIDARIS?

LIDT testing of optics at CW regime

High-power laser source:

- Yb: Fiber Laser;
- 1070 nm;
- 6 kW average power.

Laser source:

- Erbium Fiber Laser;
- 1.5 µm, single-mode;
- 100 W average power.

Wavefront sensing and thermovision

- Available at CW regime.
- Possibility to monitor and investigate laser-induced wavefront and temperature changes versus power.
- Testing of functional damage.

Low loss absorption measurements

- IR-VIS-UV.
- Based on PCI (Photothermal Common-Path Interferometer).
- Absorption tests:
  - L-scans, T-scans, Time scans.
- Endurance tests.

International RnD activities

- Project ESPRESSO II in cooperation with the European Space Agency: R&D of high-power space optics longevity qualification procedure.
- Participation in LIDT testing ISO-21254 standard review board.

Optics lifetime estimation

- Currently available for high-repetition rate FS and PS laser pulses.
- Other testing regimes and customized testing routines available upon request (please ask).

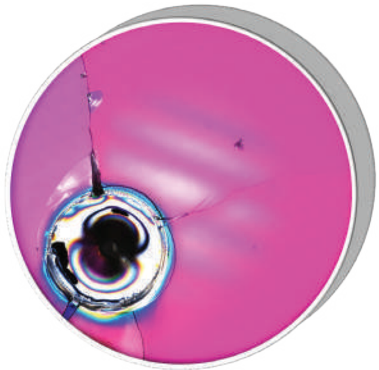
Advancing LIDT measurement reports

- Under request reports will include:
  - Laser-induced damage classification according to failure modes based on damage morphology;
  - Analysis (statistics) of initiated objects (damages) on the optics surface occurring with increased fluence during the raster scan.

CW TESTING CAPABILITIES AT LIDARIS

LIDT testing at CW regime is available now!

Laser damage induced at CW laser irradiation is usually related to thermal absorption. Due to the different damage mechanisms, LIDT measured at the pulsed regime cannot be recalculated to the CW regime. Thermal laser damage is often extremely destructive. Shattered optics can cause serious harm to the surroundings and operators. **Test your high-power CW optics to avoid unexpected breakage!**



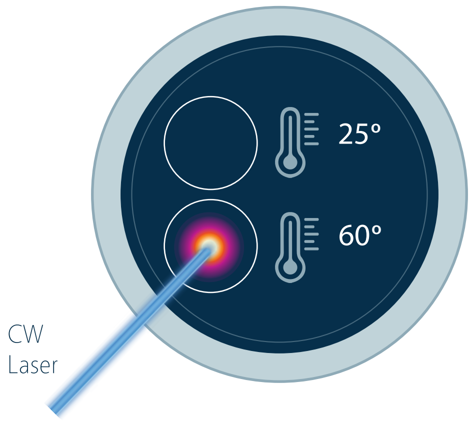
Available testing conditions

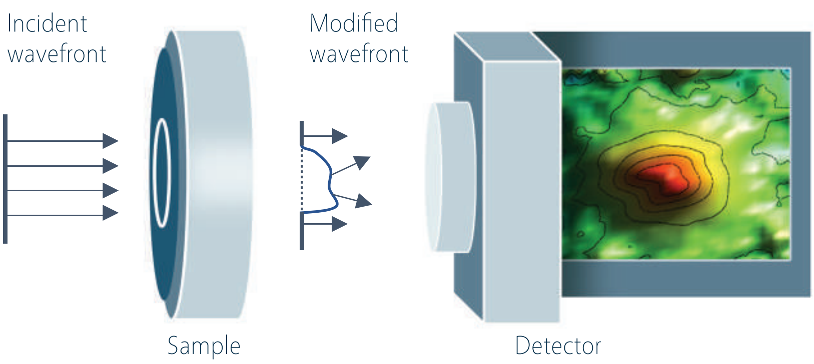
Laser source	Average power, W	Wavelengths, nm	Application
Yb (Fiber Laser)	6000	1070	Tunable single shot: 1 ms - 60 s(1) LIDT testing & raster scanning
Er (Fiber Laser)	100	1567	LIDT testing & raster scanning for metallic coatings

(1) Longer exposure times are available on demand.

Wavefront sensing and thermovision

When exposed to intense laser irradiation, spectral properties of the optical element can change at lover irradiation level than laser-induced damage (especially in the CW regime). The increased surface temperature can cause thermal lensing, wavefront deformation, defocusing of incident laser light, etc. In a sense, the optical element will be functionally damaged, because it will lose its intended specification. Thus, in this case, **the functional laser damage criteria** should be determined.





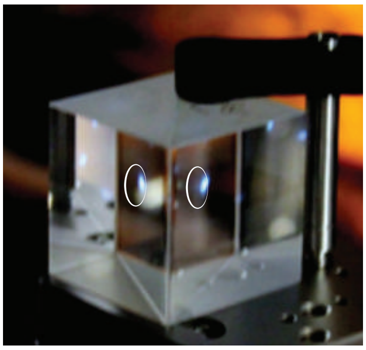
Wavefront sensing

Thermovision

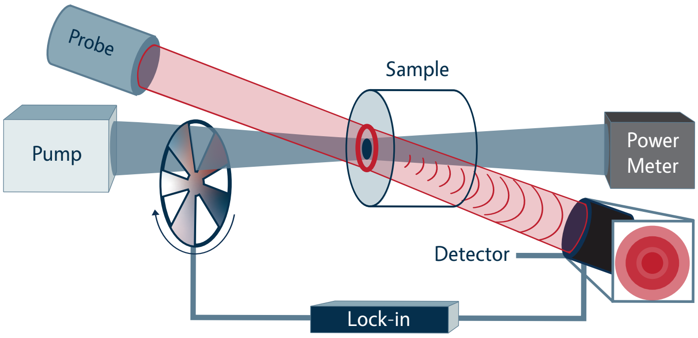
To address these important issues, **Lidaris upgraded the CW test bench with capabilities to monitor temperature on the sample surface and wavefront changes.** Contact us to learn how this procedure can be applied to your specific case.

ABSORPTION TESTING OF OPTICAL COATINGS

The absorptance of the optical element is not a constant, but rather a quantity that is dependent on location, intensity, and time. **Photothermal Common-path Interferometry (PCI)** is probably the most popular option for characterization of low loss **optical absorptance** of dielectric coatings **at ppm level.**



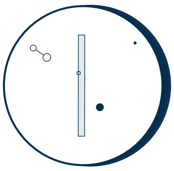
How does it work?



It is a spatially resolved pump-probe technique. The focused pump beam creates local increase of the sample temperature, which in turn modifies the local refractive index of the material. Such modification is sensed by a low-intensity probe beam. An interference pattern is created on the detector after propagating through the free space. Amplitude of the temperature modulation can be taken to be proportional to the absorbed power and thus to the local absorption.

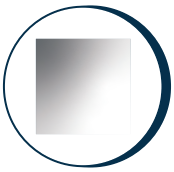
Available testing protocols

1D surface absorption measurement (T-scan)

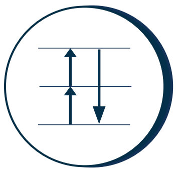


Longitudinal scan can distinguish front-, back surface and bulk (L-scan)

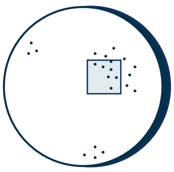
2D surface absorption sample homogeneity test (large area scan)



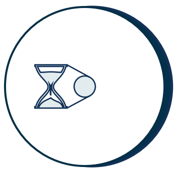
Nonlinearity test



2D surface absorption of scratches & digs (high resulution area scan)



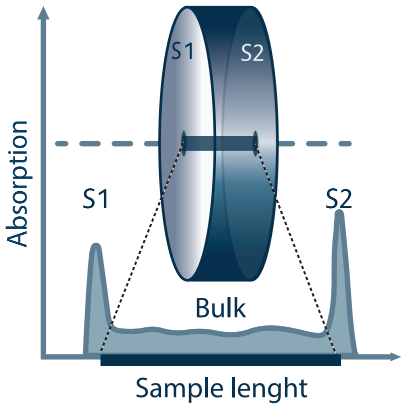
Time-dependence of absorption on a single point (Time scan)

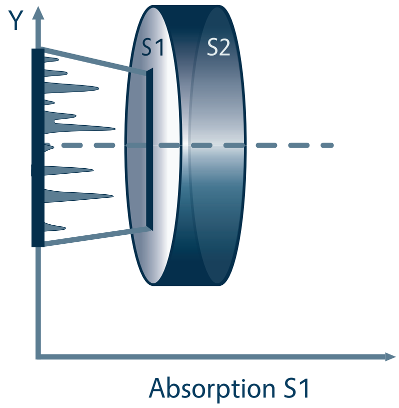


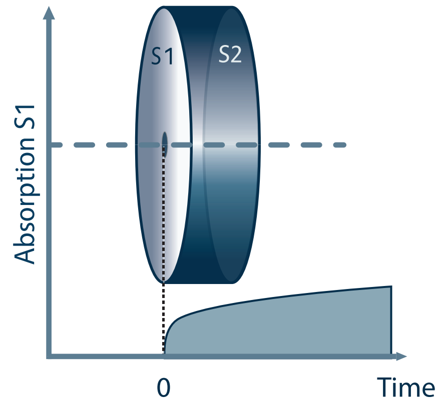
Upon request custom measurements are also available using any combination of available measurement protocols (Longitudinal, Time, Transverse, Area or Nonlinear Scans).

ABSORPTION TESTING OF OPTICAL COATINGS

Laser light can be absorbed in the front surface, bulk, or rear side of the optical element. Furthermore, absorptance can change over time (increase, decrease or depend on the peak intensity). To ensure reliable and accurate results, minimum sample absorption characterization requires at least three types of scans: L(ongitudinal)-scan, Time-scan, and T(ransverse) scan.







Longitudinal scan (L-scan)

Absorption is measured in the direction parallel to the optical axis. This test is necessary to locate the surface of interest for further measurements. During this scan front-, back-, and bulk absorption of the optical element can be distinguished.

Transverse scan (T-scan)

Absorption is measured for the surface of interest (typically S1) in the direction perpendicular to the optical axis. Overall sample absorption is defined as the median value of the T-scan test. This test shows homogeneity of the absorbing surface.

Time scan

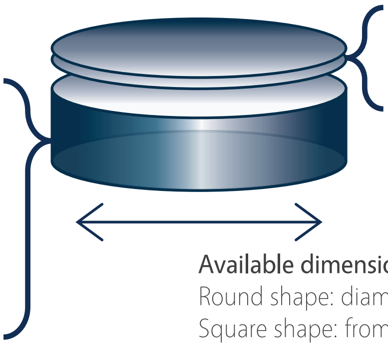
Absorption is measured at a single test site at the surface of interest for a prolonged period of time. Standard time scan is 10 min per single spot per test surface. This test shows if absorptance is dependent on time.

Available testing conditions and samples

Wavelenght, nm	Irradiation regime
1070	CW
532	q-CW, Mhz
Ask for availability	
1064	q-CW, Mhz
355	q-CW, Mhz
266	q-CW, Mhz

Acceptable samples are flat optics with coatings and known substrate material

Available substrates:
CaF2
Fused Silica (7980)
Quartz
N-BK7
ß-BBO
LBO
YAG



Available coatings:
Any thin film coating transparent at 632nm

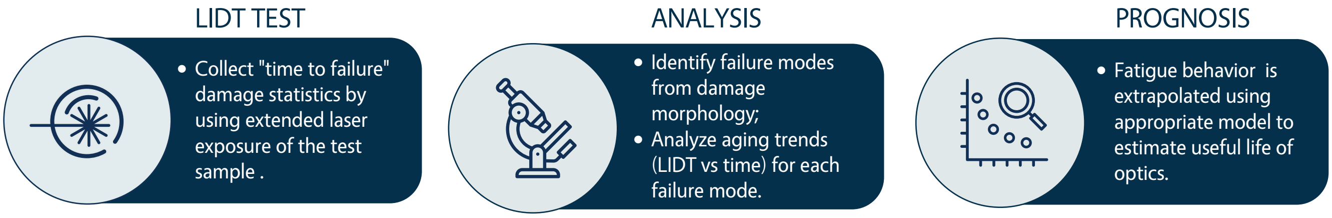
Available dimensions:
Round shape: diameter up to 50.8 mm
Square shape: from 5x5 to 50x50 mm

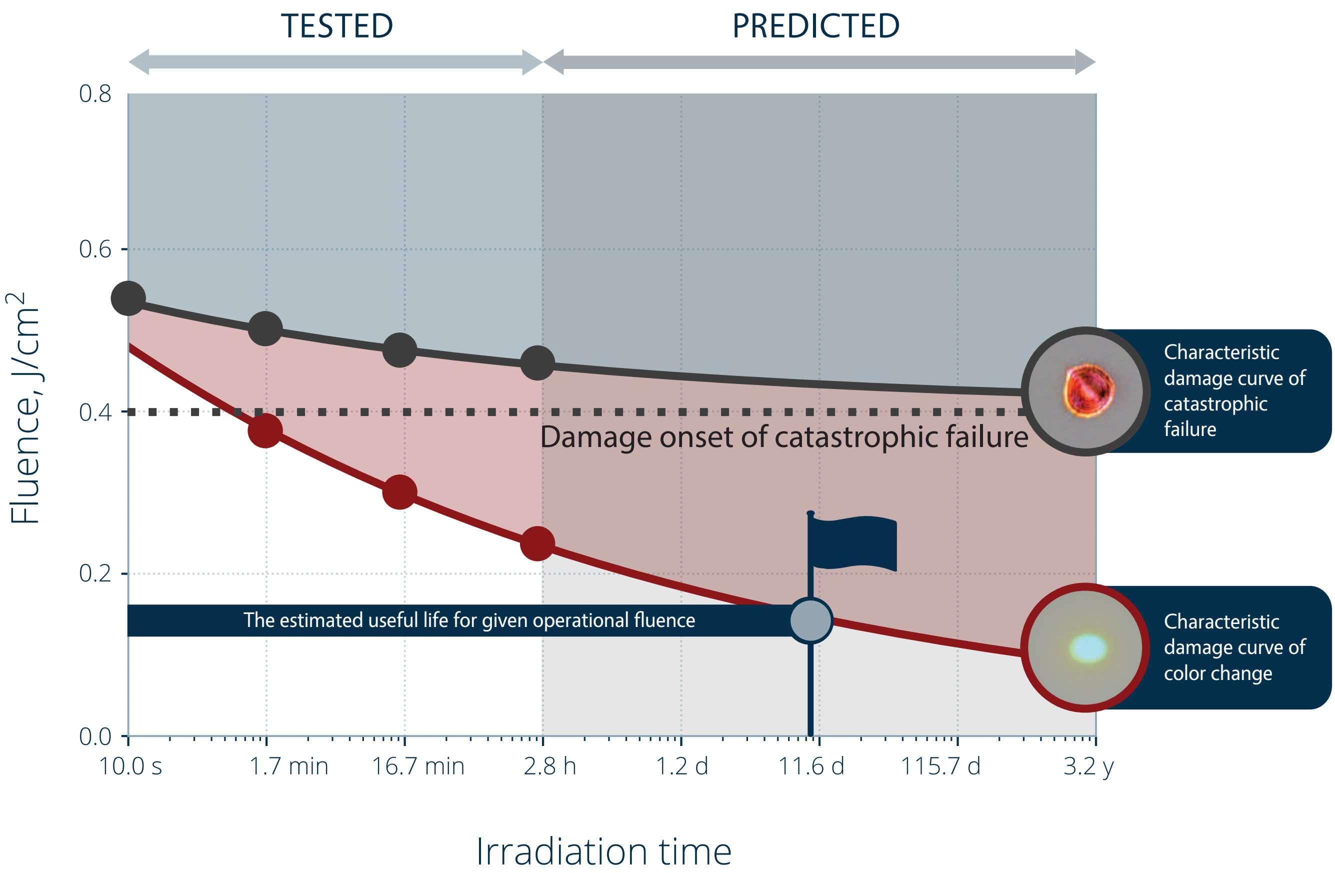
Each testing includes detailed measurement reports.

ACCELERATED LIFETIME TESTING OF FEMTOSECOND AND PICOSECOND OPTICS

Long-term failure-free operation is a goal of many industrial and scientific laser systems. However, typical LIDT testing usually is limited to irradiations lasting only a few seconds or minutes. To match real-life application requirements (such as years of uninterrupted laser operation) much longer testing is needed. Thus we employ novel statistical analysis techniques [1] to estimate the lifetime of optical components by characterization and prediction of optical fatigue behavior.

How does it work?

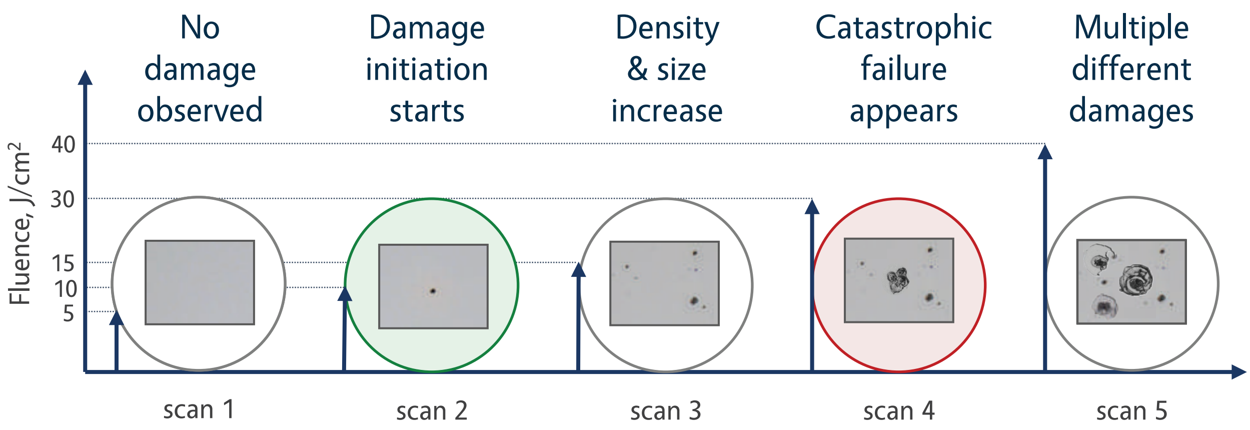




[1] L. Smalakys, A. Melninkaitis, "Predicting lifetime of optical components with Bayesian inference" Opt Express. 2021 Jan 18;29(2):903-915

RASTER SCAN PROCEDURE FOR BENCHMARKING LIDT OF LARGE OPTICS

Raster scan application for LIDT measurements is gaining popularity every year. It is a helpful procedure when the optical element has a low density of sporadic defects (other testing protocols tend to overestimate LIDT in this case). Also, raster scanning is often applied to certify large aperture optics and whenever there is a need to know the worst-case scenario. Now Lidaris provides even more information from standard raster scan tests. Introducing a new feature - **statistics of laser-induced surface objects as a function of laser irradiation level.**

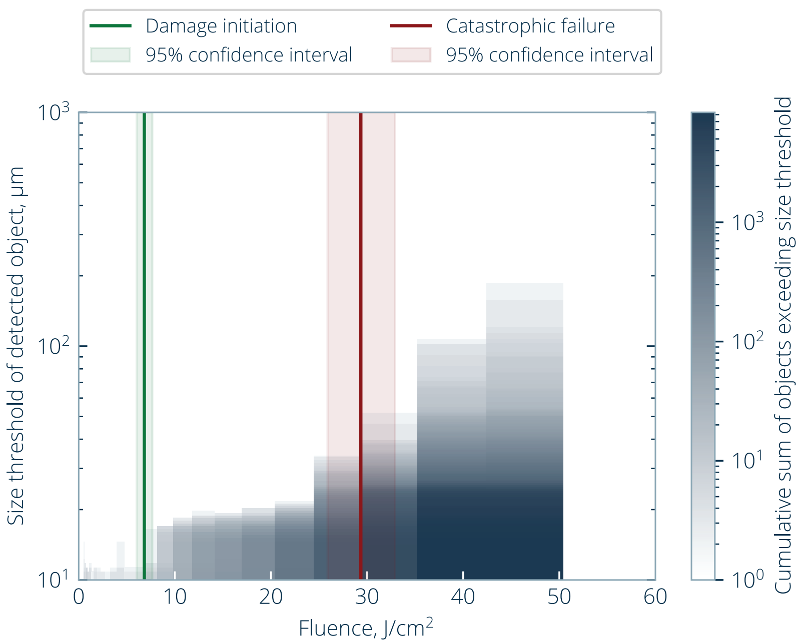


Single sample scanned multiple times with increasing laser fluence

How is it done?

Microscopic images are taken before the test and after each new scan. Then all images are analyzed for new objects (defects). A figure of new objects distribution displays the cumulative distribution of objects exceeding defined object size for each new scan level. New objects are distinguished from the surrounding area while applying various image analysis methods.

Contact Lidaris experts to learn more about the objects on your optical element!



AVAILABLE LIDT TESTING CONDITIONS

Most popular standard LIDT testing conditions with fast turnaround

Pulse range	Laser	Effective pulse duration [1]	Wavelengths, nm	Pulse repetition rate, Hz
CW	CW Ytterbium (Yb) Fiber Laser	30 s	1070	Single shot
ns	Nd:YAG (single mode)	10 ns 5 ns 5 ns ~5 ns	1064 532 355 266	100
ps-fs	Yb:KGW (Kerr lens mode-lock)	All tunable: 190 fs - 12 ps[2]	1030 515 343	1000 - 50000
fs	Ti:Sapphire (Kerr lens mode-lock)	45 fs	800	100 - 1000

Available irradiation conditions (check for availability)

CW: Ytterbium (Yb) Fiber Laser	Tunable: 1 ms - 30 s[3]	1070	Single shot or <500Hz
CW: Erbium (Er) Fiber Laser	Tunable: 2 ms - 30 s[3]	1567	Single shot or <500Hz
Nd: YAG (single- and multi-mode)	10 ns 5 ns 5 ns ~5 ns 4 ns	1064 532 355 266 213	1-100
Nd: YAG OPO (single mode)	~4 ns	710 - 810 1500 - 2100	1-100[2]
Yb: KGW (Kerr lens mode-lock)	135 ps at 1030 nm All tunable: 190 fs - 12 ps[2]	1030 515 343 258	Tunable: 1 -1000000[2]
Ti: Sapphire[3] (Kerr lens mode-lock)	135 ps at 800 nm Tunable: 45 fs - 12 ps[2] 45 fs - 1 ps 45 fs - 500 fs	800 400 266	Tunable: 10, 100, 1000
Ti: Sapphire OPO (Kerr lens mode-lock)	~40 - 80 fs	250 - 2500[4]	Tunable: 10, 100, 1000[2]

(1) Effective pulse duration measured at Full Width Half Maximum
(2) Maximum energy and pulse duration depend on the selected wavelength
(3) Longer exposure times are available on demand.
(4) Pulse duration at wavelengths <500 nm and >1600 nm is relative between 40 - 80 fs (please ask for availability at specific wavelength).
(5) at the CW regime curently only: 1) random polarization is available 2) the smallest available AOI: 12°

Available for all pulsed laser irradiation conditions: Polarization State: Circular/Linear (S, P); Different AOI: 0-75°; Test Environment: Air (room temperature), Vacuum (down to 10^{-6} mbar).

Fast turnaround (within 24 hours) upon request.
Typical turnaround 3-5 business days for standard testing configurations:
(NS regime: 1064 nm, 532 nm, 355 nm, 266 nm, FS regime: 1030 nm, 532 nm, 343 nm).

HOW TO CHOOSE THE APPROPRIATE LASER DAMAGE TESTING PROCEDURE?

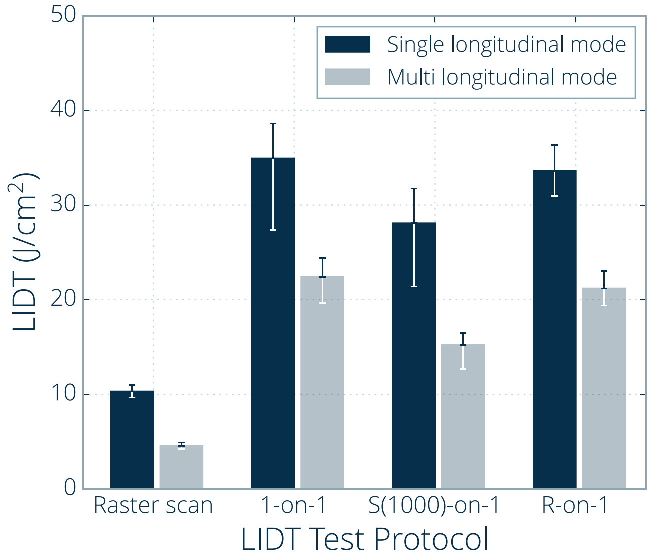
The LIDT is often reported as a single number, without mentioning the testing details. It creates the possibility to manipulate LIDT numbers. **The end-users should be careful when choosing a testing approach** as the meaning of reported LIDT could be different depending on the selected testing protocol and damage criteria.

In the award-winning research, Lidaris team members compared four LIDT testing protocols on a single HR mirror. The results show significant variation in measured LIDT values. It means that **each testing protocol is sensitive to different damage failure modes** (mechanisms).

To help our clients avoid confusion, the Lidaris team created useful guidelines on how to select the appropriate LIDT test protocol.

Award wining research at SPIE LASER DAMAGE 2020

All tests performed on a single HR sample: 1064nm, ~10ns, 0 deg.

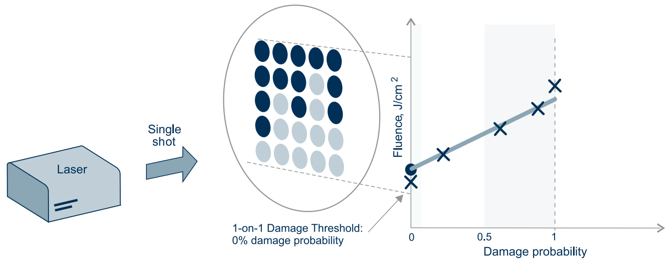


[2] R. Pakalnyte et al Laser-induced Damage in Optical Materials 2019, 1117318 (17 December 2019)

TEST PROTOCOL	USE THIS TEST PROTOCOL:	MOST COMMON RISKS:
Classical ISO 1-on-1	For fast screening (quick feedback) experiments: • to test LIDT driven by high-density defects; • to investigate the intrinsic LIDT of the material; - To optimize optic's manufacturing processes; - To test optical element when front-, back- or bulk are damaged simultaneously;	- **Overestimates LIDT for samples with low defect density;** - Fatigue (incubation) effects are not considered; - Annealing of neighboring test sites is possible at the CW regime;
Classical ISO S-on-1	- To characterize fatigue driven laser damage; - To investigate different laser damage failure modes; - To estimate optic's lifetime; - To compare your data with historical published data;	- **Overestimates LIDT for samples with low defect density;** - Time consuming if tested at low-frequency irradiation; - Annealing of neighboring test sites is possible if tested at high-frequency irradiation;
Functional ISO R(S)-on-1	- Only to measure a rough estimate of true LIDT; - To test samples with limited test area; - To study the conditioning effect (in combination with 1-on-1);	- **Not suited for samples with low defect density;** - Laser conditioning is possible; - Fatigue (incubation) effects are not considered; - Usually is time-consuming;
Functional Raster Scan Test	- To test samples with low-density (rare) defects; - To measure damage density as a function of irradiance level; - To study conditioning, annealing, or laser cleaning effects; - To study laser damage growth; - To test/certify large optics;	- **No fatigue (incubation) effects are considered;** - Laser conditioning is possible; - Usually is time-consuming; - LIDT can be incorrect due to contamination caused by surface ablation or poor handling; - Results can't be directly compared unless;
ISO Certification or "Pass-Fail" Test	- Preliminary screening of non-conforming optics; - Endurance testing; - Validation of optics lifetime predictions; - Routine testing;	- **False-negative results are possible in the case of:** • low defect density (use raster scan instead); • delayed fatigue effect (use extended irradiation dose if possible); - no information about LIDT;

ISO 1-on-1 test

The 1-on-1 test is a relatively simple technique for a "non-fatigue" LIDT determination.



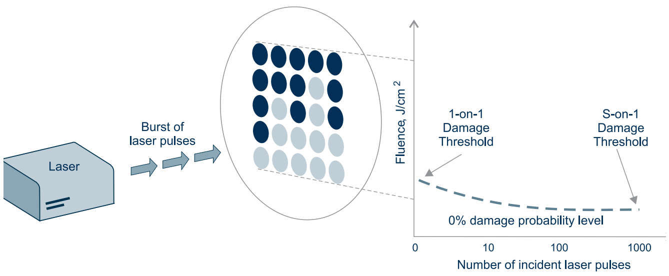
Principle: Every site on optic's surface is irradiated by a single laser pulse. The LIDT is estimated by fitting damage probability statistics versus applied pulse energy relation using appropriate extrapolation model.

Use this test for:

- Optics manufacture (polishing or coating) optimization.
- Investigation of fundamental material properties.
- Identification of distinct defects.
- Quick feedback and relative comparison of the samples.

ISO S-on-1 test

The S-on-1 test is the most common LIDT test. It is a multipulse procedure, which considers optics aging (fatigue) effects.



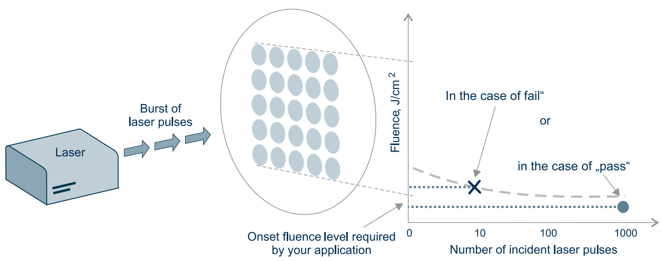
Principle: Every site on optic's surface is exposed by a fixed (S) amount of repetitive pulses. The LIDT is reported as a function of incident laser pulses.

Use this test to:

- Accurately characterize the LIDT of laser optics.
- Learn about the optic's aging process.
- Consider effects of repetition rate.
- Extrapolate results to the high exposure dose (available in some cases).

ISO Pass/Fail (Damage Certification) test

Pass/Fail test is designed to separate good and bad optics at predefined laser fluence.



Principle: Multiple laser pulses at a fixed fluence are applied on either one or more test sites. If no damage is observed, optics can be further used after testing. Otherwise, the component does not meet the specifications and cannot be used anyway.

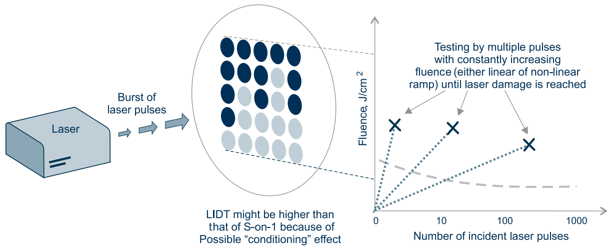
Use this test to:

- Monitor optic's quality on a daily basis.
- Check purchased optic's quality before use in critical applications.
- Inspect whether optical element meets qualifications.

R -on-1 (ramp) test

The R-on-1 is a non-standard test. It provides rough information about LIDT for surface limited samples (e.g. fibers, small crystals).

Principle: The test surface is divided into test sites (considerably fewer test sites, than in the S-on-1 case). Each test site is irradiated with a burst of pulses (e. g. 1000) at constant fluence. At each site, the pulse energy is constantly increased (ramped) until the damage is reached.



Use this test to:

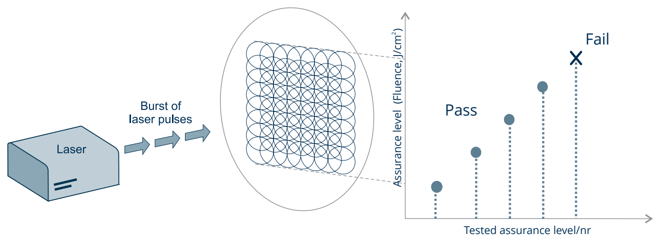
- Test surface limited samples (if S-on-1 test is unavailable).
- Relatively compare production processes or vendors.
- Investigate conditioning (in terms of optical absorption or unknown type of defect reduction).

Be aware: Continuous laser interaction with material might cause conditioning effect. Thus, R-on-1 LIDT can be overestimated if compared to S-on-1 results.

Raster scan test

The raster scan technique helps to detect very rare defects, which could be missed by applying the S-on-1 test.

Principle: Fluence handling capability of the sample is investigated by performing a sub-aperture multiple pulse raster scanning procedure. A selected area of the sample is divided into a number of sites with a diameter proportional to the laser beam's diameter. Each site is exposed with a selected number of pulses at the investigated fluence value.



Use this test for:

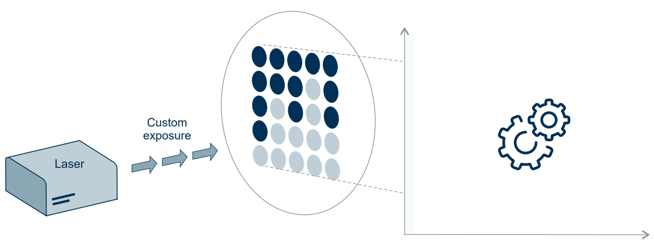
- Characterization of the worst case scenario.
- Optics with small defect densities (e. g. super polished samples).
- Large aperture optics.

Be aware: There are different raster scan application methods. Consult the providers before ordering.

Custom LIDT test

The custom LIDT test is designed to provide the maximum information about LIDT in specific cases.

Principle: The needs are discussed with the customer. Standard test methods are adjusted to meet specific requirements.



Use this test in the case of:

- Custom irradiation conditions: very large number of incident pulses (>1000 per site), also very large or very small (micro-focus) laser test beam diameter;
- Custom exposure algorithm;
- Custom test site layout;
- Custom damage interpretation;
- Custom analysis.

Be aware: Custom tests are more expensive and have longer lead times. Not all custom tests can be compared with standard tests.

HOW CAN I ORDER?

Lidaris has developed a user-friendly online ordering system **my.lidaris.com.** There you can easily tell us your needs and ask for advice. Lidaris experts are here to help you navigate all the information and get the most benefit from the testing.

VISIT my.lidaris.com

Easy online ordering system

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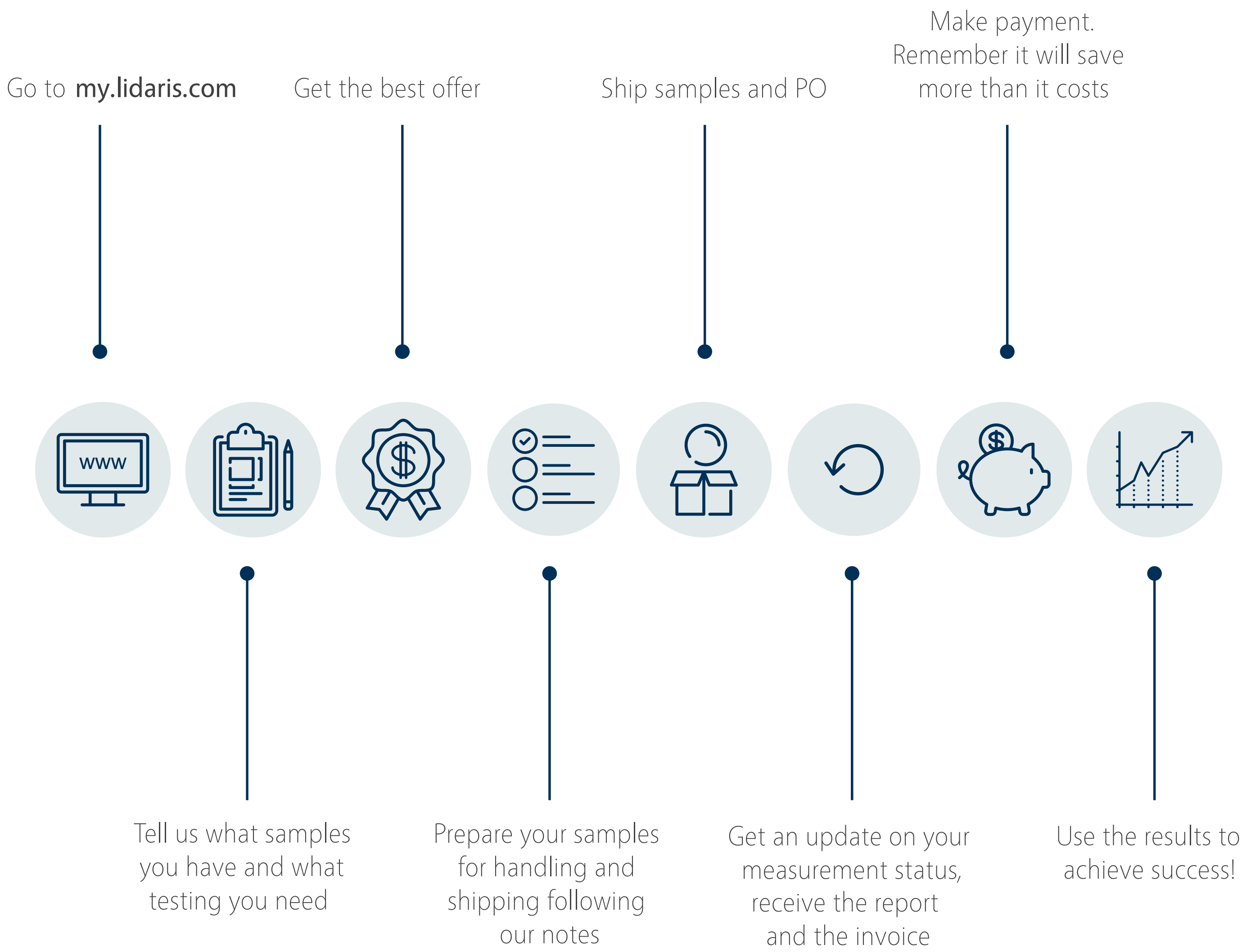


WHY SHOULD I TEST MY OPTICS AT LIDARIS?

OUR TEAM
14
PEOPLE

WE SERVE
150
COMPANIES

PhDs
3

EXPERIENCE
>20
YEARS IN LIDT

R&D
PROJECTS
>20
COMPLETED

EXPORT
85%
US, EU, ASIA

LIDARIS is a "destruction company" offering a wide range of Laser-Induced Damage Threshold (LIDT) metrology services for companies that manufacture, trade, or integrate laser optics. LIDT numbers describe optical resistance (safe light intensity operation limit) of optical parts such as lenses, mirrors, windows, or similar optical elements with intended use in high power laser systems. Thus, LIDT testing provides evidence related to optic's quality and helps to make important decisions.

LIDARIS was founded in 2012 as a spin-off of the Vilnius University Laser Research Center by a group of scientists working intensively in the field of laser-induced damage phenomena. The LIDARIS team gained more than 20 years of research experience in the field of laser-induced damage of optical elements and thin films.

Currently, LIDARIS acts in the global market serving European, American, and Asian companies - the leaders of today's laser market, including manufacturers, suppliers of optics and laser systems, and Space Agencies. More than 150 organizations use LIDARIS services on a daily basis. Scientific contributions of LIDARIS members were 3 times awarded by the SPIE Laser Damage community. The dynamic team is committed to delivering its customers the state-of-the-art knowledge required to survive laser damage.

SPIE. LASER DAMAGE

3x Internationally Awarded

esa

Two RnD projects in cooperation with ESA: ESPRESSO I and ESPRESSO II are dedicated to ESsential PREparation Steps for Qualification Longevity of Space Optics

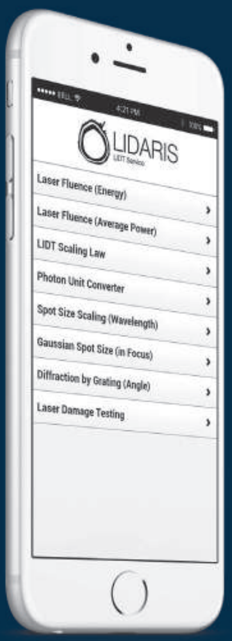
WE ACCEPT ORDERS WORLDWIDE

CERTIFIED MANAGEMENT SYSTEM
SISTEMŲ REGISTRAS
ISO 9001

LITHUANIAN LASER ASSOCIATION

MEMBER of EPIC

LIDARIS CALC



Try online

Google play

Download on the App Store

Lidaris Calc - a free software tool for smartphones equipped with laser related calculators that are frequently required in practice.

Lidaris Calc:

- estimates laser peak fluence and peak power;
- scales damage threshold of dielectrics with pulse duration;
- performs conversions between popular photonic units;
- estimates spot size of focused Gaussian beams;
- calculates diffraction angles of diffraction gratings.

Calculations can be done by providing intuitive parameters, such as laser beam diameter, laser pulse energy or average power, wavelength, repetition rate, and etc. It can save a lot of Your time when adjusting laser systems at the optical table.

START TO INNOVATE NOW

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www.lidaris.com

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