LASER COMPONENTS®

Valuable Information on Coatings

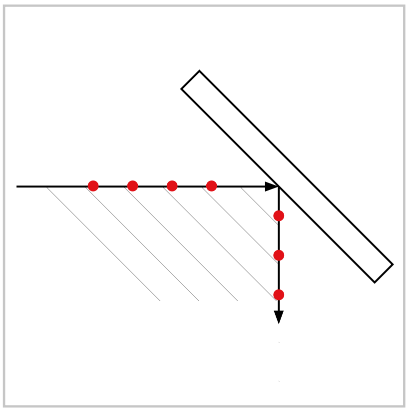
For the development of your optical system and the selection of optical components, it makes sense to have basic knowledge about the subject of coatings. We will give you a brief introduction on coatings in the following pages. For more in-depth questions, we can point you to our LASER COMPONENTS optics team, the members of which would be happy to assist you further.

Definition of the Direction of Polarization for a Laser Beam

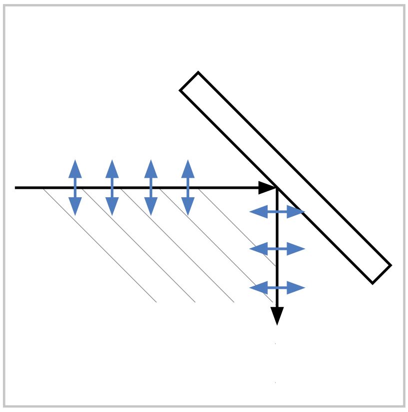
Light is described as a transversal wave that can have two directions of polarization perpendicular to the direction of propagation. This effect is often used to achieve an optimal coating performance.

Determining the Direction of Polarization

Knowing the direction of polarization is crucial, even in the planning stage of a system. The polarization is often described in relation to the plane of the table on which the system is based. However, reflection does not always occur in the table plane, which is why we will be referring to the bending plane in the following. It is defined by the incident beam and the reflected beam.



s-pol reflection:
Beam is polarized perpendicular to the bending plane



p-pol reflection:
Beam is polarized parallel to the bending plane

Germany & Other Countries
Laser Components Germany GmbH
Tel: +49 8142 2864 – 0
Fax: +49 8142 2864 – 11
info@lasercomponents.com
www.lasercomponents.com

France
Laser Components S.A.S.
Tel: +33 1 39 59 52 25
Fax: +33 1 39 59 53 50
info@lasercomponents.fr
www.lasercomponents.fr

United Kingdom
Laser Components (UK) Ltd.
Tel: +44 1245 491 499
Fax: +44 1245 491 801
info@lasercomponents.co.uk
www.lasercomponents.co.uk

Nordic Countries
Laser Components Nordic AB
Tel: +46 31 703 71 73
Fax: +46 31 703 71 01
info@lasercomponents.se
www.lasercomponents.se

USA
Laser Components USA, Inc.
Tel: +1 603 821 – 7040
Fax: +1 603 821 – 7041
info@laser-components.com
www.laser-components.com

Reflection Ratio of Dielectric Coatings

The u-pol, s-pol, and p-pol reflection values of bending mirrors correlate at a fixed ratio with each other. The following applies for an angle of incidence of 45°:

$R_{u\text{-}pol} = 0.5 \times (R_{p\text{-}pol} + R_{s\text{-}pol})$

Mirrors at Different Angles

The coating on a dielectric mirror is generally only defined for a single angle of incidence. If this mirror is used at a different angle of incidence, the central wavelength and the range of reflection for the mirror are shifted.

0° mirrors used at an angle of incidence of 45°

In this case, the central wavelength of these mirrors is shifted to shorter wavelengths. The following applies:

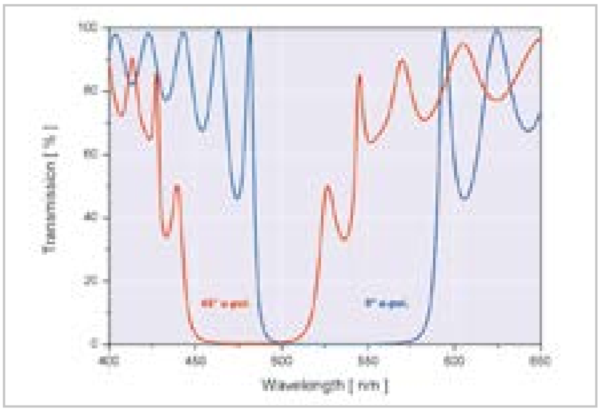
- $\lambda_{Central}$ (45°) ≈ $\lambda_{Central}$ (0°) x 0.9

45° mirrors used at an angle of incidence of 0°

The central wavelength of these mirrors is shifted to longer wavelengths. The following applies:

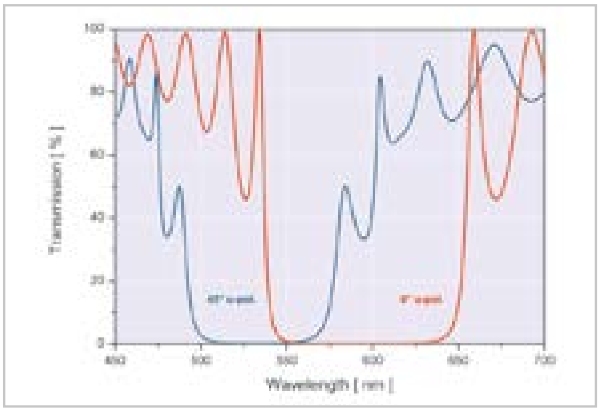
- $\lambda_{Central}$ (0°) ≈ $\lambda_{Central}$ (45°) x 1.1

HR 532 nm / 0°



0° mirror; used at 45°

HR 532 nm / 45°



45° mirror; used at 0°

Germany & Other Countries
Laser Components Germany GmbH
Tel: +49 8142 2864 – 0
Fax: +49 8142 2864 – 11
info@lasercomponents.com
www.lasercomponents.com

France
Laser Components S.A.S.
Tel: +33 1 39 59 52 25
Fax: +33 1 39 59 53 50
info@lasercomponents.fr
www.lasercomponents.fr

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USA
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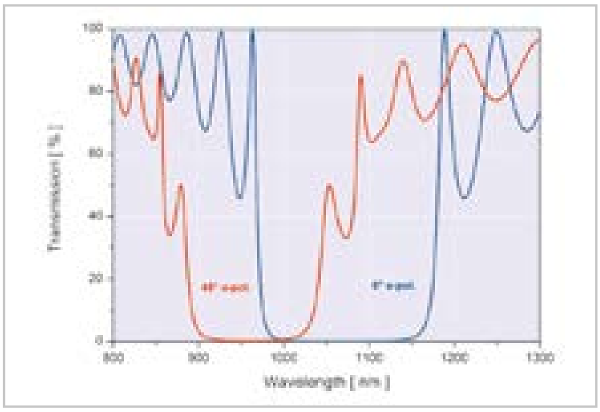
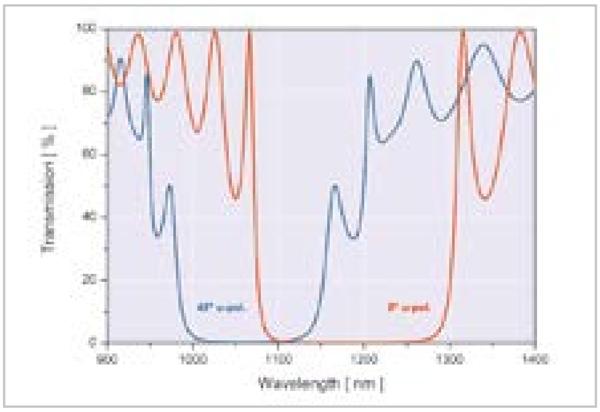
Tel: +1 603 821 – 7040
Fax: +1 603 821 – 7041
info@laser-components.com
www.laser-components.com

HR 1064 nm / 0°



0° mirror; used at 45°

HR 1064 nm / 45°



45° mirror; used at 0°

Typical Bandwidths of Dielectric Coatings

The bandwidths of dielectric coatings are dependent on the central wavelength $\lambda_{Central}$ and the angle of incidence as well as on the coating design and coating materials used. The polarization dependency must also be considered if the angle of incidence deviates from zero.

As a rule of thumb, the following standards should be noted.

Generally, reflection values cannot be guaranteed across the whole bandwidth Δλ.
The following information serves as orientation.

The typical bandwidth Δλ is defined as wavelength range for which:

R > 99 %	for AOI 0°
R > 98 %	for AOI 45°

Typical Bandwidths of High Power Coatings 266 nm to 2000 nm:

- End mirrors (0° angle of incidence)
  $\Delta\lambda \approx \lambda_{Central} \times 0.1$
- Bending mirrors (45° angle of incidence)
  u-pol: $\Delta\lambda \approx \lambda_{Central} \times 0.1$
  s-pol: $\Delta\lambda \approx \lambda_{Central} \times 0.15$
  p-pol: $\Delta\lambda \approx \lambda_{Central} \times 0.05$

Germany & Other Countries
Laser Components Germany GmbH
Tel: +49 8142 2864 – 0
Fax: +49 8142 2864 – 11
info@lasercomponents.com
www.lasercomponents.com

France
Laser Components S.A.S.
Tel: +33 1 39 59 52 25
Fax: +33 1 39 59 53 50
info@lasercomponents.fr
www.lasercomponents.fr

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Fax: +44 1245 491 801
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Tel: +46 31 703 71 73
Fax: +46 31 703 71 01
info@lasercomponents.se
www.lasercomponents.se

USA
Laser Components USA, Inc.
Tel: +1 603 821 – 7040
Fax: +1 603 821 – 7041
info@laser-components.com
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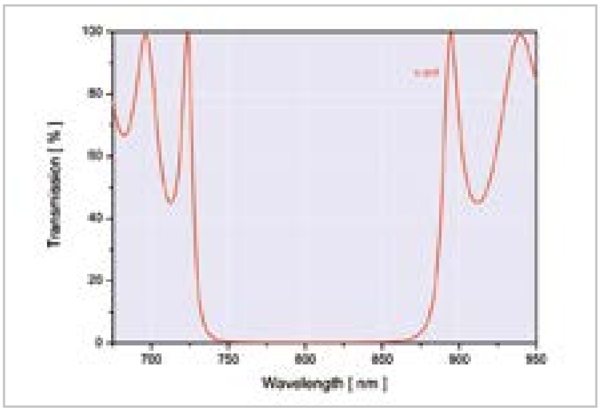
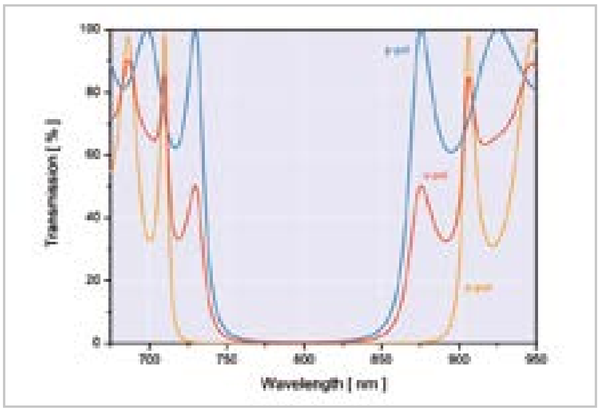
HR 800 nm / 0°; high power



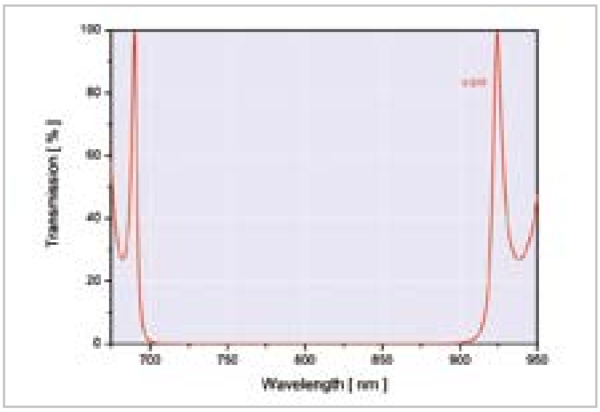
HR 800 nm / 45°; high power



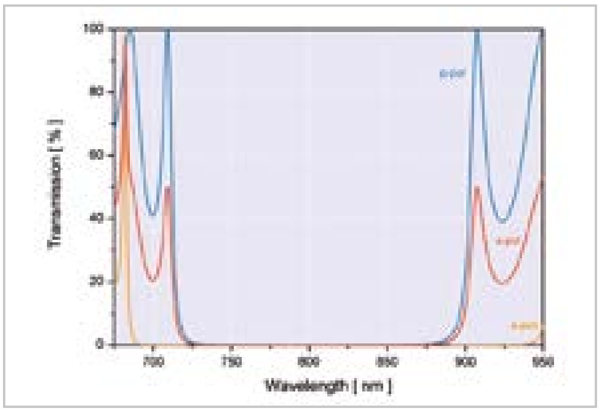
Typical Bandwidths of cw/fs Coatings 450 nm to 1600 nm

- End mirrors (0° angle of incidence)
  $\Delta\lambda \approx \lambda_{Central} \times 0.15$
- Bending mirrors (45° angle of incidence)
  u-pol: $\Delta\lambda \approx \lambda_{Central} \times 0.15$
  s-pol: $\Delta\lambda \approx \lambda_{Central} \times 0.25$
  p-pol: $\Delta\lambda \approx \lambda_{Central} \times 0.1$

HR 800 nm / 0°; cw/fs



HR 800 nm / 45°; cw/fs



Germany & Other Countries
Laser Components Germany GmbH
Tel: +49 8142 2864 – 0
Fax: +49 8142 2864 – 11
info@lasercomponents.com
www.lasercomponents.com

France
Laser Components S.A.S.
Tel: +33 1 39 59 52 25
Fax: +33 1 39 59 53 50
info@lasercomponents.fr
www.lasercomponents.fr

United Kingdom
Laser Components (UK) Ltd.
Tel: +44 1245 491 499
Fax: +44 1245 491 801
info@lasercomponents.co.uk
www.lasercomponents.co.uk

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Laser Components Nordic AB
Tel: +46 31 703 71 73
Fax: +46 31 703 71 01
info@lasercomponents.se
www.lasercomponents.se

USA
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Tel: +1 603 821 – 7040
Fax: +1 603 821 – 7041
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Center Wavelength [nm]	AOI 0°	AOI 45°		
	Δλ for R > 99%	u-pol: Δλ for R > 98%	s-pol: Δλ for R > 98%	p-pol: Δλ for R > 98%
266	± 13 nm	± 13 nm	± 20 nm	± 7 nm
355	± 15 nm	± 15 nm	± 25 nm	± 8 nm
532	± 25 nm	± 25 nm	± 35 nm	± 13 nm
800 high power coating	± 40 nm	± 40 nm	± 60 nm	± 20 nm
800 cw/fs coating	± 60 nm	± 60 nm	± 100 nm	± 30 nm
1064	± 50 nm	± 50 nm	± 78 nm	± 25 nm

All values refer to high power coating unless stated otherwise.

"Golden Rules" for Short-pass and Long-pass Mirrors

When deciding whether to use a long-pass or short-pass mirror to separate several wavelengths, the following rules can be applied.

- **Bandwidth**
  The bandwidth for the reflected part of the beam is limited. For the best possible beam division or combination, it is important to allow a wavelength range to be transmitted and individual wavelengths to be reflected.
  Examples: HR1064HT400-700
  HR355HT532+1064
- **Polarization**
  The absolute degree of reflection is higher for s-polarized light than it is for p-polarized light. For transmission the relationship is the exact opposite. Therefore, keep the polarizations in your assembly in mind.
- **Reflection better than transmission**
  The reflection of a beam is more efficient. If you require greater efficiency at a certain wavelength for your application, consider this when selecting a mirror.
- **Beam combination of SHG, THG, ...**
  A reflection peak is generated at the corresponding λ/2, λ/3,... parts of the reflected wavelength.
  A long-pass coating should be the preferred choice for this combination.
  Example: Instead of an HR1064+532HT355 coating, an HR355HT532+1064 coating would be preferred.

Combination of Coatings

- With our modern coating equipment, different coatings can be combined with one another in one coating run. You will profit from these options and minimize your coating expenses.
- The following combinations can be manufactured in one batch:
- Different angles of incidence
- Various central wavelengths (difference of ± 10 %)
- Highly and partially reflective coatings
- Different substrate dimensions
- To some extent different substrate materials

Germany & Other Countries
Laser Components Germany GmbH
Tel: +49 8142 2864 – 0
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www.lasercomponents.com

France
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Tel: +33 1 39 59 52 25
Fax: +33 1 39 59 53 50
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info@lasercomponents.co.uk
www.lasercomponents.co.uk

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info@lasercomponents.se
www.lasercomponents.se

USA
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Tel: +1 603 821 – 7040
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info@laser-components.com
www.laser-components.com

Damage Threshold Measurement

Modern Q-switched lasers with ns pulses or ps and fs systems can achieve very high power densities. The amount of power is restricted by various factors, including but not limited to the damage threshold of the optical material, the dielectric coating, and the active laser material itself. The damage threshold of optical components is determined to a large extent by the laser resistance of the substrate material and the coating applied. Crucial laser criteria that must be taken into account include the following: power density, pulse energy, beam geometry, beam cross section, beam focussing, pulse duration, pulse repetition rate, temporal pulse form, and transient response and field strength distribution.

The role of LIDT (laser induced damage threshold) measurements in the development of powerful lasers and their corresponding components is an important one. Reliable and reproducible methods are used in the characterization of optical laser components, in particular coatings. These methods are explained in more detail below. They are standardized and normalized processes that allow the damage resistance of laser optics to be assessed.

Inspection Methods According to ISO 11254

There are two different standard inspection methods.

Single Pulse Measurements

Single pulse measurements are identified as 1-on-1 measurements. In single pulse measurements, each point of measurement of a substrate is exposed to a laser pulse that has a specifically defined amount of energy.

Multi-pulse Method

In the multi-pulse method, so-called S-on-1 measurements are taken. That is to say, a position is exposed to a pulse sequence of S pulses that have a high repetition rate. Single pulse measurement is thus a special type of measurement of the multi-pulse method in which S = 1. Typical S-on-1 measurements reach values of S = 100,000 and up. This allows the long-term behavior of an optical component to be analyzed.

Fundamentals of S-on-1 Measurement

The measurement setup, which consists of a laser system, a variable energy attenuator, a focussing unit, beam diagnosis, a movable substrate mount, and the in situ detection of resulting damage, is crucial to achieving qualitative measurements.

For nanosecond pulses, a stable system consisting of an Nd:YAG laser pumped with flash lamps is often used with an oscillator amplifier unit. Typically, the wavelength is 1064 nm or higher harmonics of this; the beam profile has a Gaussian shaped cross section. To analyze the behavior at femtosecond pulses, a Ti:Sa system with a central wavelength of 800 nm is generally used.

The energy density of each one of these pulses is measured constantly. To detect the resulting damage a microscope objective with a magnification of more than 100 is used during measurement. In addition, after measurement the substrates are analyzed using a Nomarski microscope.

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Germany & Other Countries
Laser Components Germany GmbH
Tel: +49 8142 2864 – 0
Fax: +49 8142 2864 – 11
info@lasercomponents.com
www.lasercomponents.com

France
Laser Components S.A.S.
Tel: +33 1 39 59 52 25
Fax: +33 1 39 59 53 50
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www.lasercomponents.fr

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Fax: +44 1245 491 801
info@lasercomponents.co.uk
www.lasercomponents.co.uk

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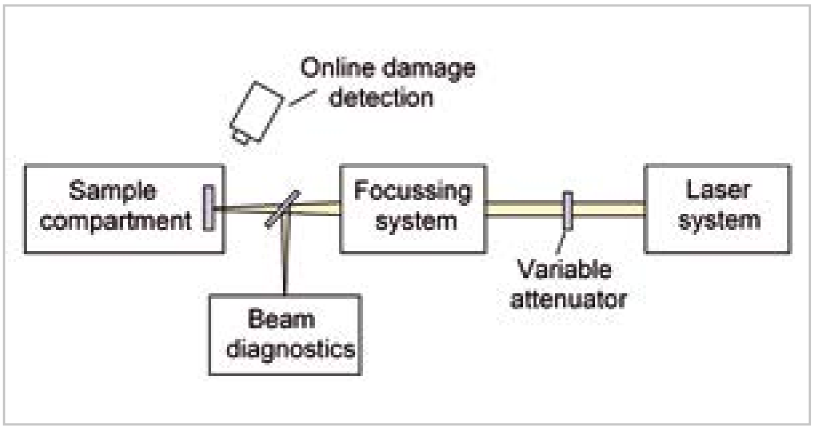
Laser Components Nordic AB
Tel: +46 31 703 71 73
Fax: +46 31 703 71 01
info@lasercomponents.se
www.lasercomponents.se

USA
Laser Components USA, Inc.
Tel: +1 603 821 – 7040
Fax: +1 603 821 – 7041
info@laser-components.com
www.laser-components.com

A substrate is typically separated into several segments that are, in turn, divided into several independent measurement points. The distance between these measurement points should amount to more than six times the beam diameter. Each measurement point within a segment is hit with a pulse train of constant energy density, and this energy density increases from segment to segment. If damage results after reaching a number of pulses of N_{min}, pulse repetition is interrupted. For this measurement point and the corresponding energy density, Q, "no damage" (a value of 0) is noted for pulse quantities of $N < N_{min}$, whereas "damage" (a value of 1) is noted for pulse quantities of $N \geq N_{min}$.



Typical setup for damage threshold measurement according to ISO 11254

Measurement Assessment

The damage values of individual measurement points can now be plotted against the applied energy density for each number of pulses, N. The range of energy between the lowest value with damage and the maximum value without damage is divided into several intervals. Within these intervals, the damage values are averaged and linearly interpolated. The point of intersection with the x-axis of the line obtained is called the 0% threshold, or ON SET value. The energy value, for which the best-fit straight line has a damage probability of 0.5, is referred to as the 50% threshold.

The 0% and 50% thresholds achieved here are also quite frequently plotted against each corresponding pulse value, N. This allows particularly accumulative effects to be observed, from which conclusions regarding the damage mechanism can be drawn.

LASER COMPONENTS allows its damage threshold tests to be performed according to ISO 11254 specifications at independent institutes and companies. There the 50% threshold is specified for a beam diameter common for the application. Focussing the laser can reduce this threshold, particularly in nanosecond pulses.

Germany & Other Countries
Laser Components Germany GmbH
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info@lasercomponents.com
www.lasercomponents.com

France
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Fax: +33 1 39 59 53 50
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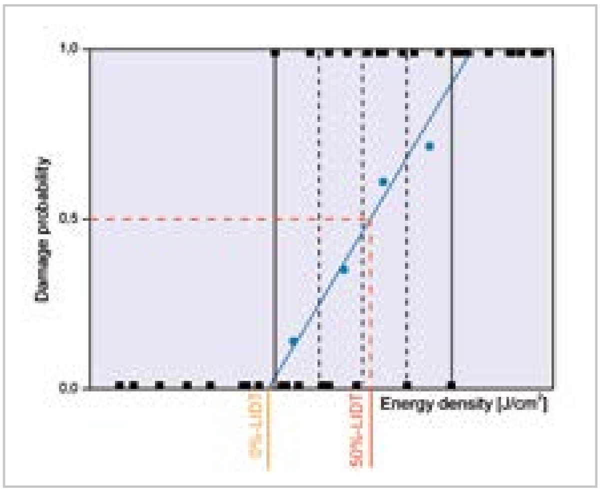

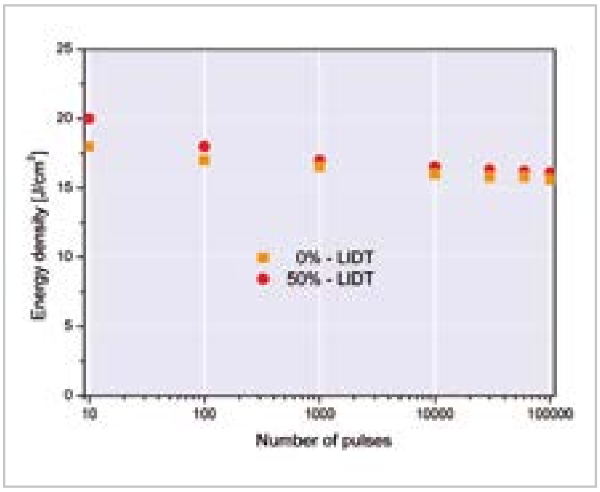

Since the quality of a substrate can significantly affect the damage threshold, damage threshold tests are performed using LC's standard substrates made of laser-polished quartz glass. In contrast, using CaF_2 or sapphire substrates, for example, does not allow a value to be determined directly because of their poor polishing quality.

Causes of Damage

The causes of laser-induced damages to dielectric layers can be manifold. Thermal effects at high power densities can lead to a strong temperature increase and a subsequent destruction of the coating. High field strengths also lead to a destruction when high energy densities at low repetition rates impact.

Contamination in the form of dust particles or residue from cleansers, the thin film left behind from adhesives, and the like also have a large effect on the damage threshold. Even the smallest changes can reduce the damage threshold of optics dramatically. To achieve the specified LIDT values it is imperative that optics be handled with extreme care.

Analyzing damage morphology can prove to be a valuable means of determining the cause of erosion or damage to a surface. Damage morphology refers to the form and design of a coating or to crystal damage.

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Tel: +49 8142 2864 – 0
Fax: +49 8142 2864 – 11
info@lasercomponents.com
www.lasercomponents.com

France
Laser Components S.A.S.
Tel: +33 1 39 59 52 25
Fax: +33 1 39 59 53 50
info@lasercomponents.fr
www.lasercomponents.fr

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Fax: +44 1245 491 801
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