RhySearch
Das Forschungs- und
Innovationszentrum Rheintal

RhySearch Optical Coatings Lab:
Laser Induced Damage Threshold (LIDT) Measurement

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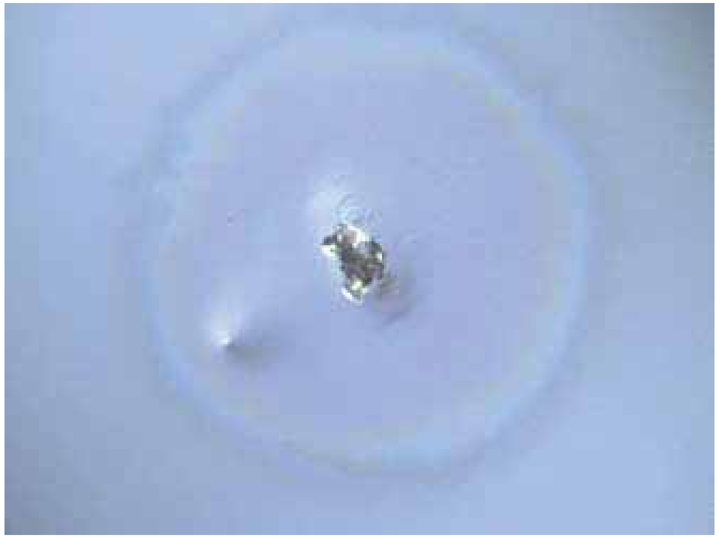
Overview

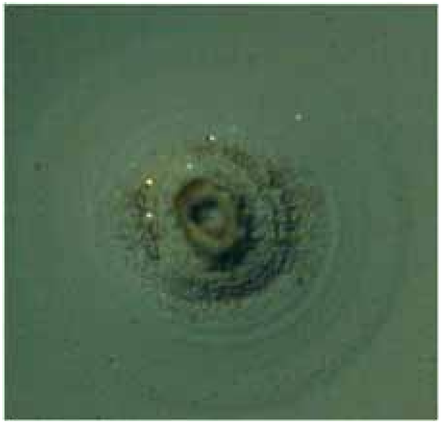
- What is the LIDT of a component?
- What can influence the LIDT of a component?
- Different measurement strategies:
  - Measurement according to the ISO 21254 Standard
    - Single-Shot Test (1-on-1)
    - Multishot Test (S-on-1)
    - Certification
  - R-on-1 Ramp-Test
  - Raster Scan

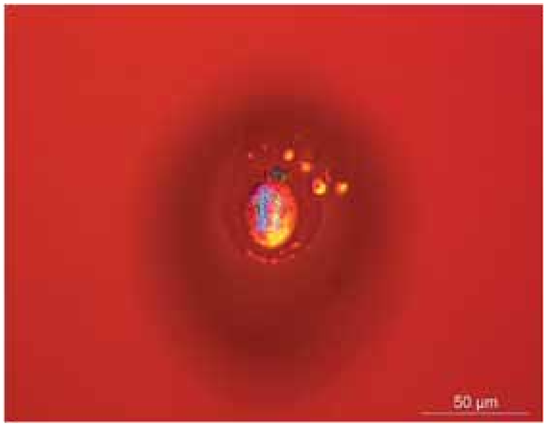


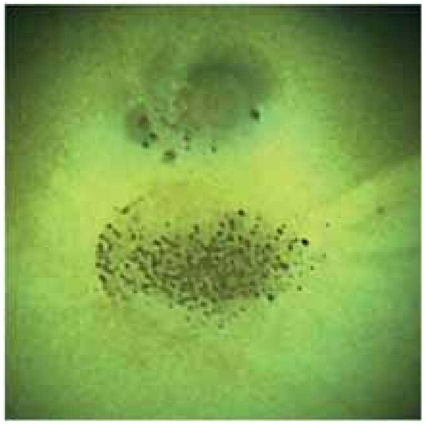
What is the LIDT of a component?

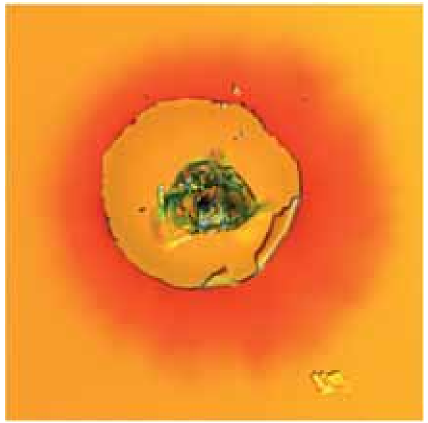
- Any permanent change in the surface or substrate properties of an optical element caused by laser radiation
- The most common form of laser destruction is the physical damage to coated optical surfaces
- Often discoloration and delamination also occur
- In sensitive applications: Minor changes in the substrate properties due to laser radiation can already be considered laser damage

→*ISO 21254: any visual change after laser radiation observed with a Nomarski Differential Interference Contrast (DIC) microscope at 10x enlargement is to be considered as damaged*









For further reading, please refer to:
Detlev Ristau (Ed.), *Laser-Induced Damage in Optical materials*, CRC Press, 2015.

What can influence the LIDT of a component?

- Laser radiation
  - Damage mechanism depends on the pulse duration:
    - ns-pulses: Defect induced (heating of defects)
    - fs-pulses: Electronically triggered damage (Electron tunneling, multi-photon absorption or a combination of the two, avalanche ionization, optical breakdown → *intrinsic damage*)
    - ps-pulses: transition between the two regimes: both due to intrinsic effects and defect induced
    - cw laser and ultra-short pulsed lasers: absorption
  - Lateral beam profile: Laser mode has a strong influence on the peak intensity
  - Temporal beam profile: Depending on the laser peak intensities this can vary strongly
  - Wavelength: UV radiation: colour centres or higher probability of multi-photon absorption; IR: absorption of OH-groups

→ The longer the pulse duration, the more energy the optic can handle. For pulse durations between 1 and 100 ns a scaling law[1] can be used to extrapolate the LIDT at a different pulse duration (y ns).

$$LIDT_{y_{ns}} = LIDT_{x_{ns}} \sqrt[0.35]{\frac{x_{ns}}{y_{ns}}}$$

[1] Rainer F, Atherton LJ, Campbell JH, DeMarco FP, Kozlowski MR, Morgan AJ, Staggs MC (1992) *Four-harmonic database of laser-damage testing*. In: Bennet HE, Chase LL, Guenther AH, Newman BE, Soileau MJ (eds) Laser-Induced Damage to Optical Materials: 1991. SPIE 1624: 116–127.

What can influence the LIDT of a component?

- Optical components:
  - Substrate: Polishing residue, sub-surface damage, refractive index, optical quality (scratch/dig, etc.)
  - Surface preparation: Adsorption of impurities from the environment,…
  - Material absorption: Can cause changes in the microstructure, melting, delamination, cracks,…
  - Defects in the material: Such as local under stoichiometry, cracks, particles, …

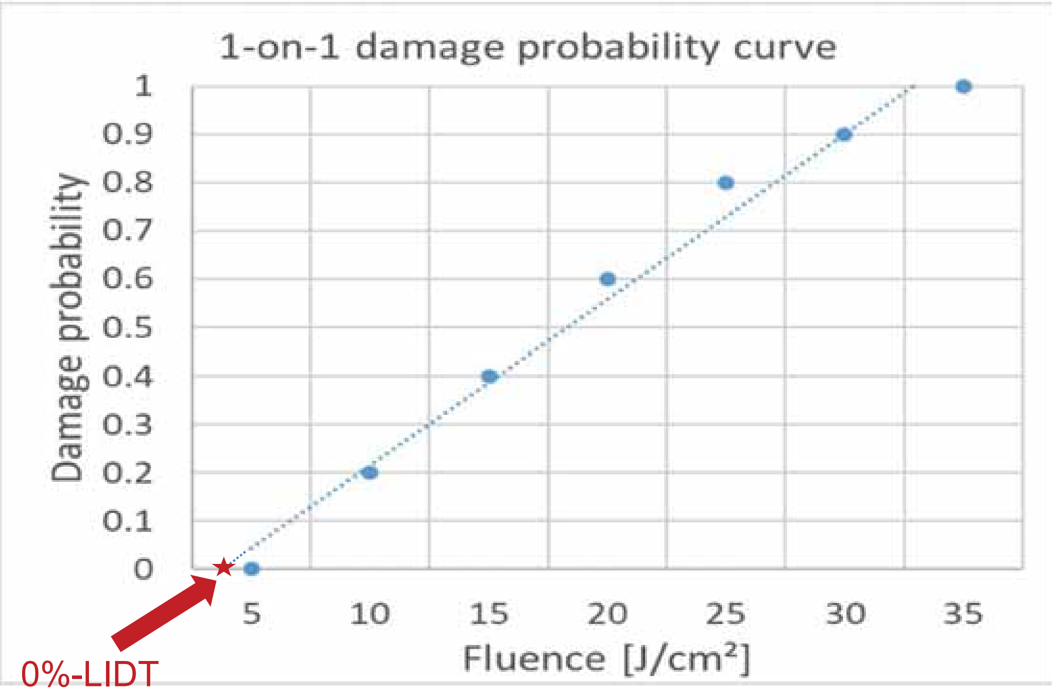
- Environmental factors:
  - Temperature: Stress in the film
  - Gas environment: Chemical or physical reactions
  - Relative humidity: Condenstaition

- LIDT is only meaningful for applications for which the environmental conditions are similar to the test conditions
- Maximum energy density with which an optical component can safely be irradiated:
  - State of equilibrium between annealing of and new generation of defects
  - Defect concentration low enough to avoid catastrophic self-focusing
- For lifetime critical applications, LIDT tests should be performed under conditions close to operating conditions

Different measurement strategies

- Measurement according to ISO 21254 Standard: Single-Shot Test (1-on-1)

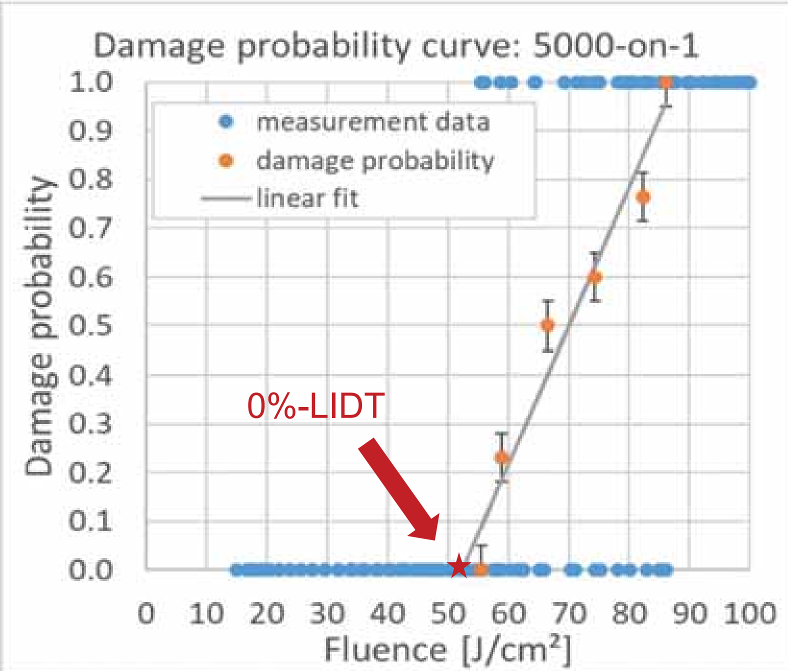
  - At least 10 sites are irradiated with a predefined energy density (1 pulse per site)
  - Then the next 10 sites are irradiated with a higher energy density (1 pulse per site)
  - Continue the procedure with increasing energy density until all 10 sites are damaged
  - Microscopic inspection to verify the result
  - Results shown in a *damage probability curve:* damage probability vs. the energy density with a linear regression fit

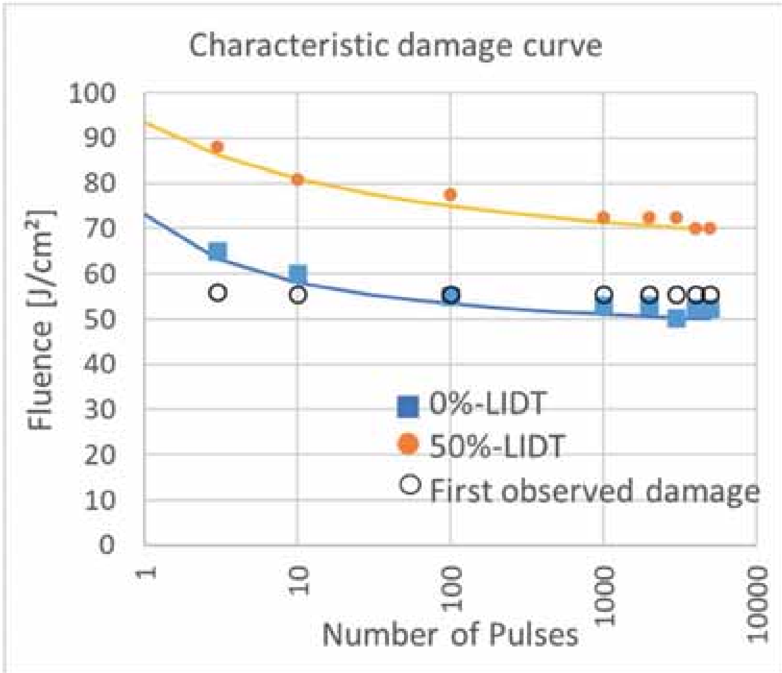


The 0%-LIDT value is the energy density at which the linear fit has a 0% damage probability

Different measurement strategies

- Measurement according to ISO 21254 Standard: Multishot Test (S-on-1)
  - At least 10 sites are irradiated with *S* number of laser pulses of a predefined energy density
  - Determination of the probability of damage is done as described in the 1-on-1 measurement procedure
  - Repetition of the procedure at different predefined energy densities for *S* laser pulses
  - Results are shown in a *damage probability curve* and for different pulse classes it is shown in a *Characteristic damage curve*
    - *Characteristic damage curve* converges to a finite energy density with increasing number of pulses
      → **Convergence behaviour contains information about laser-induced aging mechanisms**

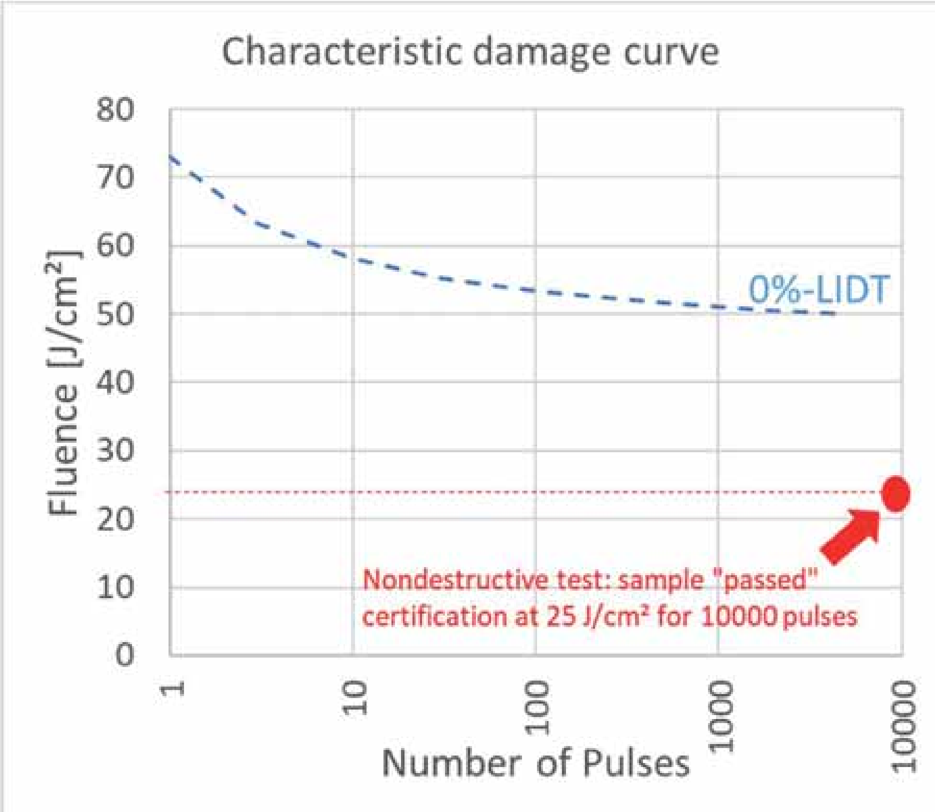




Different measurement strategies

- Measurement according to ISO 21254 Standard: LIDT Certification

  - A number of sites on the component to be certified are irradiated with the energy density to be certified
    - usually only one sample site if the number of irradiation pulses are very large
  - These tests are useful in the case where expensive and unique optical parts have to be qualified
  - If no damage occurs, continued use of the sample is possible



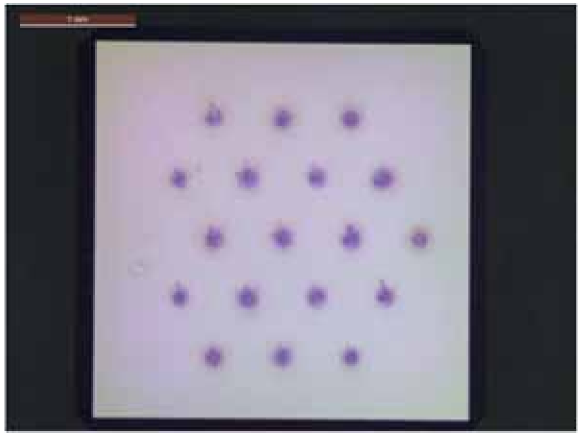
Different measurement strategies

- R-on-1 Ramp Test

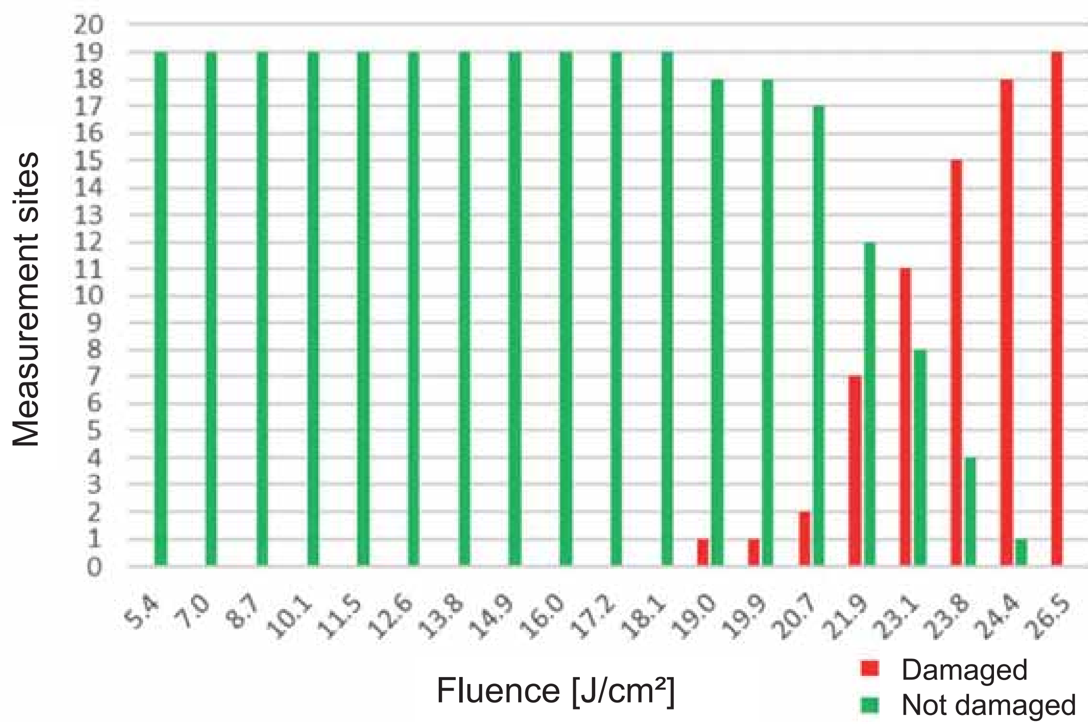
  – Several sites are irradiated with R pulses at steadily increasing energy density
  – Irradiation of the next site as soon as destruction occurs or the number of pulses R is reached
  – Representation as in S-on-1, but no linear regression possible

    → Indicate the LIDT as the largest energy density with 0% probability of destruction

  – Useful with small surfaces (such as optical fibers or crystals)
  – Method shows laser conditioning effect (LIDT increases with time) → Difficult interpretation

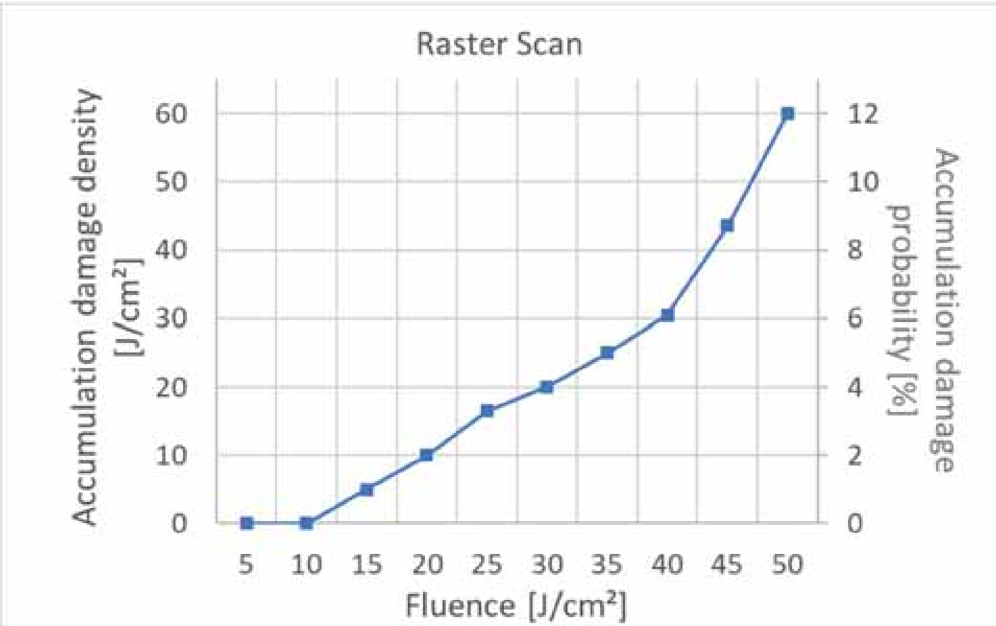


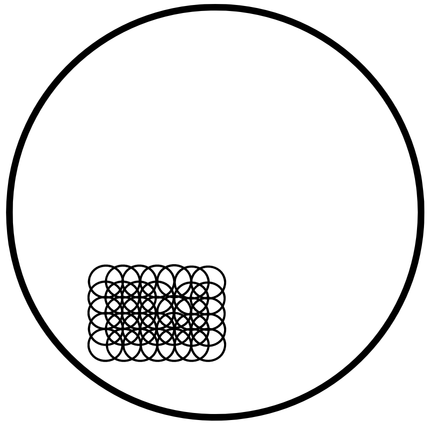
Above:
Matrix of LIDT measurement sites used in a ramp-test on a 3.6 mm x 3.6 mm laser crystal



Different measurement strategies

- Raster Scan Test
  - The individual laser pulses follow a serpentine raster pattern
  - The irradiated sites overlap as they are separated by the 90% point of the Gaussian peak for a chosen focused spot diameter
  - A predefined area of the component is scanned. Damage is observed via scattered light, or microscopic inspection before and after irradiation
  - Each site is exposed to a selected number of pulses at a selected energy density
  - If all sites survive, the laser fluence is increased by a predetermined amount and the raster scan is run again on a new area of the component until damage is observed





Above:
Example of overlapping sites used during a raster scan measurement

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Join us at the Symposium on Optical Coatings for Laser Applications in Buchs on 11th April 2019!

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