Optics for Advanced 50 J/cm^2 @1.5 µm Applications

By Laurynas Šatas, 2018

Growing interest in 1.5 µm

Over recent years there has been a growing interest for eye-safe laser sources emitting at ~1.5 µm [1]. Typically, such emission is provided by lasers based on erbium (Er^{3+}) ions and operating on the $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition. This radiation is strongly absorbed by the eye's cornea and lens and thus it cannot reach the sensitive retina which opens a new field for eye-safe applications. Erbium lasers are widely used in such applications as free-space optical communication, remote sensing (LIDAR technology), wind sensing and range-finding for civil and defence fields. While requirements for new generation industrial grade resonators operating at low pulse frequencies include a high pulse energy and peak power, they also depend on good beam quality and low divergence, as well as a compact and robust design, preferentially with passive cooling of a laser head.

Eye-safe laser

The design of such a laser is relatively simple. Materials for compact Er^{3+} lasers are phosphate glasses co-doped with Er^{3+} and Yb^{3+} ions [2]. Co-doping with Yb^{3+} ions is needed to provide the efficient pumping of the laser material at 960–980 nm according to the $^2F_{7/2} \rightarrow {}^2F_{5/2}$ transition of the Yb^{3+} ions. This spectral range corresponds to emission wavelengths of the cost-effective commercial high-power InGaAs laser diodes. The generation of a pulsed output from a compact Erbium laser is normally provided by the passive Q-switching. The well-recognized saturable absorber for an Er^{3+} laser is based on cobalt (Co^{2+}) ions located in tetrahedral sites of crystals, e.g. Co^{2+}:$MgAl_2O_4$ single crystal (Co^{2+}:spinel) . It provides high absorption cross-section for Co^{2+} ions and, consequently, low saturation fluence at the Er^{3+} laser wavelength (~0.5 J/cm^2), fast recovery time (~350 ns), small non-saturable losses and high modulation depth, good thermal properties, and high radiation resistance. State of the art Co^{2+}:$MgAl_2O_4$ single crystals are grown by the Czochralski method. The growth is complicated by the high melting temperature of this compound (~2130 °C), but it is the only production route suitable for industrial applications with high repeatability in volumes of thousands finished optical components. As a potential replacement ceramic based solution is discussed around the world, but the problems of damage resistance, homogeneity and many more are not being solved so far. [3,4]

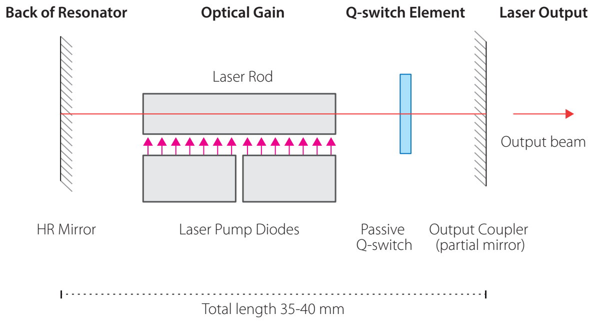


Figure 1. Typical 8 mJ resonator which could bring a challenge of 40-50 J/cm^2 to component

Challenges

From first sight, the 8 mJ single shoot (eye-safe limit for class 1 laser safety) doesn't sound like a big number in the century of high average power laser sources. However, optimization of compact and reliable cavity design is a challenging task for a laser engineer. For example, the resonator which emits 8 mJ with pulse duration at 15 ns and a beam diameter of 100 µm will put components to the challenge of handling more than 5.2 GW/cm^2 (>38 J/cm^2) intracavity, which is hardly achievable in the market. This problem can be solved by optimization of the following parameters:

1. Optimizing mode area of the laser
2. Consider a multi-mode solution instead of the single mode
3. Adjusting the output coupler and end mirror radius of curvatures
4. Adjusting initial transmission of Q switch and reflectivity of output coupler

However, all these adjustments are limited to a certain energy levels which can be withheld by the system's weakest optical component. This leads to reduction of other parameters such as beam quality, beam size, divergence, reliability, energy efficiency and overall price.

Laser damage threshold

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. [5]

Components developed and manufactured in Altechna are typically qualified with determination of LIDT in by performing a standardized S-on-1 test procedure in LIDARIS (Lithuania). LIDT value is determined by fitting experimental damage probability data with a model derived for a Poisson damage process assuming degenerate defect ensemble. [6]

Altechna‘s solution for highest energies

Development of new generation optical components which are capable of managing today’s challenges is a complex task. It involves more than one discipline starting from material science and ending with engineering. Altechna engineers identified several technological bottlenecks of high power Er^{3+} based solid state resonators and generated roadblocks to the solution. In particular, these systems require high-quality Co^{2+}:$MgAl_2O_4$ crystals capable of handling >50 J/cm^2 peak fluency coupled with superb optical and thermal properties. High-quality optical components based on recent technological breakthrough are going into production. Altechna expects that achieved power levels will allow our customers to reconsider resonator geometries and get new solutions for the applications such as remote sensing and range-finding for the civil and defence fields.

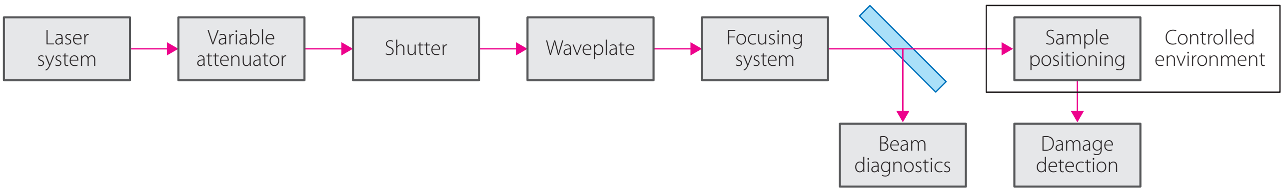


Figure 2. Typical LIDT test setup at 0° of incidence

High LIDT coated Co:Spinel (Co^{2+}:$MgAl_2O_4$) crystals

1. Co^{2+} Concentrations: (0.05~0.35) wt%
2. Surface quality: 10-5 S-D
3. Surface flatness: <λ/10 @ 632.8 nm
4. Parallelism error: <5 arcsec
5. LIDT > 50 J/cm^2 @ 1540 nm, 20 ns, 100 Hz

*Measured LIDT R (1000)-on-1 @ 1540 nm, 4.9 ns, 100 Hz, 0° – 38.9 J/cm^2 (equivalent of >78.6 J/cm^2 @ 20 ns)

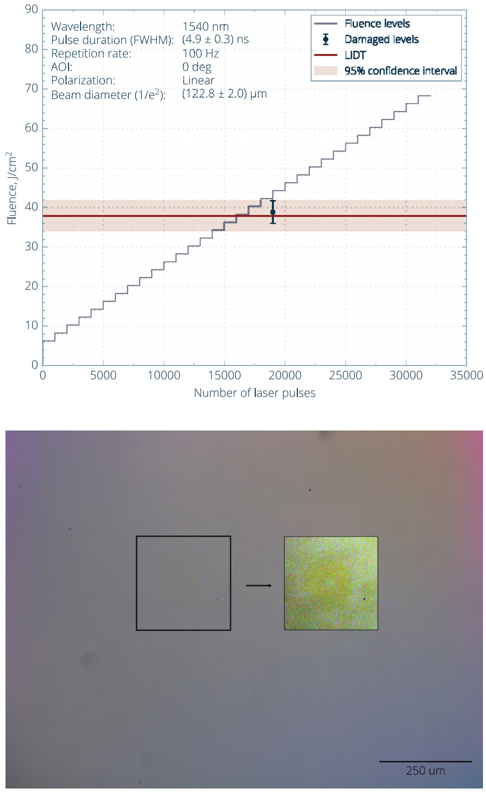
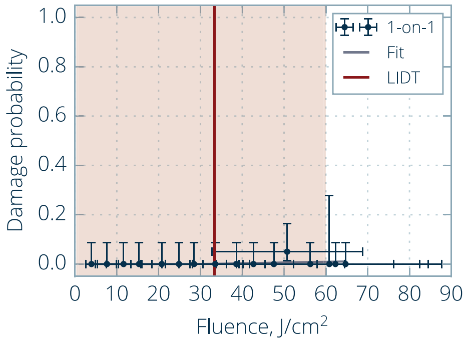


Figure 3. R-on-1 test results and typical damage morphology: fluence 38.9 J/cm^2, damage after 1000 pulse(s) in fluence level. High contrast image. [7]

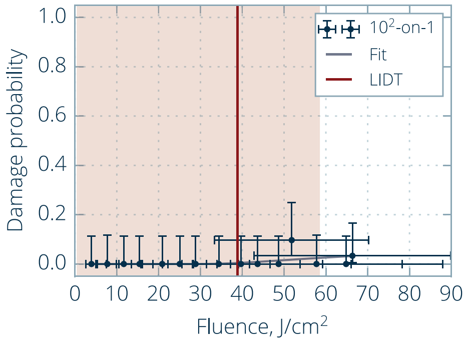
High LIDT Cavity Mirrors

1. Any common glass: N-BK7, UVFS
2. Superb accuracy for ROC and centering tolerances
3. Dielectric coating sputtered with minimum 3 metal oxides
4. EM field optimization
5. Low defect concentration
6. LIDT > 50 J/cm² @ 1540 nm, 20 ns, 100 Hz

*Measured LIDT 100-on-1 @ 1540 nm, 4.1ns, 100 Hz, 0deg – 39J/cm²
(equivalent of > 86.1 J/cm² @ 20 ns)



(a) 1-on-1



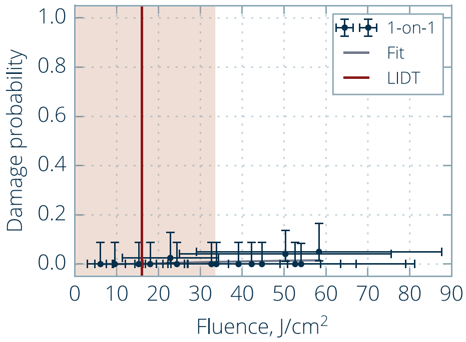
(c) 10^2-on-1

Figure 4. Damage probability plots. [7]

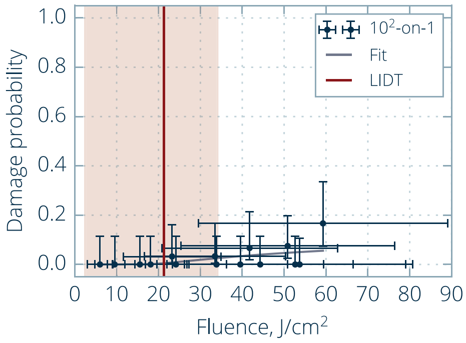
High LIDT output couplers

1. Any common glass: N-BK7, UVFS
2. Dielectric coating sputtered with a minimum of 3 different materials
3. EM field optimization
4. Low defect concentration
5. LIDT > 50 J/cm² @ 1540 nm, 20 ns, 100 Hz

*Measured LIDT 100-on-1 @ 1540 nm, 4.2 ns, 100 Hz, 0deg – 21.3J/cm²
(equivalent of >46.48 J/cm² @ 20 ns)



(a) 1-on-1



(c) 10^2-on-1

Figure 5. Damage probability plots. [7]

References

[1] AANSI Standard Z136.1-2000, American National Standard for Safe Use of Lasers (2000)

[2] Karlsson G., Laurell F., Tellefsen J., Denker B., Galagan B., Osiko V. and Sverchkov S. „Development and characterization of Yb-Er laser glass for high average power laser diode pumping“ 2002 Appl. Phys. B 75 41–6

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[4] Adrian Goldstein A., Loiko P., Burshtein Z., Skoptsov N., Glazunov I., Galun E., Kuleshov N., Yumashev K., „Development of Saturable Absorbers for Laser Passive Q-Switching near 1.5 lm Based on Transparent Ceramic $Co^{2}+:MgAl_2O_4$“ Journal of the American Ceramic Society • April 2016

[5] 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)

[6] 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)

[7] Tested at Lidaris