LIDT for femtosecond laser optical components

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Motivation

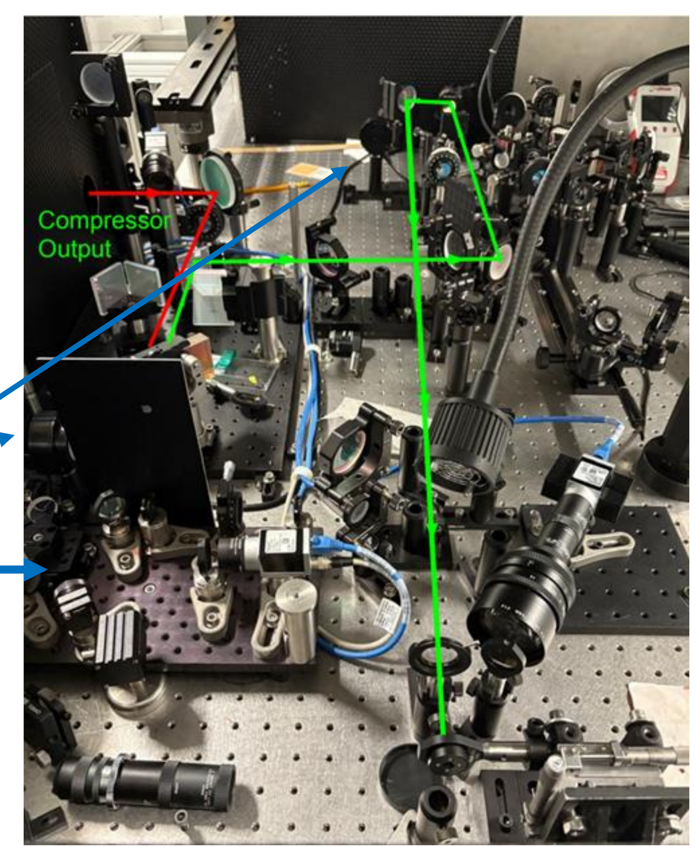
Optical technology is pushed to the upper limits of damage with the advent of ultrafast high-power (UFHP) lasers. UFHP are at the forefront of particle accelerators, being used in interaction with electron beams to produce high-gradient electron acceleration, generation of compact radiation sources like inverse Compton scattering and free electron lasers. The UFHP laser levels, repetition rates, and operating environmental conditions lower the damage threshold of the optical components of femtosecond lasers uttering them useless if not used in the given parameters. In this regard, the present study provides the threshold levels for various optical components used in 800nm femtosecond lasers. The optical materials tested, analyzed and discussed here are beta barium borate (BBO), Ti:Sapphire (Ti:Sa), Zinc Selenide (ZnSe), Cadmium Teluride (CdTe), Thalium Bromo-Iodide (KRS 5), and Gallium Arsenide (GaAs), which are of particular interest, as they are the main medium for the optical parametric amplification (OPA), oscillator used for UFHP lasers such as the one at the input stage of the Long Wave-Infrared (LWIR) UFHP laser system at Brookhaven National Laboratory (BNL), etc. It is important to mention that current studies of these crystals, in this context, show few to no consistent laser induced damage threshold (LIDT) analysis, making this study an important reference for the UFHP laser community. Post-experiment analysis using optical and scanning electron microscopy revealed detailed damage structure, providing insights into the material behavior under high-intensity laser exposure. As part of this work, we utilized 3DOptix and Select Nonlinear Optics (SNLO) software packages, to design and analyze the experimental results, including beam profile analysis and damage threshold quantification.

Instrumentation

The procedure involved the use of a 800nm (NIR) Ti:Sapphire UFHP laser with a repetition rate of 240 Hz, pulse duration of about ~100 fs, and excellent stability (±3 μJ from the central value) throughout the duration of the tests.

The LIDT metrology setup used two Gentec energy meters for energy measurements, an in house built autocorrelator to measure the beam pulse duration and two Basler cameras for beam profile measurements and damage monitoring.

The NIR beam was transported to the experimental table via vacuum through a laser beam transport system.

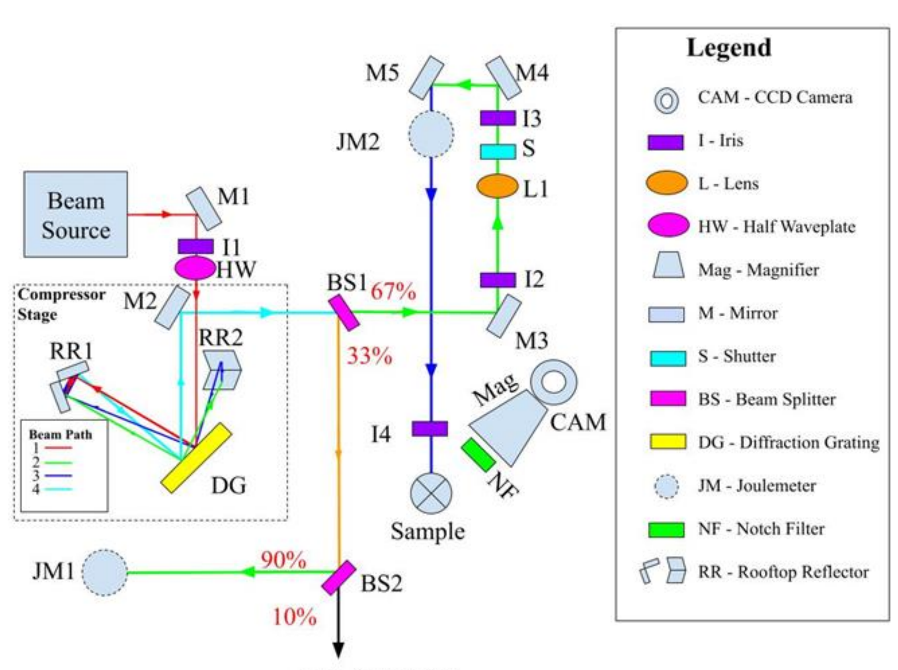


Methodology

The laser beam was focused to a diameter of 167-300 μm and the fluence levels were varied between 15 μJ/spot size and 800 μJ/spot size, depending on the sample studied.

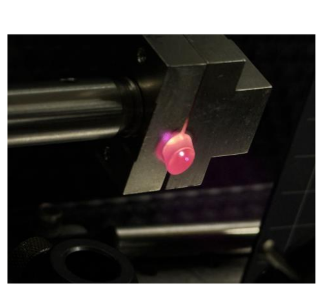
The beam profile and pulse durations were collected in the morning, prior to every test indicating excellent stability from day to day experiments.

The background was collected with the laser blocked but all other sources of light on.



LIDT Results

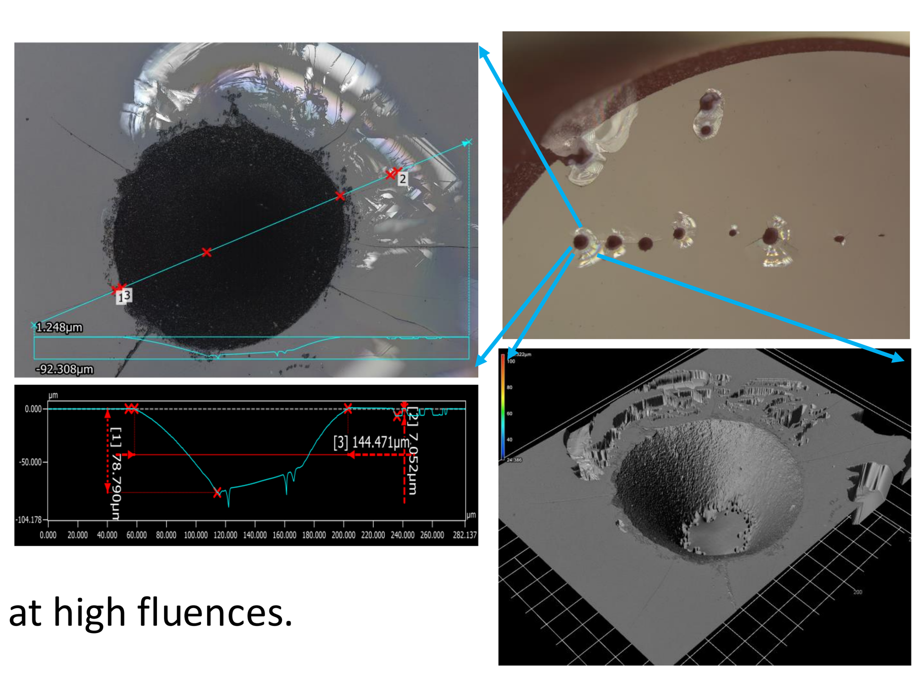
Ti:Sapphire



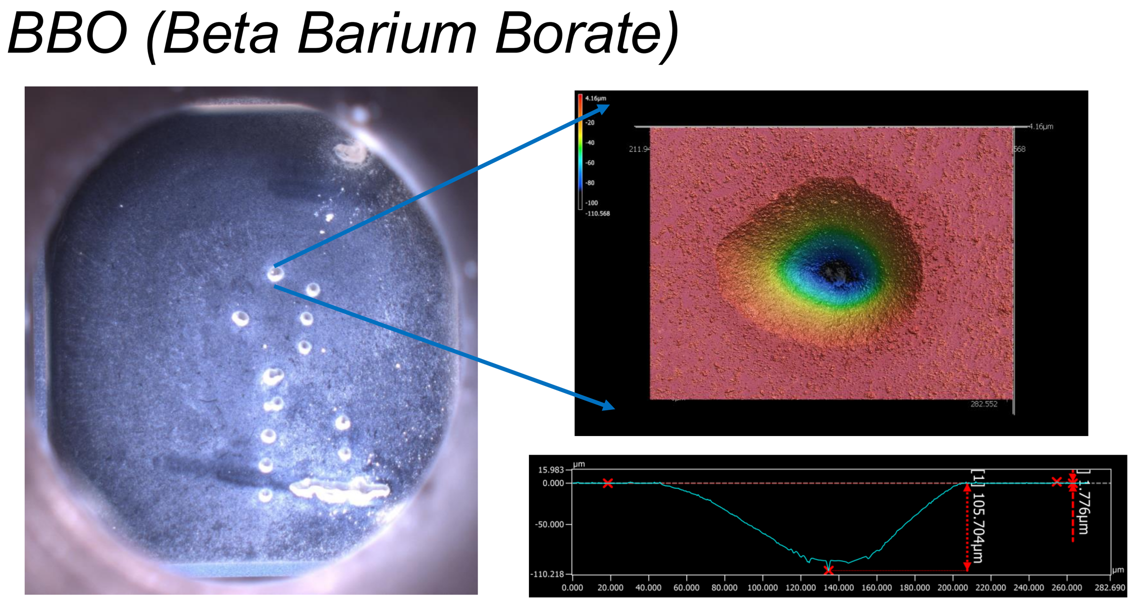
Ti:Sa is the crystal of choice for NIR UFHP lasers around the world due to its ability to lase in a very wide band centered at 800nm.

It has high mechanical strength with a transmission window between 0.15 to 5.5 μm and refractive index of 1.76 at 800 nm. Melting temperature of Ti:Sa is 2035°C.

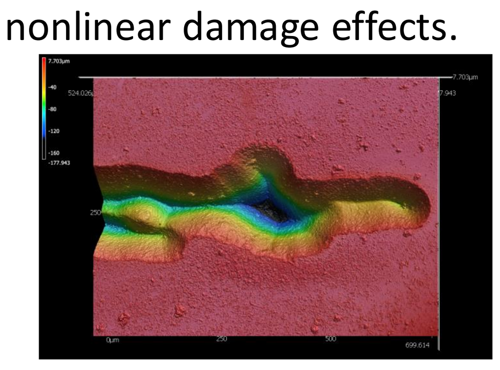
Cracks joined by material bulging is observed at high fluences.



BBO (Beta Barium Borate)

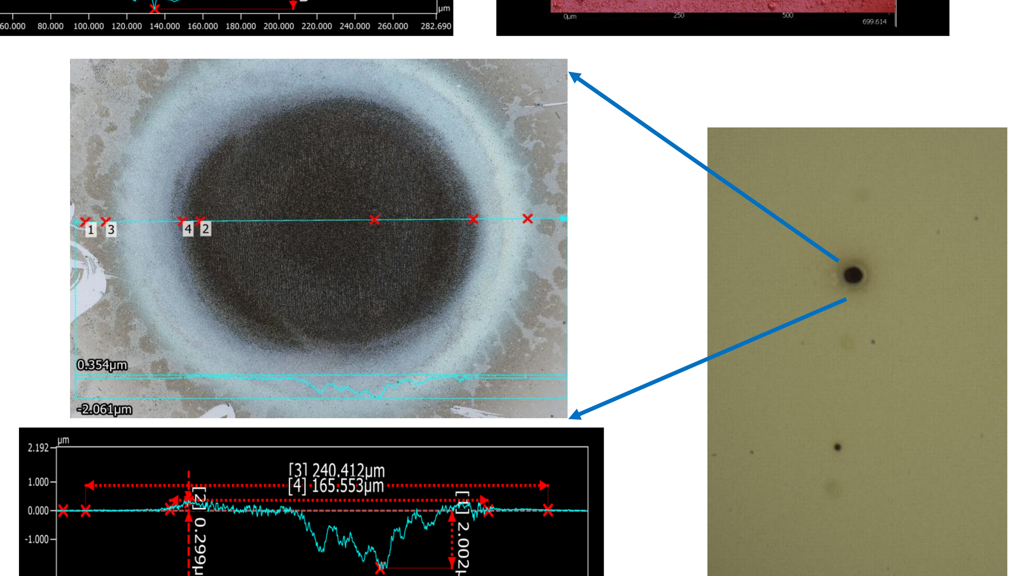


Nonlinear crystal used in Optical Parametric Amplification (OPA). Material defects lead to nonlinear damage effects.



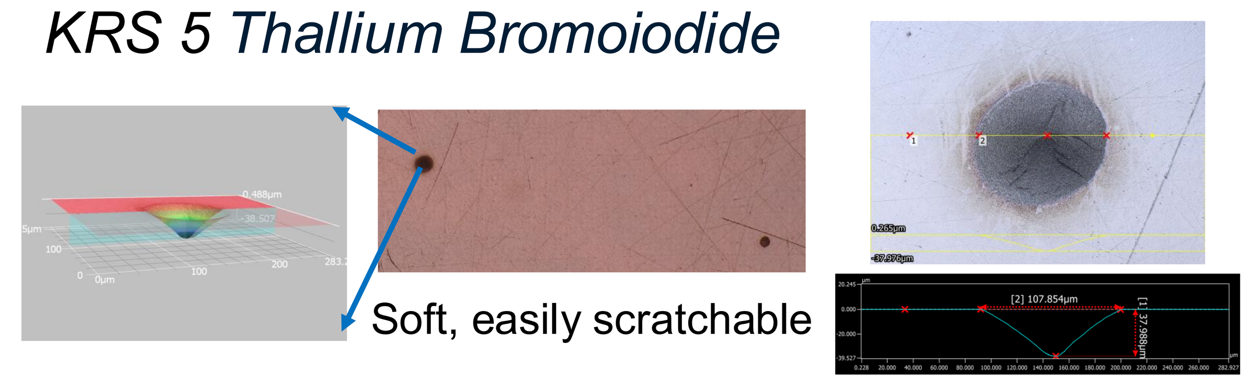
ZnSe (Zinc Selenide)

ZnSe has a transmission window in 0.5 to 22 μm, and a refractive index of 2.52 at 800 nm, being used as a plasma mirror for CO_2 laser control systems. It is a relatively soft material which displays rapid damage. The periodic surface structure is easily visible at high fluences.



LIDT Results cont'd

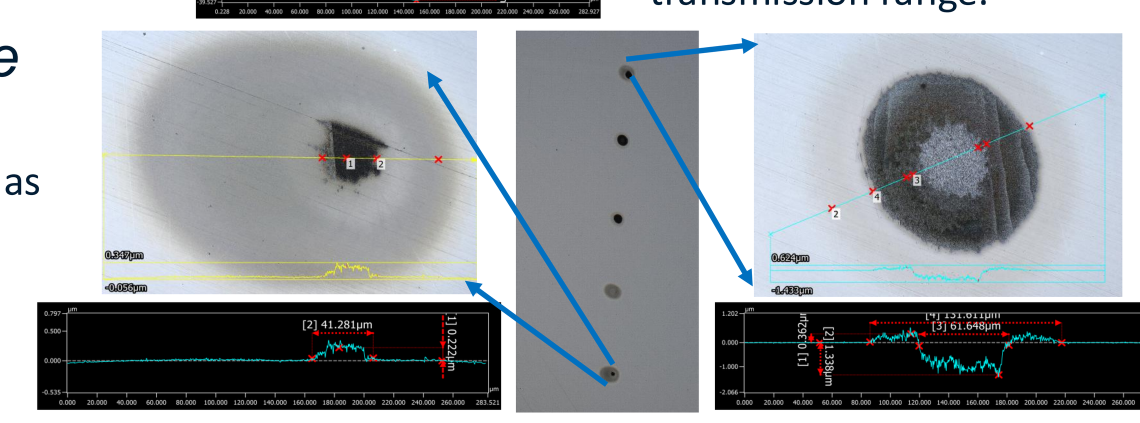
KRS 5 Thallium Bromoiodide



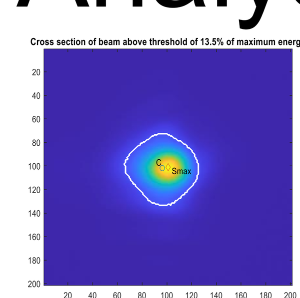
KRS 5 is a synthetic crystal primarily used in infrared spectroscopy and other optical applications due to its high refractive index (2.51 at 800nm) and 0.7-32 um transmission range.

CdTe Cadmium telluride

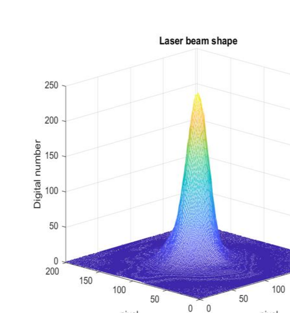
CdTe has a transmission window between 2 and 25 um, and is used as a semiconducting material in thin-film solar cells. It is also used in infrared optical windows, Mid IR detectors (InCdTe), or CO_2 lasers control systems. Small surface scratches are critical to CdTe LIDT



Analysis



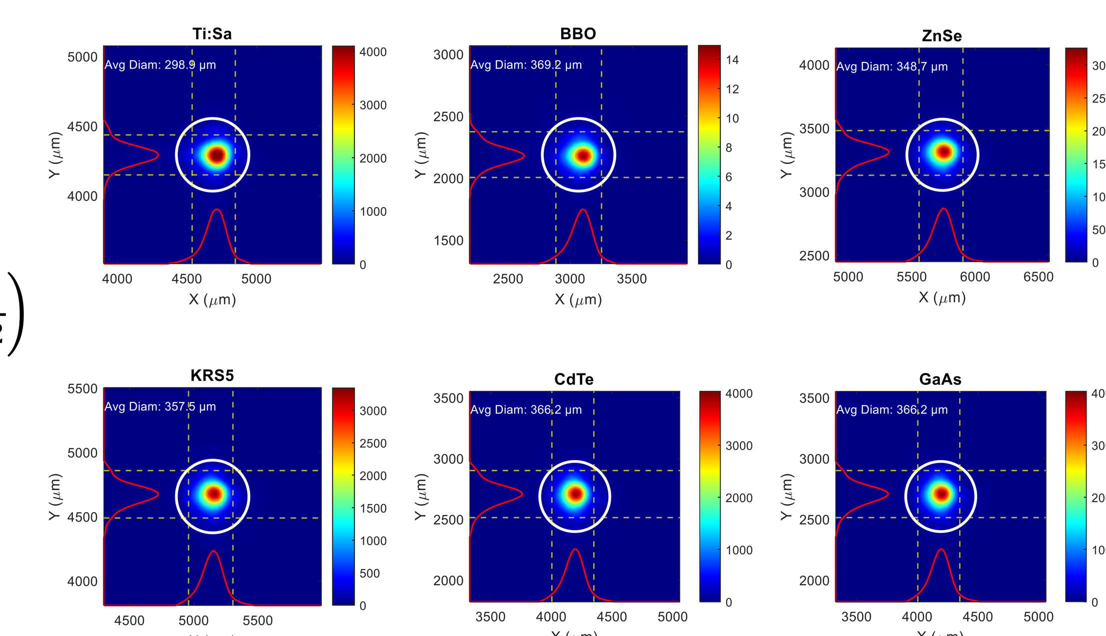
$$F_{ave} = \frac{2E}{\pi\omega_0{}^2}\left(\frac{J}{cm^2}\right)$$

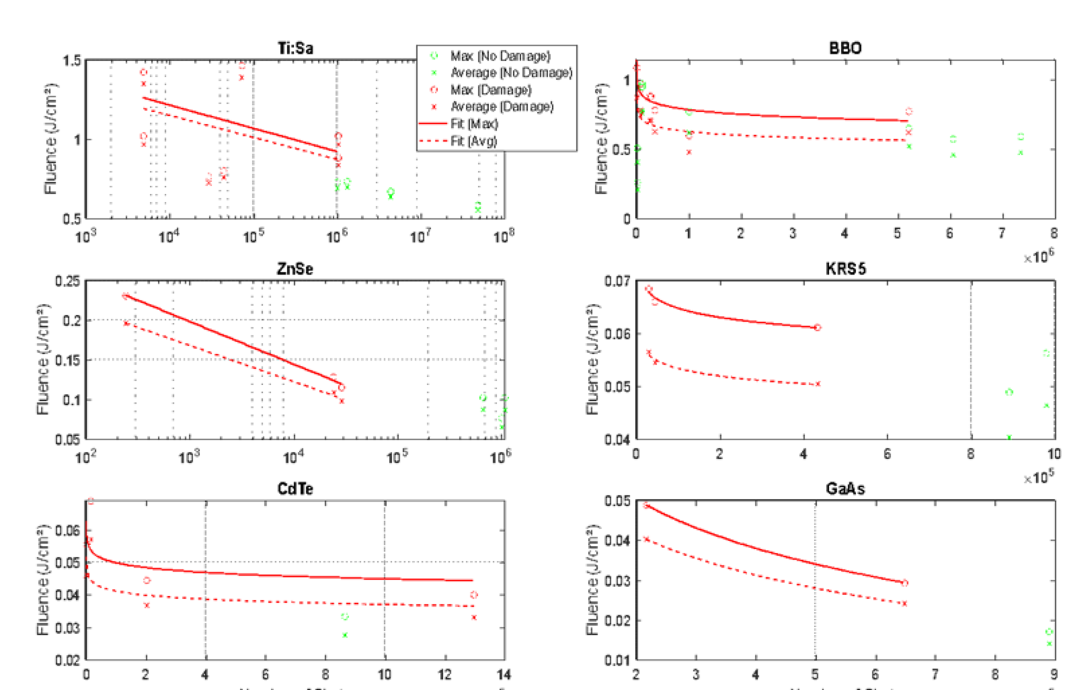


The approximate Gaussian shape of the laser is obvious from the cross

Laser beam quality is assessed and the fluence is calculated based on Beam spot size and beam energy on the sample

$$F_{max} = \frac{E_{pulse}}{S_{total}} * \frac{S_{max}}{Pixel\ Area}\left(\frac{J}{cm^2}\right)$$





Conclusions and Future work

The different damaging mechanisms were observed and LIDT values were calculated. The analysis conducted lead to the conclusion that a careful inspection needs to be performed on any crystal used in UFHP lasers, as small defects can lead to much lower LIDT values than expected. Future work involves a thorough study of the damage mechanisms in the materials studied here and measurements of LIDT of ZnSe, KRS5, CdTe, GaAs, BaF_2 and other components at 9.2 μm.

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