Visualization of inhomogeneities in Ti:Sapphire laser medium

Vojtěch Miller[1,2,3]* and Karel Žídek[2]

[1] *Technical University of Liberec, Studentská 1402/2 461 17 Liberec 1, Liberec, Czech Republic*
[2] *TOPTEC, Institute of Plasma Physics of the Czech Academy of Sciences, Za Slovankou 1782/3, 182 00 Prague 8, Czech Republic*
[3] *CRYTUR, spol. s r.o., Na Lukách 2283, 511 01 Turnov, Czech Republic*

Abstract. This work presents innovative methods for visualizing inhomogeneities and stress distributions in Ti:Sa (titanium-doped sapphire) crystals, which are challenging to assess due to their birefringent nature. Two experimental approaches were developed: the first enables two-dimensional mapping of the Figure of Merit (FoM) and absorption at wavelengths of 532 nm, 780 nm, and 1550 nm, revealing variations in absorption across the crystal. The second experiment utilizes circularly polarized light and polarization imaging to detect internal stress and defects. The results demonstrate the successful visualization of lateral absorption, stress, and core features within the crystals, offering insights into their optical quality. These techniques provide new possibility for evaluation of laser materials, with significant implications for improving the manufacturing and selection processes of Ti:Sa crystals in advanced laser applications.

1 Introduction

The accurate visualization of inhomogeneities in laser media, particularly in birefringent materials such as Ti:Sa (titanium-doped sapphire) single crystals, is a significant challenge in the field of laser optics. Ti:Sa is widely used due to its favourable properties, but its birefringent nature complicates the detection and analysis of defects and inhomogeneities, which can adversely affect laser performance. Traditional methods struggle to provide clear and reliable information about these imperfections.

In this work, we introduce new experimental approach along with experiment published last year to address this challenge. The first experiment enables two-dimensional measurements of the Figure of Merit (FoM) as well as absorption at wavelengths of 532 nm, 780 nm, and 1550 nm. These measurements provide insights into the material's optical properties and potential defects. The second experiment utilizes circularly polarized light, which propagates through the crystal samples and is subsequently analysed using a polarization camera. This method allows for the detailed examination of stress and inhomogeneities within the crystal structure, offering a new perspective on internal defects that were previously difficult to visualize. [1–3]

2 Methods

Two distinct experiments were designed to visualize inhomogeneities in Ti:Sa crystals and their results have been compared and interpreted together.

2.1 Absorption Measurement Experiment

A setup was developed for two-dimensional FoM measurements derived from measurements at wavelengths of 532 nm, 780 nm, and 1550 nm. As depicted in Figure 1, the experimental setup consists of two lasers to generate respective wavelength, several optical elements to clear and manipulate the laser beams, integration sphere to collect the light and set of photodiodes to detect the signal. The crystal samples were positioned in the path of the laser beams, and absorption was measured across different wavelengths. [1,4]

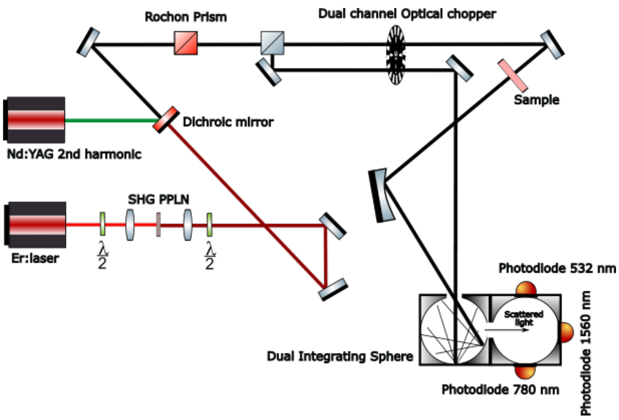

Fig 1. Schematic diagram of the setup for measuring FoM in Ti:Sa crystals.

2.2 Circularly Polarized Light Analysis

The second experimental setup involves the propagation of circularly polarized light through the Ti:Sa

* Corresponding author: vojtech.miller@tul.cz

https://doi.org/10.1051/epjconf/202430906024

samples. Laser beam propagates through set of optical elements to obtain a circularly collimated light. Beam is then expanded to propagate through large area of the crystal. Propagated light is then deexpanded and captured using a polarization camera. The schematic in Fig 2 illustrates the schematics of this experiment. The captured images are then separated and processed to analyse stress and inhomogeneities within the crystal. [5,6]

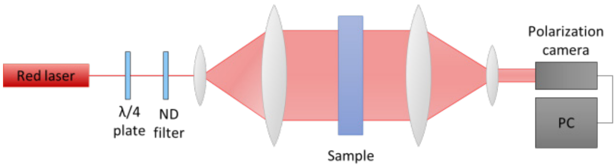

Fig 2. Schematic diagram of the circularly polarized light analysis setup.

3 Results and Interpretation

The first set of experiments enabled the two-dimensional mapping of both FoM and absorption across the crystal samples. As shown in Figure 3, the visualization demonstrates a non-uniform distribution of absorption, indicating variations in the material's optical quality, inhomogeneities and possible localization of dopants. Resulting image in Fig. 3 reveals wavelength-dependent spatial absorption characteristics.

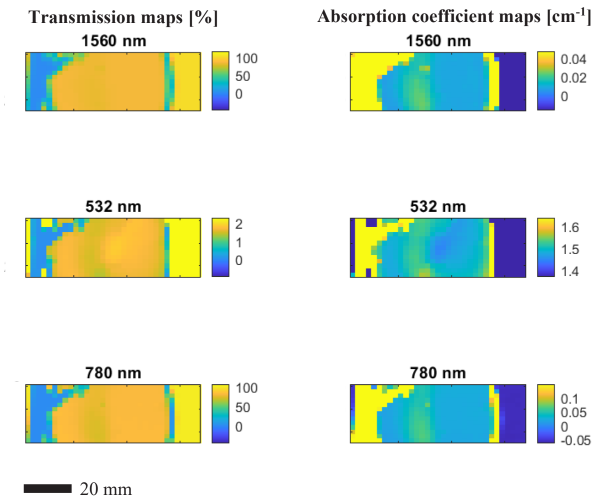

Fig 3. Distribution of the transmission (left) and absorption coefficient (right) in a Ti:Sa crystal for different wavelengths. Each image visualises part of the dia 45 mm Ti:Sa sample.

In the second experiment, the use of circularly polarized light allowed for detailed imaging of the internal structure of the crystals. Fig 4. displays the distribution of index of refraction inhomogeneity. The polarization camera captured variations in polarization states, which were processed to identify regions with different index of refraction and internal defects, such as inhomogeneities in the crystal lattice.

Interference fringes in the Figure 4 are present due to the coherent nature of the used light source nevertheless the inhomogeneities regions are still visible as large areas underneath the interference fringes.

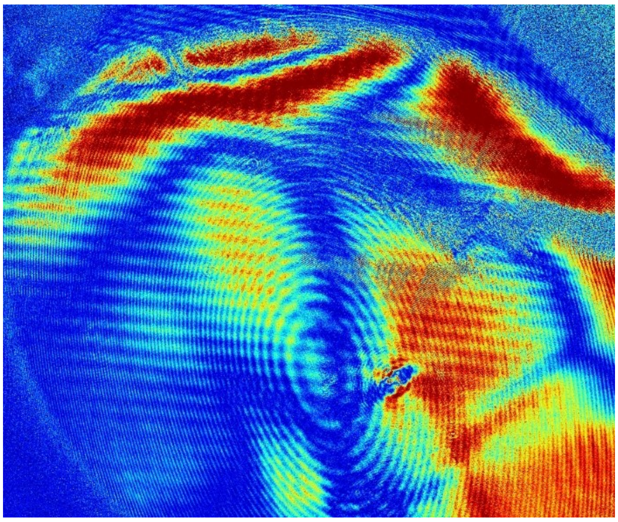

Fig. 4 Visualization of lateral index of refraction inhomogeneities within the Ti crystal.

These visualizations provide insights into the quality and inhomogeneity lateral distribution of Ti:Sa crystals. The ability to map FoM and stress distributions allows for a more detailed understanding of crystal properties, potentially leading to improved crystal manufacturing and selection processes for laser applications.

4 Conclusion

This study successfully demonstrates innovative techniques for visualizing inhomogeneities, absorption characteristics, and stress distributions in Ti:Sa crystals. By employing two-dimensional FoM measurements and circularly polarized light analysis, we were able to reveal detailed internal features that provides enhanced detection of non-processable regions of laser crystals, ensuring better performance in practical applications.

References

1. V. Miller, K. Zidek, Vol. 62, No. 5, Applied Optics (2023)

2. G. Alombert-Goget, Y. Guyot, A. Nehari, O. Benamara, N. Blanchard, A. Brenier, N. Barthalay, K. Lebbou, CrystEngComm, 20(4), 412–419 (2018). ISSN 1466-8033

3. A. Nehari, A. Brenier et al. Crystal Growth & Design, 11(2), 445–448. (2011) ISSN 1528-7483, 1528-7505

4. D. B. Joyce, F. Schmid, Journal of Crystal Growth, 312(8), (2010) 1138–1141. ISSN 00220248.

5. Connor Lane, David Rode, Thomas Rosgen Vol. 60, No. 27, Applied Optics (2021)

6. Takashi Onuma, Yukitoshi Otani, Optics Communications 69–73, 315 (2014)