Stress-Optic Coefficient Measurement with an IR Polarimeter

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Introduction

The Near Infrared Polarimeter (NIRPOL) is an imaging Muller Matrix Polarimeter designed by the Polarization Lab at the University of Arizona. The instrument is used for taking polarimetric measurements of a sample undergoing a stressing load. These measurements provide information on stress-based birefringent properties a material, and ultimately quantifying the stress-optic coefficient, C in Figure 1.

Birefringence-Modeling Stress

Birefringence is the difference in refractive indices between orthogonal polarizations and is an intrinsic property of anisotropic materials. Mechanical stress can induce birefringence in an isotropic sample. The stress-optic coefficient is the linear relation between the magnitude of induced birefringence, Δn, and induced stress. The stress-optic coefficient is reported in units of inverse Tera-Pascals $[TPa]^{-1}$.

$$\Delta n = C(\sigma_1 - \sigma_2)$$

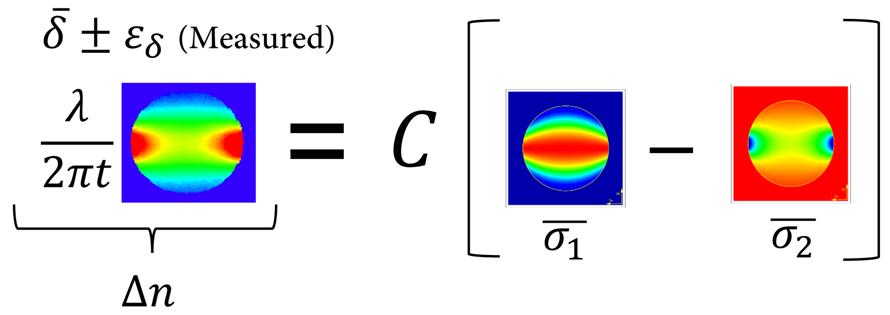


Fig.1 The relationship between principal stresses (σ) and the stress-optic coefficient (C)

A cylindrical sample is loaded with diametrically opposed, concentrated force. The plane-stress approximation is used as the z-axis stress is decoupled from x and y for light propagating along the z-axis. The stress fields were simulated with both an analytical model and Finite Element Analysis (FEA).

Finite Element Analysis

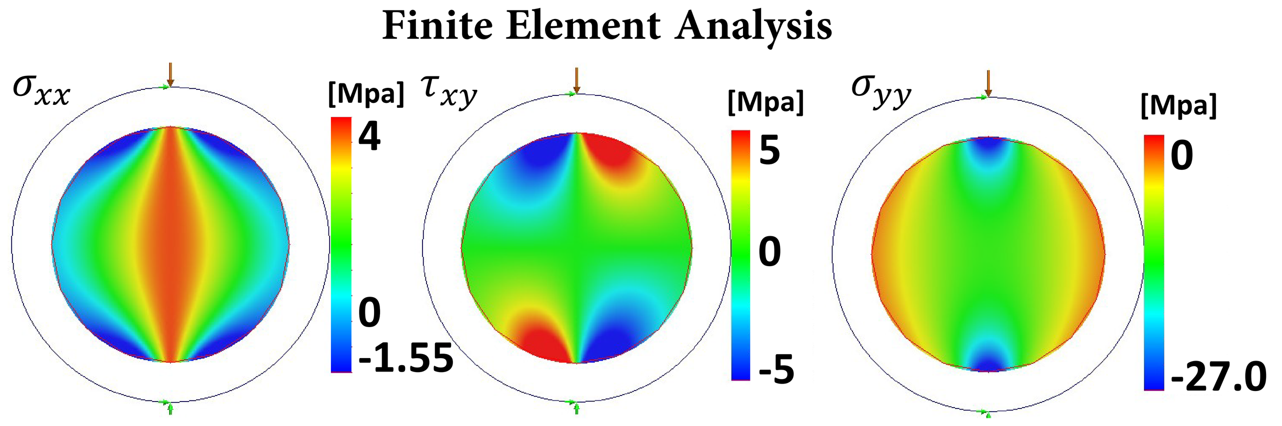


Fig.2 Normal and sheer stresses of a sample in compression, modeled using FEA

Closed Form Solution

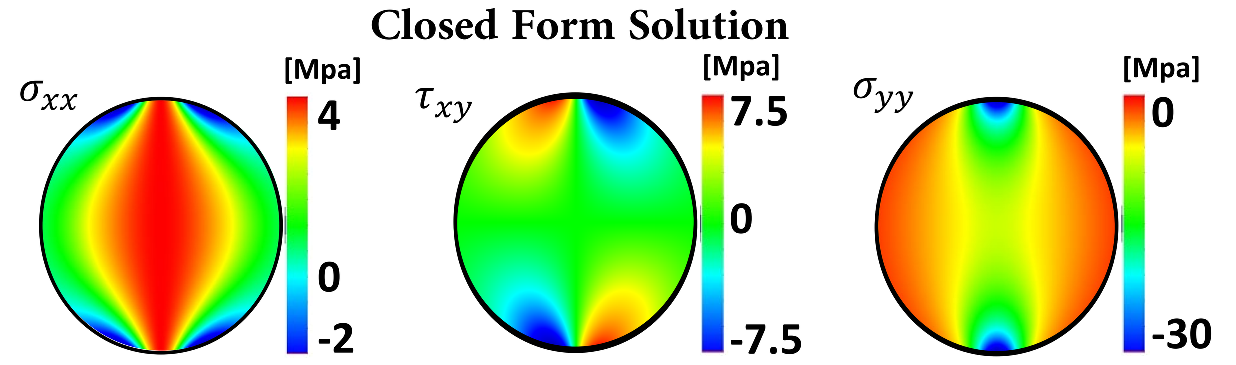


Fig.3 Normal and sheer stresses of a sample in compression, modeled using closed form solutions

The difference of the two principal stresses is used in Equation 1 to calculate the stress-optic coefficient.

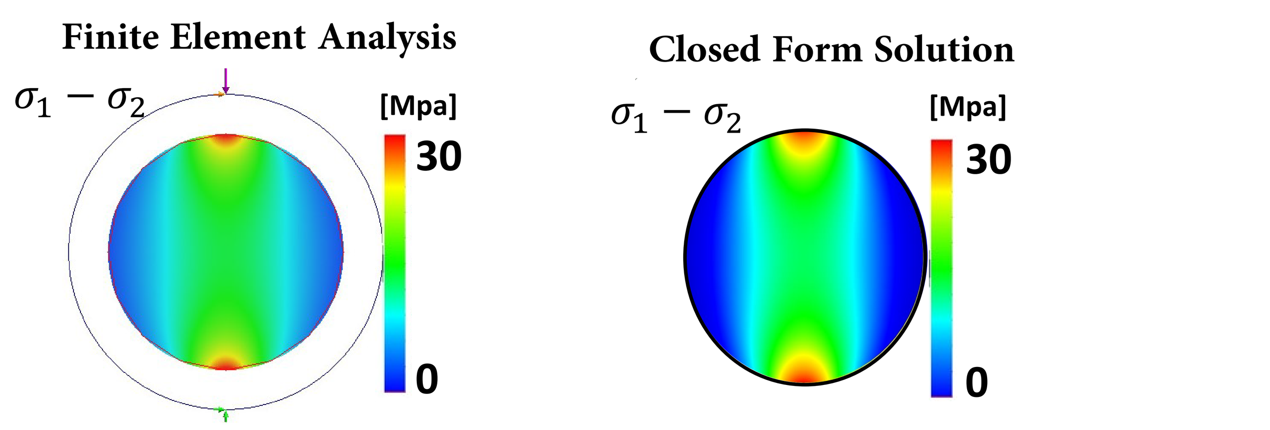
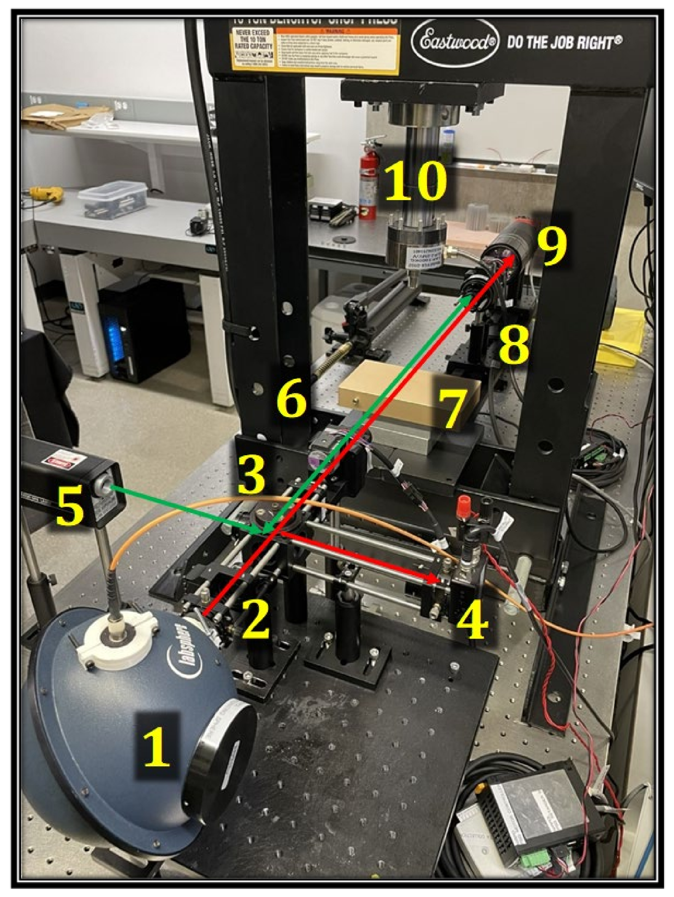


Fig.4: The difference in normal stresses in both FEA (left) and closed form solution (right)

Measurements and Data Reduction



The NIRPOL stress-optic testbed consists of: (1) Integrating Sphere, (2) Collimating Lens, (3) Beamsplitter, (4) Reference Detector, (5) Alignment Laser, (6) Polarization State Generator, (7) Sample Stage, (8) Polarization State Analyzer, (9) InGaAs Camera, (10) precision load cell, and Ten-Ton Hydraulic Press.

The Mueller matrix image is measured at five loading forces. The linear retardance is extracted and averaged from a central 100 pixel region of interest in Figure 5.

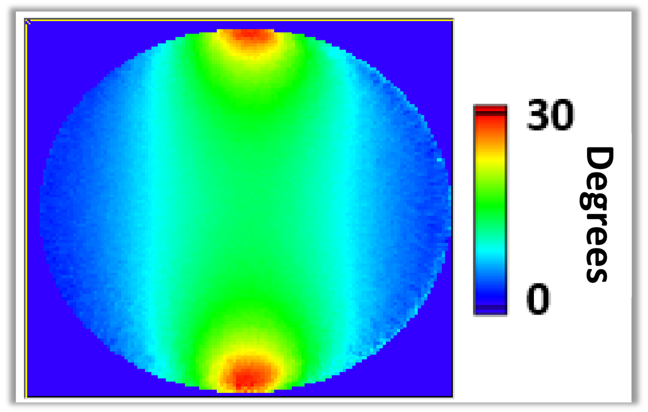


Fig.5 Linear retardance magnitude of an N-BK7 sample under 200 N loading force

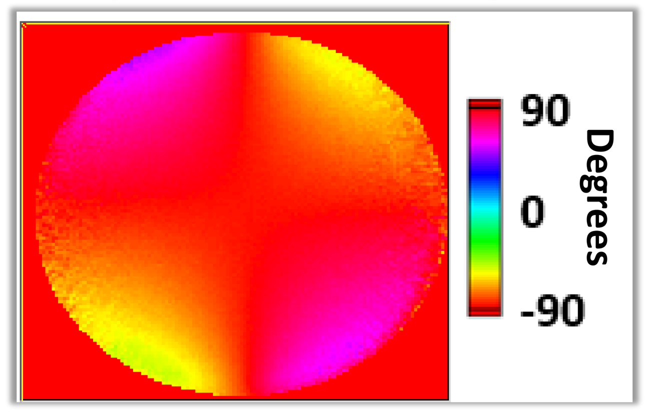


Fig.6 Retardance orientation of an N-BK7 sample under 200 N loading force

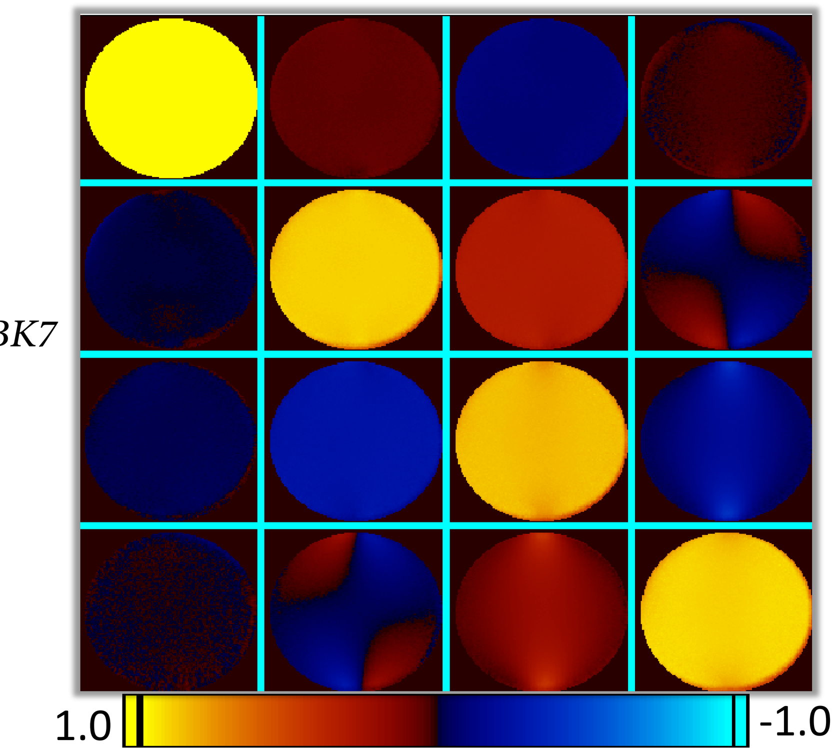


Fig.7 Mueller matrix image of an N-BK7 sample under 200 N loading force at 1550 nm

The stress optic coefficient is computed by fitting a linear trend to measured birefringence versus simulated principal stress difference.

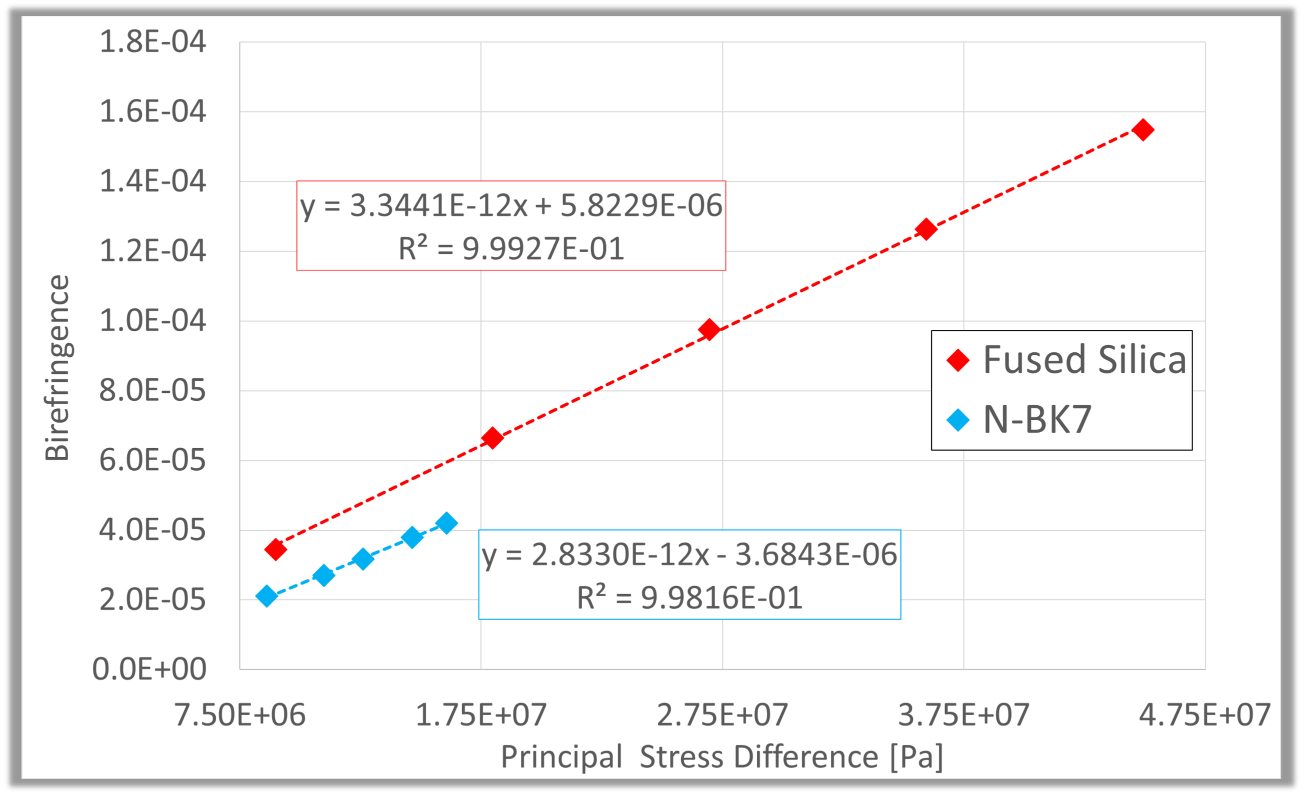


Fig.8 Linear fits show a stress-optic coefficient of 3.34E-12 for Fused Silica, and 2.833E-12 for N-BK7

Land Acknowledgement

We respectfully acknowledge the University of Arizona is on the land and territories of Indigenous peoples. Today, Arizona is home to 22 federally recognized tribes, with Tucson being home to the O'odham and the Yaqui. Committed to diversity and inclusion, the University strives to build sustainable relationships with sovereign Native Nations and Indigenous communities through education offerings, partnerships, and community service.

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Results

The stress-optic coefficient of N-BK7 was measured as $2.83 \pm 0.1057[TPa]^{-1}$ at 1550nm. The published N-BK7 value measured at visible wavelengths is $2.77\ [TPa]^{-1} \pm 3\%$. This agreement validates the experimental Mueller matrix imaging methods and supports the common assumption of minor wavelength dependence of the stress-optic coefficient.

Future Work

NIRPOL will be used to investigate stress in naturally anisotropic materials. Such materials have multiple stress-optic coefficients which characterize the unique stress response for each axis of the crystal lattice. Sapphire samples were measured: one C-Plate (top row of Figure 9) and one A-plate (bottom row of Figure 9).

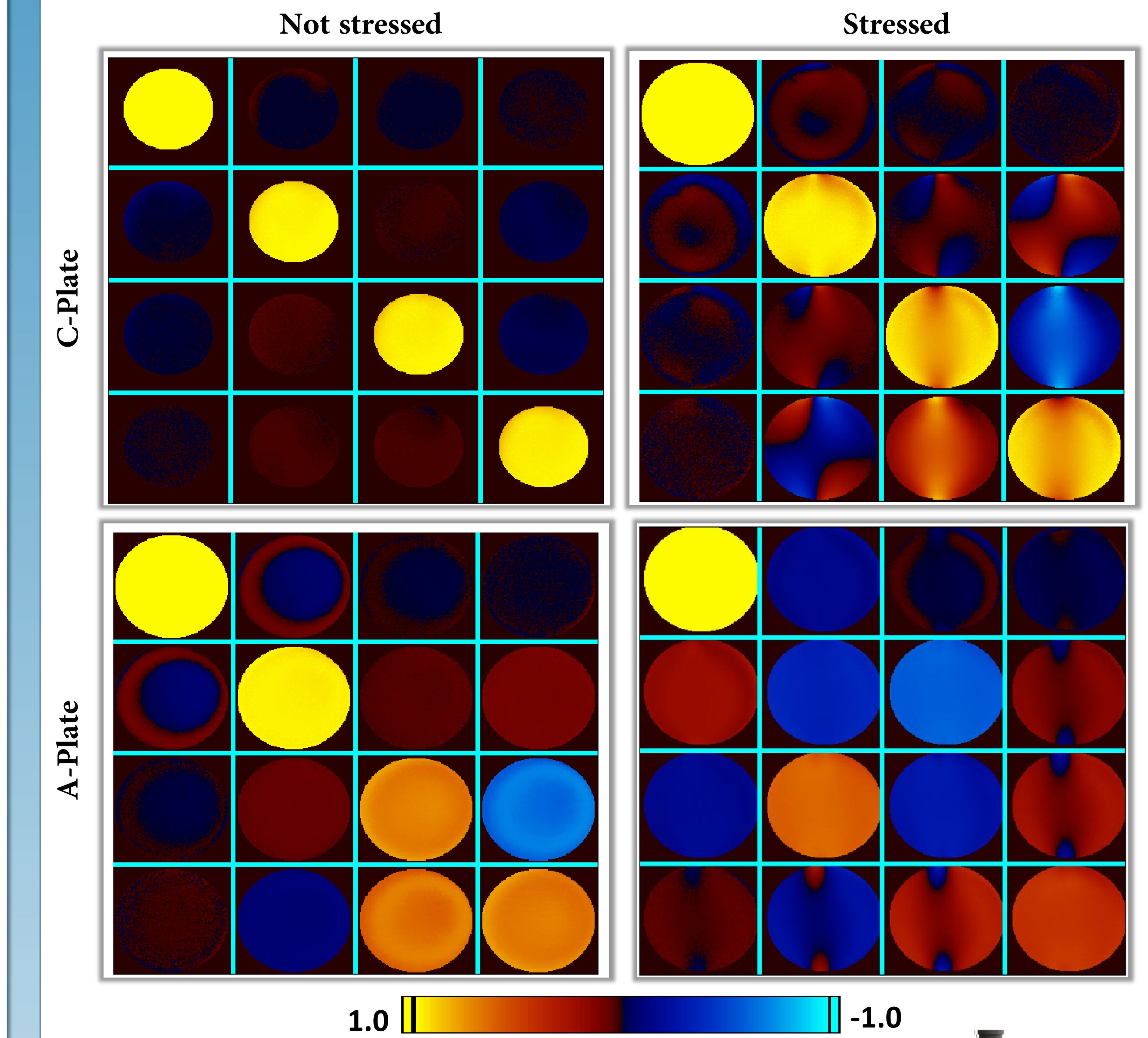

Fig.9: Mueller images of a 5mm thick 25mm diameter sapphire sample with varying crystal plane orientations not stressed (left) and stressed (right) one kilo-N loading force

The stress-optic coefficient is known to be dependent on material temperature [2]. NIRPOL will be equipped with sample heating capabilities to investigate this relationship in temperatures. Proper insulation is being designed for the heated press to prevent thermal coupling with PSA, PSG and precision load cell.

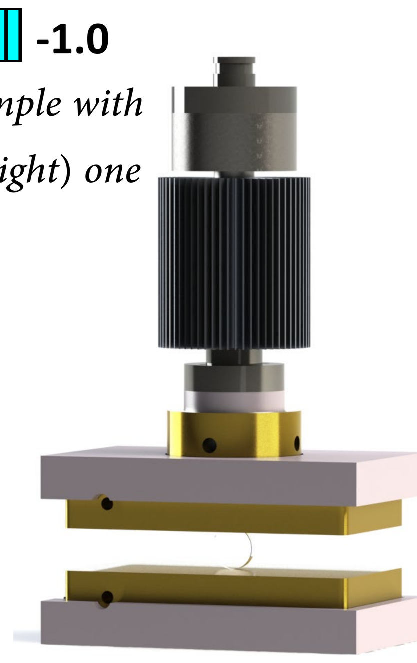

Fig.10: CAD of NIRPOL sample stage

Connect With The Lab

To learn more about the current state of NIRPOL please visit our OSF page.

To discover more of the Polarization Lab's research, visit of webpage!

References

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