University of Arizona Polarization Lab

Polarization RayTracing with Polaris

For the last decade, large numbers of polarization critical optical systems have been commercialized in diverse areas including liquid crystal projectors and displays, ellipsometers for semiconductor process testing, earth-observing satellite systems, interferometric measuring systems, and fluorescence microscopes. In response, optical design programs have added polarization analysis features but polarization is a fundamental property of light and although software additions enable particular calculations they are ill-equipped for general-purpose polarization ray tracing.

Our solution is a new, research-grade polarization ray trace engine, *Polaris*, built from the ground-up to incorporate polarization at a fundamental level. In developing Polaris*, the University team has demonstrated several technological advances not currently available in commercial products, including:

- Extension of Jones matrices for integration of polarization into ray-tracing by using a single three-dimensional ray tracing coordinate system.
- Complete model of biaxial crystals including gyrotropic materials
- Integration of vector diffraction efficiencies in a ray-trace program
- Integration of stress birefringence in a ray-tracing program incorporating links to biaxial finite element mechanical models and injection molding models
- Automated ray multiplication at all birefringent materials and diffracting structures

Features, such as models of crystal polarization, are beginning to appear in commercially available ray tracing programs, but exist in very limiting forms. The complete biaxial crystal algorithm in Polaris has not been demonstrated in optical ray tracing code before. Figure 1 illustrates total internal reflection from inside a block of calcite. Ray splitting, refraction, and reflection are evident.

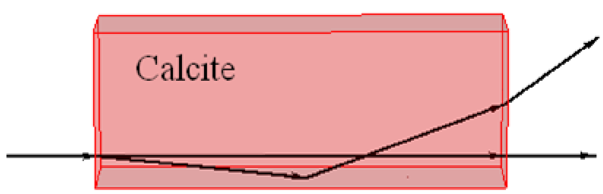


Figure 1: Ray-splitting in a block of calcite. Ordinary ray travels straight while extraordinary ray refracts and undergoes total internal reflection at the bottom surface before refracting out of the calcite block.

The University of Arizona Polarization Laboratory is a recognized leader in polarization engineering and polarization measurement. Lead by Dr. Russell Chipman, our state-of-the-art polarization measurement facilities complement our modeling capabilities

* Funded by Science Foundation of Arizona grant #SRG 0374-07, in partnership with *Breault Research Organization* (BRO), Tucson, Az.

through ray-tracing with measured components. Measurements assist in the verification of algorithms.

Polarization Modeling Capabilities

Polaris incorporates ray tracing algorithms for refraction, reflection, and diffraction in birefringent crystals, diffraction gratings, polarizers and retarders, thin-films, and other polarizing media, as well as conventional isotropic glasses. Full polarization information in the form of a three-dimensional polarization ray trace matrix (an extension to the Jones matrix) is captured with each ray path in addition to traditional geometric optics quantities. Sequential and non-sequential ray tracing is supported for common optical surfaces. Applications include:

- **Polarization PSF and MTF:** Polarization performance characterized in terms of Point Spread Function and Modulation Transfer Function displayed as Jones matrices.

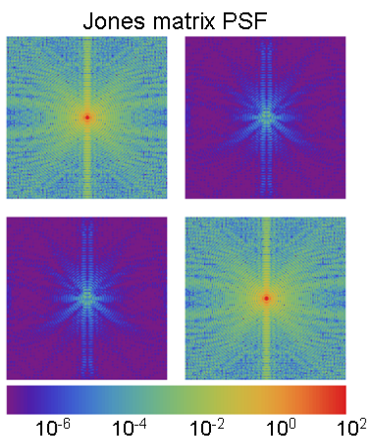


Figure 2: Polarization performance of a single plastic lens with stress birefringence from injection molding is described in terms of Jones matrix elements.

- **Stress Birefringence:** Effects of full stress tensors and stress gradients are computed and their effects on polarization evaluated.

- **Biaxial Ellipsometry:** Complete characterization of the orientations and complex indices of refraction of general biaxial thin films and substrates.

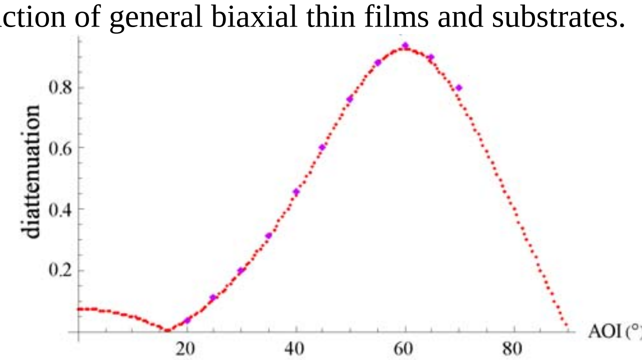


Figure 3: Comparison of polarization diattenuation measurement (purple dots) and ray-trace results (red line) for 293nm of TiO_2 coated on to a crystal calcite substrate (λ = 550nm)

– **Depolarization:** Investigating new data analysis techniques to unlock depolarization information in scattered light.

– **Low Polarization Thin-Film Coatings Design:** Design and verification of multi-layer thin-film coatings with low polarization properties and effective reflectivity performance to reduce polarization sensitivity and polarization aberrations.

– **Rigorous Coupled Wave Theory:** Diffractive structures to controllably modify polarization properties.

– **Polarizer Models:** Realistic wiregrid, crystal, and plastic sheet polarizers show leakage of skew rays.

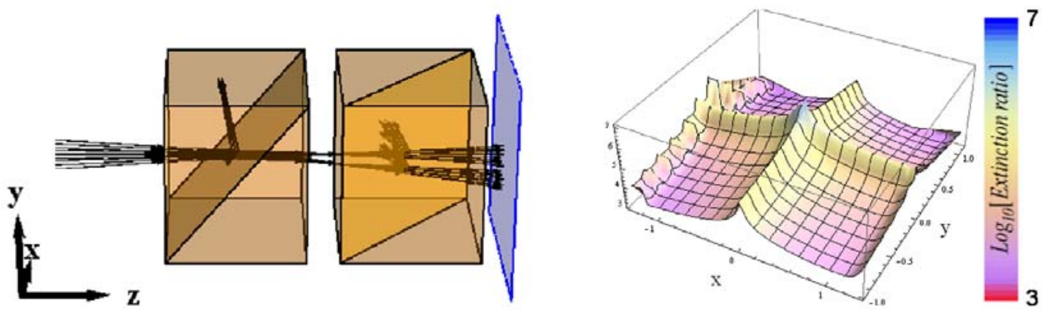


Figure 4: Circularly polarized rays traced through two Glan-Taylor polarizers with crossed axes. Extinction ratio varies considerably across a ±3° field of view.

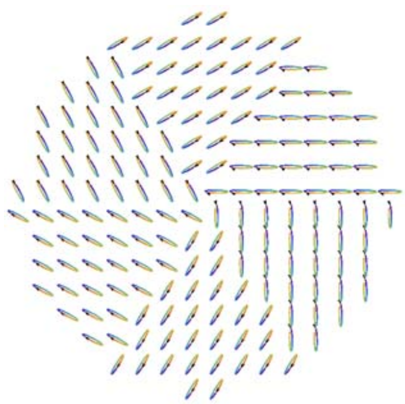
Research Team

The University of Arizona Polarization Laboratory is lead by Dr. Russell Chipman, winner of the 2007 SPIE G.G. Stokes award for “advancement of the field of polarization engineering.” Russell brings over 20 years of experience in polarization system design and analysis.

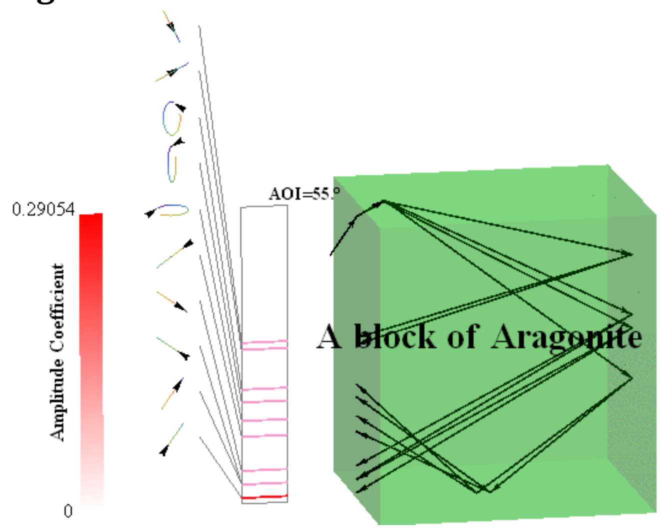
The Polarization Laboratory is staffed by 4 full-time research scientists: Steve McClain, Meredith Kupinski, Greg Smith, and Karlton Crabtree. The group additionally consists of 10 graduate students, and 4 undergraduate students. Polaris ray-tracing development forms a large portion of our group activities, occupying 6 graduate students working to resolve complex issues related to polarization ray tracing.

Polarization Laboratory [Russell Chipman]
College of Optical Sciences
University of Arizona
1630 E. University Blvd.
Tucson, AZ 85721
ph: (520) 626-9435
fax: (520) 626-4599
web: http://www.optics.arizona.edu/chipman/

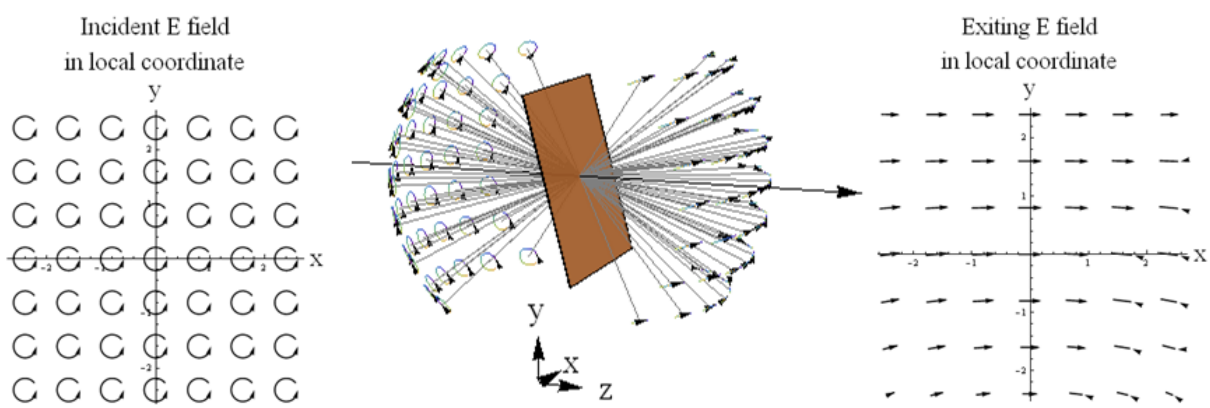
Polaris RayTracing Demonstrations



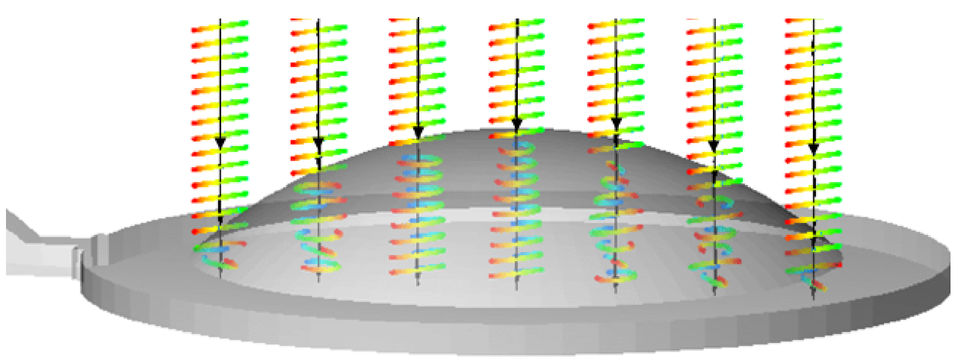
Polarization state exiting a metalized hollow corner-cube retroreflector when circular polarization is incident.



A single ray incident on a block of aragonite crystal reflects and splits multiple times before returning to original surface.



Focused circularly polarized rays incident on a tilted wiregrid polarizer show light leakage at large angles.



A line of rays propagating through a finite-element model of stress-birefringence in an injection molded lens. Polarization changes on propagation depend on local stress tensor. (surface refraction ignored)