NC STATE UNIVERSITY

24-284SB: Single-Shot Polarization Imaging of Defects in Fiber Spinning

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Objectives

1. To implement a single-shot polarization imaging system on the Hills fiber spinning line to capture defects such as bubbles, polymer chain misalignments and surface roughness in real-time.
2. To compile a database of fiber polarization states (retardance and polymer chain alignment) for various polymer materials under different spinning parameters.
3. To develop and implement a machine learning-based automated process monitoring method for real-time defect detection and classification in single and multi-fiber spinning production.

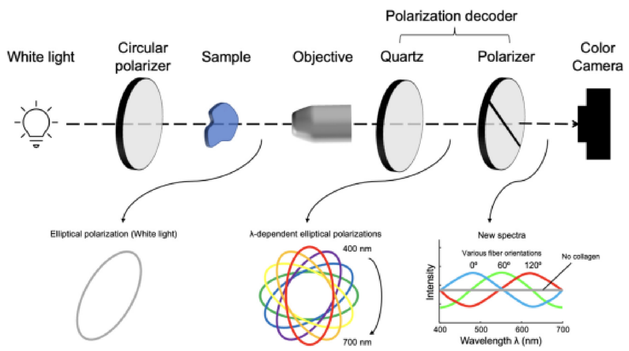
Single-Shot Imaging

Instant Polarized Light Microscopy (IPOL π) and Polarized Shearing Interference Microscopy (PSIM) are single-shot techniques designed for real-time imaging of birefringence in fast-moving fibers. These methods capture polarization data in a single frame, making them ideal for high-speed fiber production, where real-time defect detection is critical.

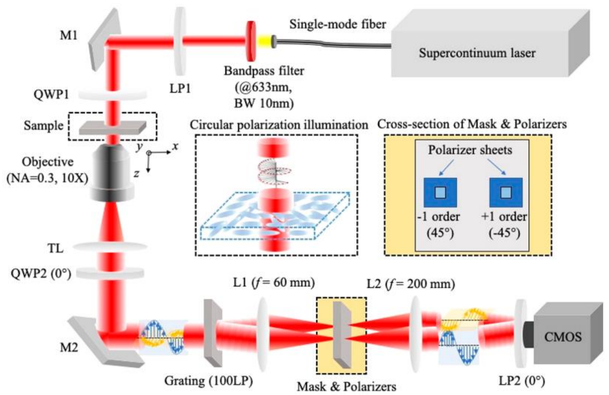
- IPOL π uses a color-coding scheme to differentiate fiber orientations, allowing for quick visualization of molecular alignment.
- PSIM provides high temporal resolution, detecting defects like molecular misalignments and surface roughness without motion artifacts.

Advantages:

- Captures dynamic processes in real-time without motion blur.
- Ideal for high-speed environments such as fiber spinning.



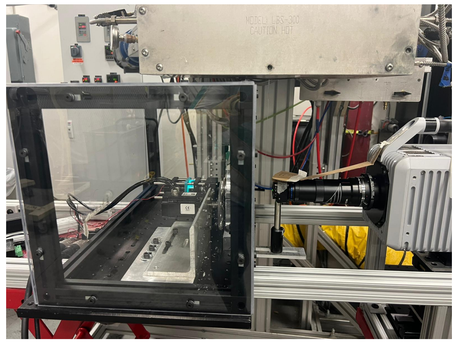
Lee et al., Optics and Lasers in Engineering (2023)

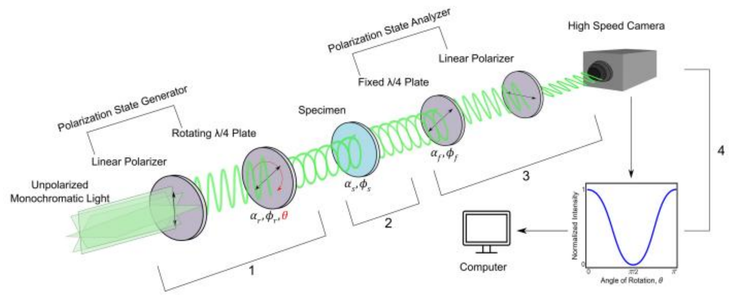


Ge et al., ACS Photonics (2021)

Multi-Shot Imaging

- Quantitative Polarized Light Microscopy (QPLM) is a multi-shot imaging technique used to assess fiber birefringence and alignment. QPLM captures polarization data over multiple frames, making it suitable for slow-moving or static fibers. It provides detailed retardation maps, revealing molecular alignment and internal stress within fibers.
- Limitations:
  - Requires multiple exposures, leading to motion blur and artifacts in high-speed fiber production.
  - Inability to capture dynamic processes in real-time, limiting its use in fast-moving environments like fiber spinning.





Timofeeva et al., Optical Engineering (2024)

Conclusion

- Single-shot polarization imaging combined with machine learning offers a robust, real-time solution for detecting fiber defects during high-speed production. These techniques improve monitoring accuracy, reduce manual inspection time, and enable automated quality control. However, challenges remain in optimizing system calibration and training machine learning models with large datasets.

- **Next steps:**
  - ✓ Refine machine learning models
  - ✓ Expand data collection
  - ✓ Implement system optimization
  - ✓ Conduct further testing

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