Random-to-Radial Polarization Conversion for Laser-Based Manufacturing Industry

June 2025

CLEO Europe 2025

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Directed Energy Research Center

ATRC

ADVANCED TECHNOLOGY RESEARCH COUNCIL

TII Technology Innovation Institute

ASPIRE

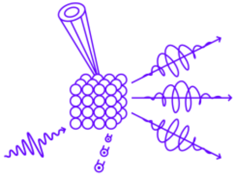
VENTURE one

Directed Energy
Research Center

- Acoustics Systems
- Sonar Systems and Underwater Com
- Radio Frequency Engineering
- Pulsed Power
- High Power Sources
- Solid State
- RF Sensors
- Stealth/Radar
- EMC Engineering
- Laser Beam Control
- Laser Matter Interaction
- Laser System Engineering
- High Power Laser
- Light Processing
- Light Sensing
- Light on Chip
- Sub Surface imaging
- Machine Learning Fundamentals
- Systems Dynamics and Resilience
- Earth Observation

Photonics department

Overview



Research Activities & Capabilities:

- AI-Enhanced Electro-Optic Sensing & Imaging
- Structured Light and Applications
- Earth Observation
- Polarimetry and Stokes measurements
- Artificial Intelligence
- Infrared and Multi-spectral imaging
- Terahertz Imaging
- Integrated Photonic Amplifiers

The Team:

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Senior Researcher

Rashed Alblooshi
Researcher

Abdelkarim Watmani
Acting Director

Presentation Outline:

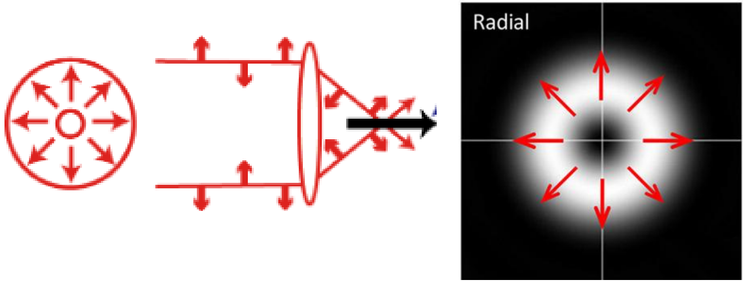
- Motivation
- Introduction to Structured Light
- Angular momentum of Light
- Vector-Vortex beams
- Methods to obtain radially and azimuthally polarized beams
- Material Processing
- Random to Radially polarized beam (R2R) Converter

Motivation

High-power single-mode fiber lasers often emit randomly polarized light due to fiber birefringence, leading to inconsistent absorption during material processing. We proposed a plug and play fully passive optical design to convert random polarization into radial polarization.

<u>This results in:</u>

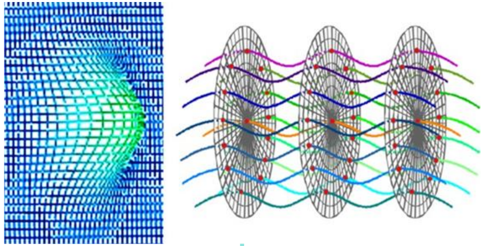
- Uniform absorption during movement
- Reduced focal intensity fluctuations
- A doughnut-shaped profile with steeper intensity gradients than Gaussian beams
- Tighter focus for enhanced precision



Radial polarization significantly improves accuracy and energy efficiency in laser-based material processing.

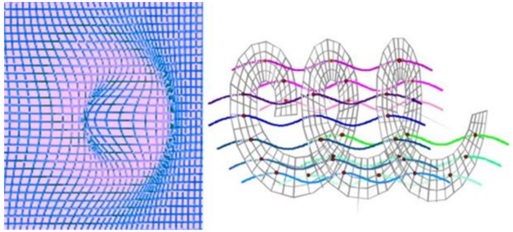
Structured light

Gaussian beam



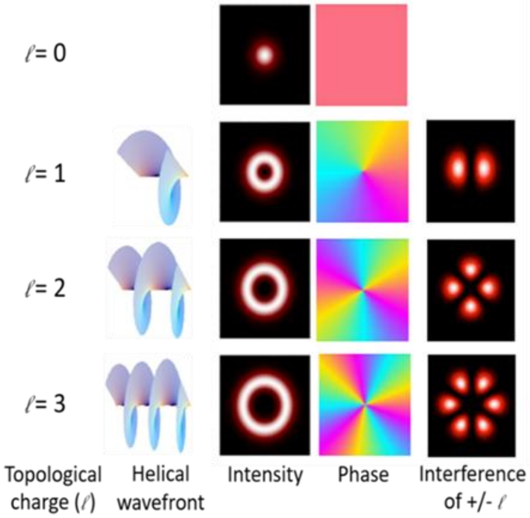
What if light can be twisted to transform into different spatial modes ?

Vortex beam



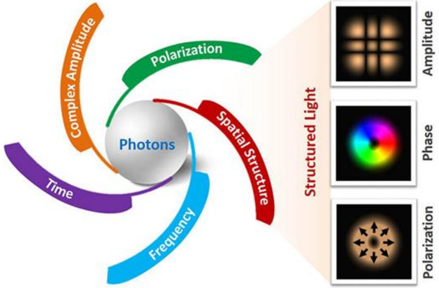
The degree of this twist and it's direction matters ? Yes

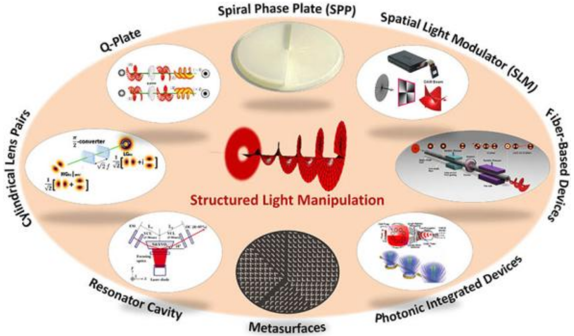
Topological Charge



Physics Today ***57****, 5, 35 (2004)*

Techniques to Generate Optical Vortices

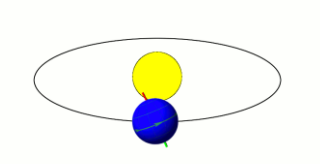


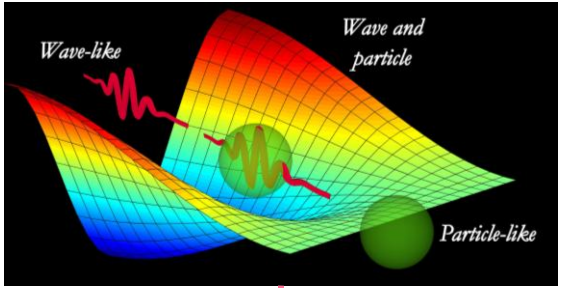


Chinese Optics Letters ***16****, 5, 050006(2018)*

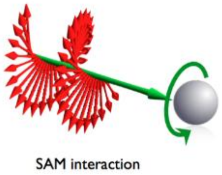
Why is it possible to manipulate light ?

Anything that spins → **Carries Angular Momentum** → **Duality of light**





Divided into two components

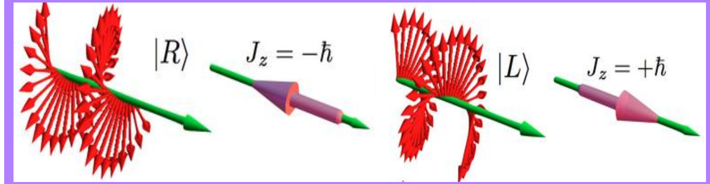


As a particle

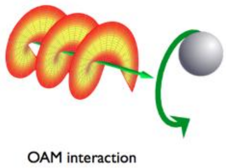
Spin angular momentum (SAM)

Polarization of light

Polarization spin Polarization spin



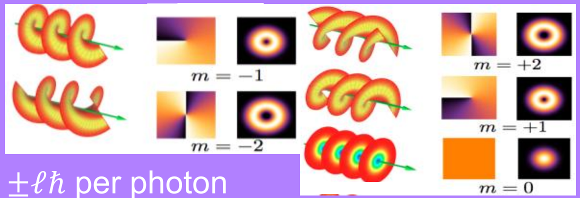
- $\pm\hbar$ per photon
- 2 degrees of freedom per photon



As a wave

Orbital angular momentum (OAM)

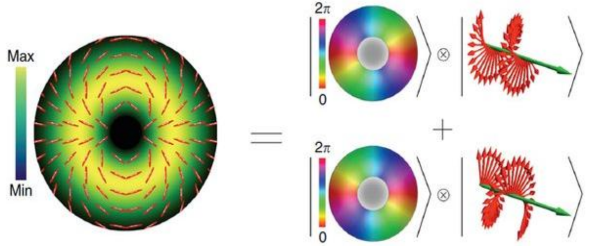
helical wavefronts / Twist



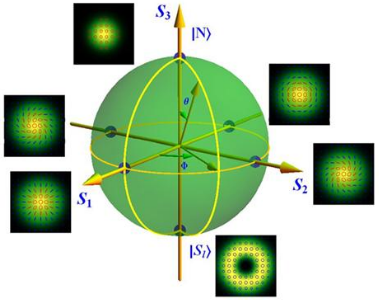
- $\pm\ell\hbar$ per photon
- Infinite degrees of freedom per photon

Vector-Vortex beams

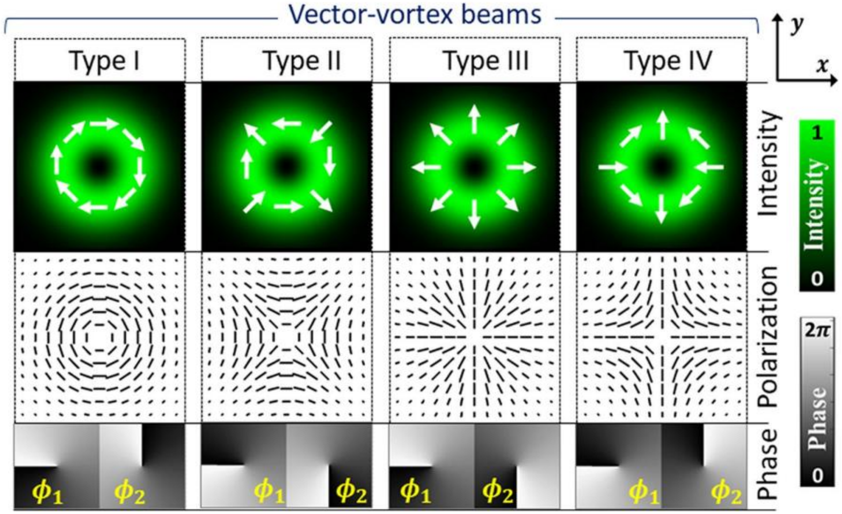
- Vector beams have spatially varying polarization along the spatial profile
- Co-axial superposition of Orthogonal polarizations with different topological charge and different sign



Nature, Light Sci Appl **8**, 90 (2019)



Proc. SPIE 10022, Holography, Diffractive Optics, and Applications VII, 100220X (31 October 2016)



Sci Rep 12, 17253 (2022).

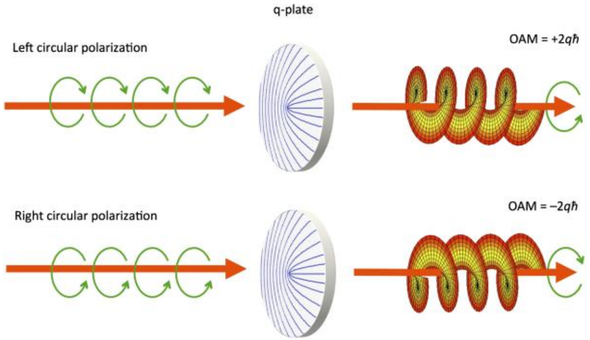
Methods for obtaining Vector Vortex beams

1. Q-plate

Converts circularly polarized light into vector beams carrying orbital angular momentum (OAM), depending on topological charge.

Challenges:

- Wavelength-sensitive (birefringence tuning)
- Power handling is limited
- Temperature-sensitive (liquid crystal based)



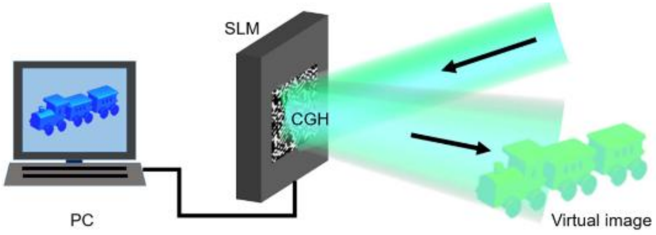
Journal of Nanophotonics, Vol. 7, Issue 1, 078598 (September 2013).

2.Spatial Light Modulator (SLM)

Modulates phase and/or polarization dynamically using computer-generated holograms.

Challenges:

- Limited damage threshold (not for high-power lasers)
- Complex calibration
- Requires polarization-sensitive alignment



Vol. 11, No. 3 / September 2019 / Advances in Optics and Photonics.

*Chinese Optics Letters **16**, 5, 050006(2018)*

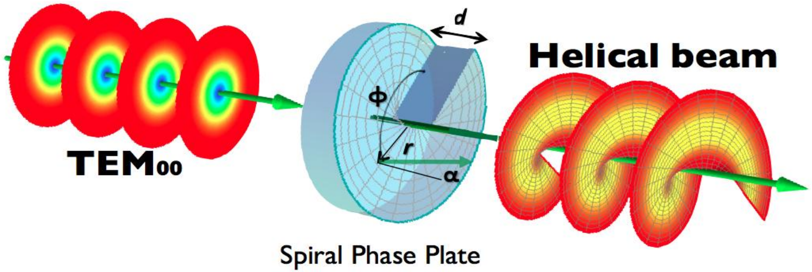
Methods for obtaining Vector Vortex beams

3. Spiral Phase Plate (SPP)

Imposes an azimuthally varying phase shift to generate vortex beams.

Challenges:

- Produces scalar vortex beams unless combined with polarization optics
- Limited to specific topological charges
- Fabrication precision required)

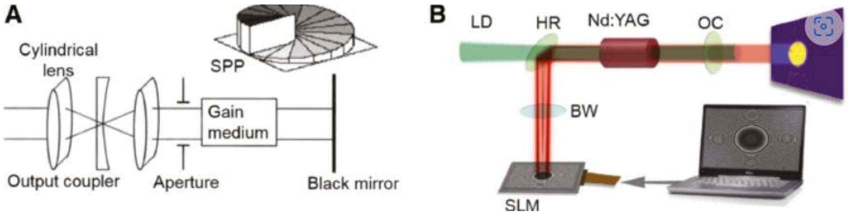


4. Resonator Cavities (Laser Mode Engineering)

Custom laser cavities designed to oscillate directly in vector vortex modes (e.g., using polarization-selective mirrors or SPPs inside).

Challenges:

- Complex and inflexible
- Fabrication/design of cavity optics
- Mode stability concerns



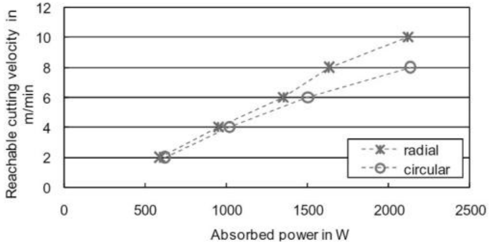
Different Cavity designs using different optical elements like SPPs and SLMs. Nanophotonics 2018; 7(9): 1533–1556.

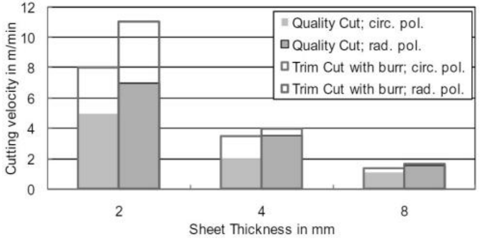
*Chinese Optics Letters **16**, 5, 050006(2018)*

Material Processing by Radially Polarized beams

Laser cutting

Using a CO_2 laser to cut thick metal sheets



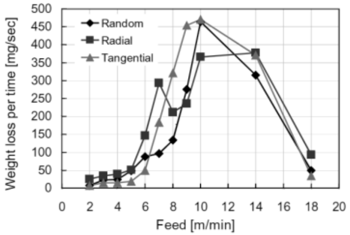


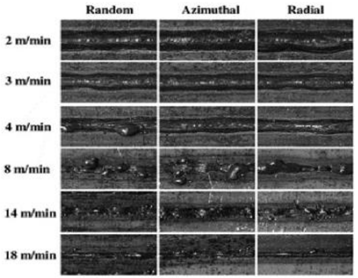
- ✓ An increase in cutting velocity up to 100%
- ✓ Improves the cut quality at lower sheet thickness with higher velocity

Physics Procedia **12** (2011) 21–30

Laser Welding

7.9 KW fiber laser used in welding 10 mm thick mild steel S235 plates





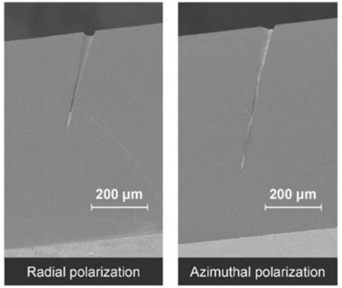
- ✓ Lower feeds yields significant weight reduction while higher feeds causes humps thus operating at the middle feeds yields the best results where radial polarization is better.

Physics Procedia **12** (2011) 21–30

Laser Drilling

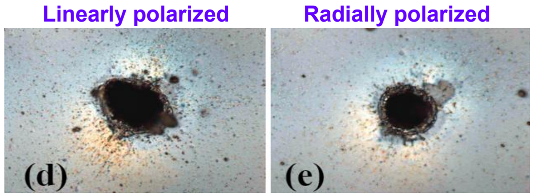
Drilling holes by a picosecond (1030 nm) pulsed in 1mm CrNi steel

- ✓ Azimuthal polarization enables deeper, faster drilling; radial suits wider holes in thin sheets



Opt. Express **18**, *22305-22313 (2010)*

Microvias drilled with a polarized beam at 100kHz repetition



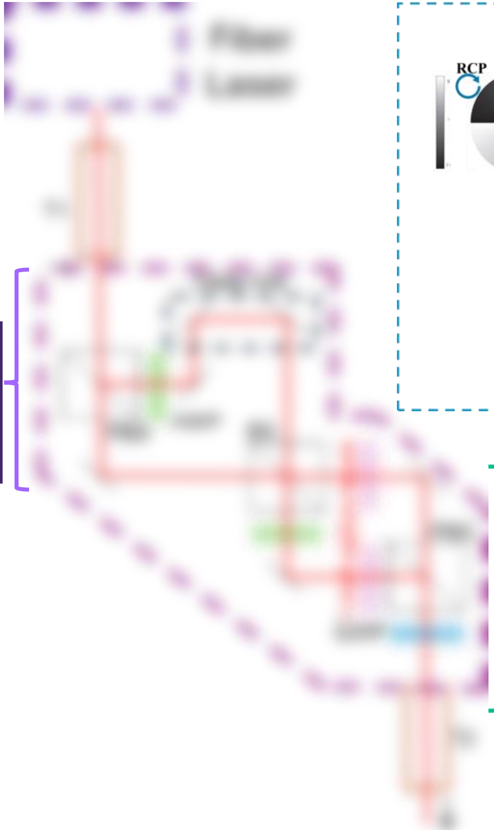
JLMN-Journal of Laser Micro/Nanoengineering Vol. **7**, *No. 3, 2012*

- ✓ Reduced diameter, extended depth, and cleaner finish

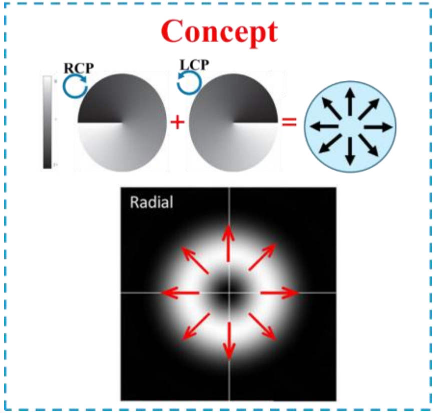
R2R – Beam Shaping Device

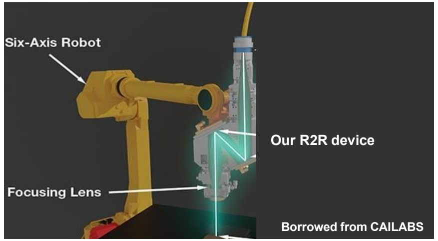
Targeted for Laser Based Manufacturing industry

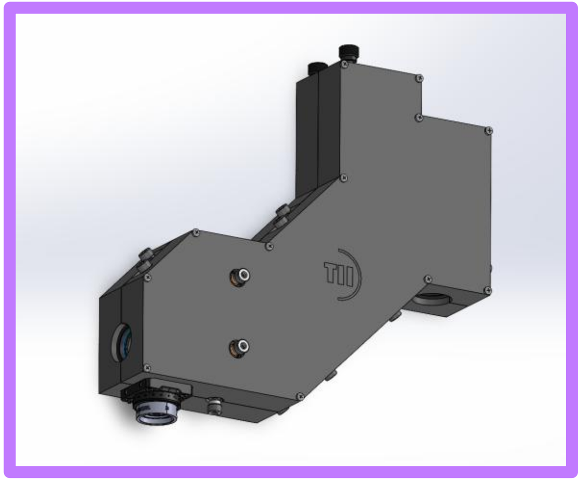
Passive polarization stabilizer



Radially polarized beam generator



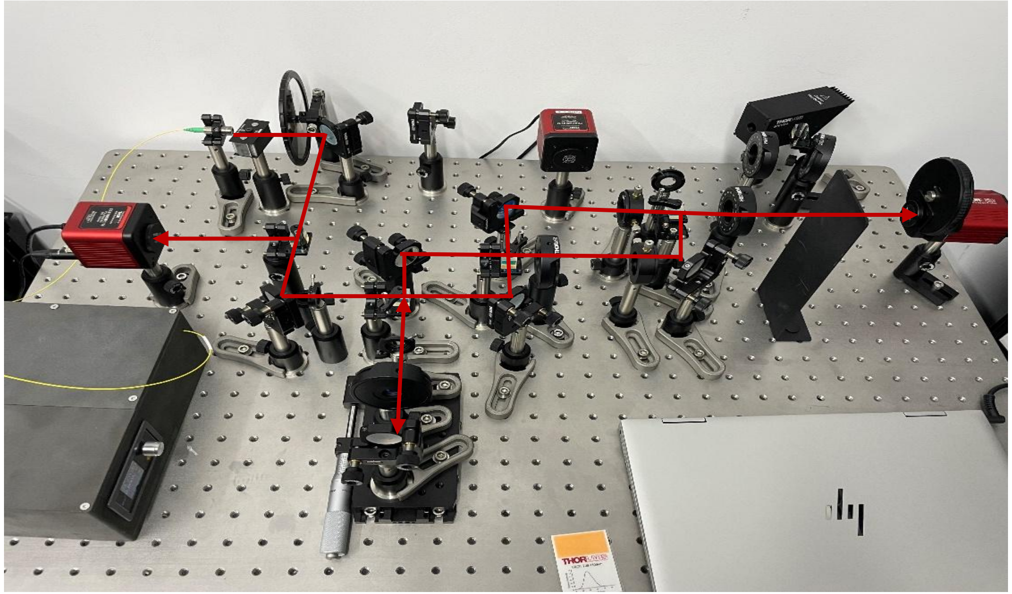


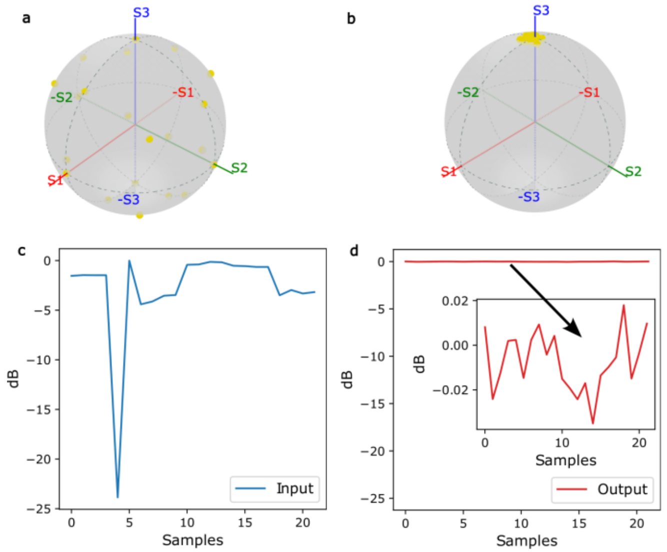


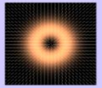
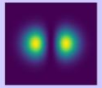
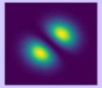
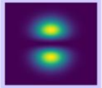
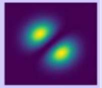
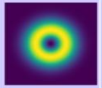
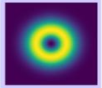
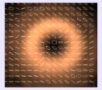
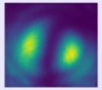
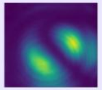
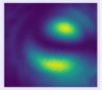
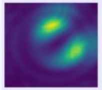
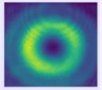
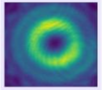
R2R – Beam Shaping Device

TRL 4 PoC Experimental Demonstrations

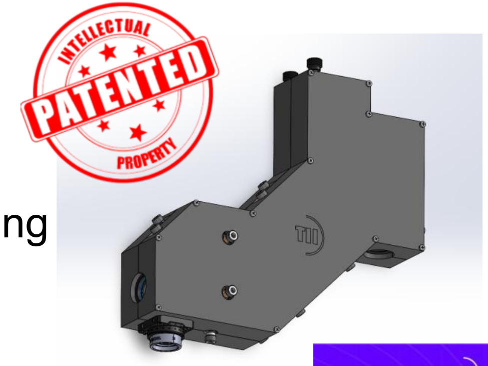
- Passive device to convert Randomly polarized beams Structured light beams
- Provides Stable Circular Polarization for Laser Comm systems
- Enables use of randomly polarized sources for polarization sensitive application





	Polarizatioa& Total Intensity	Horizontal	Anti-diagonal	Vertical	Diagonal	Left	Right
Sim.							
Exp.							

R2R – Beam Shaping Device



- ✓ Our device is patent pending currently
- ✓ Was awarded the Best Additive Manufacturing Project in 1 minute in the 3rd Additive Manufacturing Conference held by TII.
- ✓ Validated by the scientific community

Next step:
We will integrate it for high-power laser integration

High Power Laser Sources division

The HPLS division specializes in the design and development of high-performance, high-power fiber lasers operating in both continuous-wave and pulsed modes, spanning a wide spectral range from the visible to the near-infrared

EmiRay – 1 µm CW

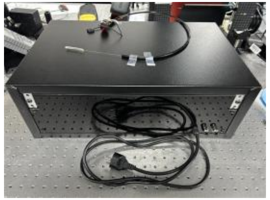
Designed for superior beam quality, efficiency and reliability, EmiRay-1 CW offers a power range from **1 W to 2.5 kW** at **1 µm**, making it ideal solution for industrial, scientific, and research applications

	EmiRay 1 W	EmiRay 1.5 kW	EmiRay 2.5 kW
Wavelength	1060-1080 nm		
Output power	1 W	1.5 kW	2.5 kW
Beam quality M^2	< 1.1	< 1.3	
Wall-plug Efficiency	40%		
Type of cooling	Air	Air/Water	Water

EmiRay – 2 µm CW

Emerging **2 µm** lasers offer unique advantages in different fields including surgery, and processing of transparent plastics

	EmiRay 2 CW
Wavelength	1940 – 2050 nm
Output power	Up to 500 W
Beam quality M^2	< 1.3
Wall-plug Efficiency	23%
Type of cooling	Air/Water



EmiRay – PULSE

We are offering a large selection of polarized **nanosecond and picosecond lasers** for different applications including LiDAR, material microprocessing, laser cutting and other advanced applications

	Infrared	Green
Wavelength	1064 nm	532 nm
Pulse duration	1 – 10 ns / 50 ps	
Pulse repetition rate	100 kHz – 10 MHz	
Peak Power	up to 500 kW	up to 200 kW
Polarization (PER)	> 15 dB	
Beam quality M^2	< 1.3	

For more info, please contact Dr Giuseppe Scurria, giuseppe.scurria@tii.ae

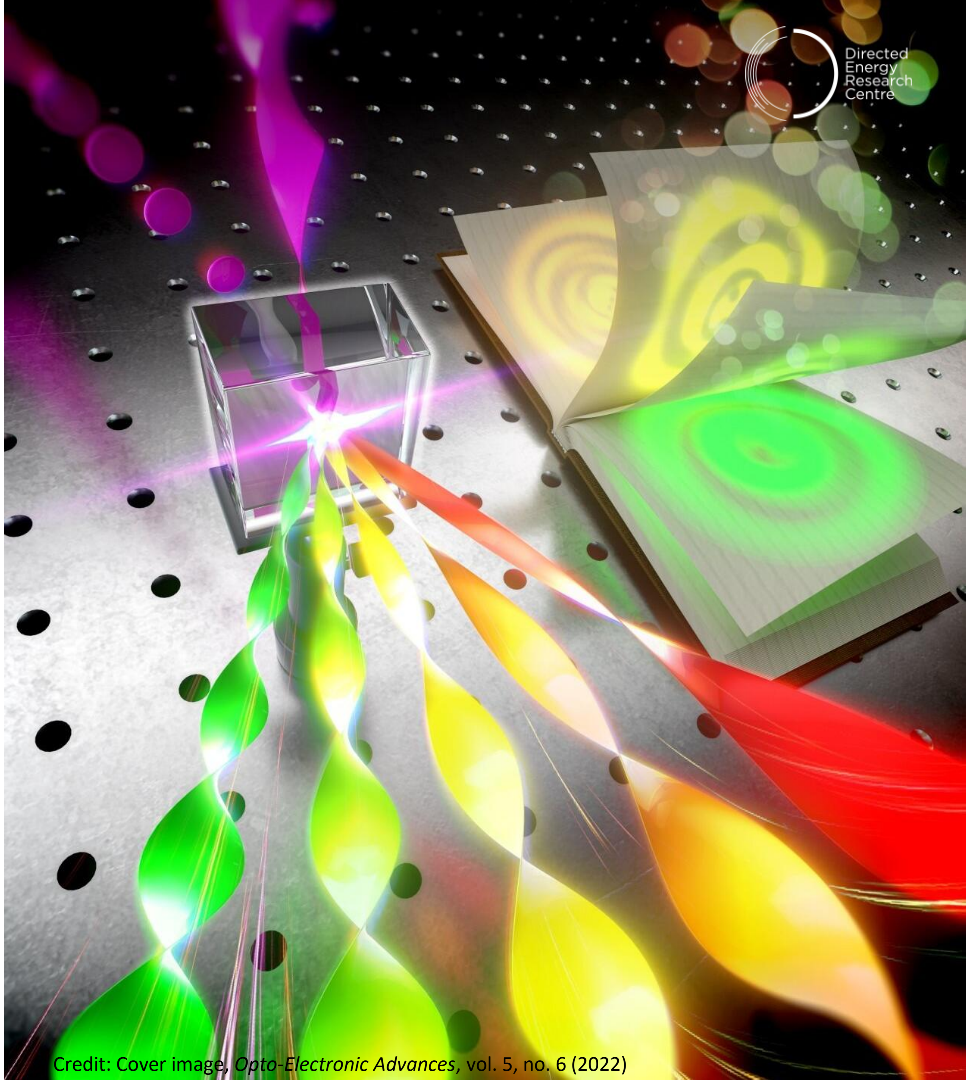
Light Processing Division

We shape light for your requirements. We invite you to explore Collaborative Projects with us!

Technology Innovation Institute

Directed Energy Research Centre

Thank you for your attention!



Credit: Cover image, *Opto-Electronic Advances*, vol. 5, no. 6 (2022)

Team and Key KPIs

Resident Team

Dr. Felix Vega
Chief Researcher

Milosch Meriac
Senior Director Signals & Electronics

Dr. Guillaume Matras
Senior Director High Power Lasers & App

Dr. Islem Yahi
Principal Researcher

Dr. Fernando Albarracin
Principal Researcher

Dr. Qingjie Yang
Lead Researcher Wave Physics

Karim Watmani
Acting Director

Bader Al Ali
PMO Lead

Yaser Aljaberi
Senior Project Manager

Umesh Panicker
Senior Manager Learning & Development

Center's KPI Overview – Q1 2025

- **33** Nationalities
- **130** Total Employees
- **46** Emiratis
- **270** Publications
- **46+** No. of differentiated products (TRL4+)
- **6** Board of Advisors
- **30** Partnerships
- **19** Patents – 8 filed