Preface

This research aims to address key challenges in interferometry when using low-coherence light, which is crucial for advancing optical measurement techniques. The study introduces innovative experimental methods for comprehensively measuring the coherence and polarization properties of light by evaluating the cross-spectral density (CSD) matrix. These techniques provide detailed insights into the vectorial coherence characteristics of light. One of the primary contributions of the thesis is the application of the developed methods to generate vortices in low-coherence light. Optical vortices, characterized by phase singularities, are typically associated with high-coherence sources, and the generation of vortices using low-coherence light marks a significant advancement. The research validates the experimental findings with extensive simulations conducted on the MATLAB platform, ensuring robustness and reliability in the analysis.

The thesis is systematically organized into **six** chapters, each addressing distinct aspects of the research. The chapters collectively cover the theoretical underpinnings, experimental designs, simulation processes, and implications of the findings. This structured approach not only demonstrates the feasibility of the proposed methods but also paves the way for further exploration in the field of low-coherent light and vortices.

Chapter 1 presents an introduction to the interferometry with coherent and low-coherent light sources and their application in the generation and detection of vortices. It begins with an introduction to light sources, categorizing them into coherent and incoherent types, and delves into their unique properties and applications in interferometry. The thesis also provides a comprehensive exploration of vortices in coherent light *i.e.,* optical vortices, their generation methods, and detection techniques. It explains various tools, such as spiral phase plates, spatial light modulators, and direct laser cavity methods, for generating vortices and highlights their applications in areas like particle trapping, optical communication, and spiral interferometry. Later, the challenges with fully coherent light and advantages of using low coherent light is highlighted. The discussion transitions to the concept of coherence, exploring its spatial and temporal aspects, the van Cittert-Zernike theorem, and how spatial coherence evolves during propagation. Established techniques for measuring scalar coherence, including Young's interferometer and advanced setups like wavefront folding and Sagnac-type interferometers, are analyzed. The unification of coherence and polarization theory, alongside the measurement of vectorial spatial coherence, forms a critical component of the thesis. Methods like the Hanbury Brown–Twiss experiment and self-referencing holography are presented as powerful tools for studying vectorial coherence. This discussion sets the foundation for investigating vortices in low-coherence light, addressing the challenges and innovative solutions presented in the research. Ultimately, the thesis outlines its objective of advancing experimental designs for evaluating the CSD matrix and leveraging these methods for generating and analyzing vortices in low-coherence light.

Chapter 2: Interferometry with coherent light and vortices

In this chapter, we propose an alternative and efficient method to generate and detect optical vortices using lithographically fabricated pinhole masks. This approach simplifies the process of creating customizable orbital angular momentum (OAM) modes compared to conventional methods involving the coaxial superposition of multiple vortex beams, which are often more complex. We designed a simple experimental setup based on Mach-Zehnder configuration to quantitatively measure both the amplitude and phase components of the vortex beams. This method's scalability and tunability make it highly desirable for practical applications. Specifically, we utilize a binary array of pinholes, to create vortices in a coherent light beam. By arranging these pinholes in a spiral structure, a plane wave can be transformed into a beam with a versatile OAM spectrum. The setup allows fine-tuning of the OAM spectrum by modifying the shape of the pinhole masks. This enables the generation of either single pure OAM modes or a superposition of multiple modes, offering a straightforward and flexible approach to customize OAM beams for specific applications. These advancements demonstrate the potential for creating efficient and scalable OAM spectra, catering to the growing demand in fields requiring precise and controllable vortex beam generation.

Chapter 3: Characterization of sources with arbitrary coherence

This chapter introduces a novel experimental technique to measure the 2×2 CSD matrix, essential for analyzing the coherence and polarization properties of incoherent vector light sources. The CSD matrix encodes the complex spatial coherence functions of an incoherent vector source, with its theoretical framework linked to the vectorial van Cittert-Zernike theorem for a far-field diffraction. To experimentally retrieve the two-dimensional complex distributions of the CSD matrix elements, a Sagnac radial shearing interferometer is utilized in conjunction with a phase-shifting technique. A five-step phase-shifting approach is employed to accurately determine the fringe visibility and phase, enabling the reconstruction of the complex matrix elements. Furthermore, the chapter presents the coherence-polarization properties of various beams in the far field, examining sources with different polarization characteristics, such as unpolarized, diagonally polarized, and spatially depolarized light. These findings underscore the influence of polarization tailoring on the coherence-polarization behaviour of incoherent vector sources, providing valuable insights into the interplay between coherence and polarization in complex optical systems.

Chapter 4: **Vortices in low coherent light by lithography: Generation and analysis**

This chapter focuses on the generation and characterization of coherence vortices in low-coherent light, a phenomenon where the two-point complex coherence function exhibits a singularity, signifying zero fringe visibility with a helical phase structure. The research introduces an innovative method to generate coherence vortices with varying topological charges by modulating the transmittance of an incoherent source using intricately designed binary pinholes. These pinholes, fabricated through lithographic techniques followed by wet etching, serve as structured apertures that shape the spatial coherence properties of the light source. The structured pinholes enable precise control over the incoherent source's transmittance, resulting in coherence vortex spectra comprising both multiple and pure OAM modes. The generated coherence vortices are embedded in the spatial coherence function, where the phase component exhibits a helical structure, and the magnitude displays a characteristic doughnut-shaped intensity profile. The theoretical framework underlying this process is rigorously developed and corroborated through both simulations and experimental results.

Chapter 5: Digital generation of coherence vortices

This chapter focuses on the generation of coherence vortices, a unique singularity in the coherence function, utilizing advanced digital devices such as spatial light modulators (SLMs) and digital micromirror devices (DMDs). The use of these devices enables precise manipulation and control over the phase and amplitude of light beams, making them pivotal in crafting the exotic spatial coherence structures that define coherence vortices.

SLMs, which offer high-resolution spatial modulation of the light field, allow for dynamic encoding of phase masks tailored to produce specific coherence vortex characteristics. This flexibility facilitates the creation of various topological charges and helical phase profiles within the coherence function. Similarly, DMDs, known for their fast response rates and binary amplitude modulation capabilities, provide a robust platform for generating structured light fields. The integration of these devices into the experimental setup ensures high precision and adaptability, crucial for studying coherence vortices in diverse configurations. Through theoretical modelling, simulations, and experimental verification, this chapter demonstrates the generation and analysis of coherence vortices using these digital tools.

Chapter 6: Conclusion and future scope

This chapter encapsulates the key findings and significant contributions of the thesis. It provides a comprehensive summary of the outcomes derived from the experimental and theoretical investigations. Additionally, it outlines potential avenues for future exploration, emphasizing how the current work can serve as a foundation for advancing research in related areas.