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Chapter 6

Conclusion

This chapter provides a comprehensive summary of the research conducted as part of this thesis, highlighting the key findings and conclusions drawn from the work. Additionally, the chapter outlines potential avenues for future research, detailing the scope and directions for further exploration and advancements in the field.

6.1 Summary

This thesis aimed to tackle critical challenges in interferometry with low-coherence light, paving the way for advancements in optical measurement techniques. It introduced innovative experimental methods for evaluating the coherence and polarization properties of light via the cross-spectral density (CSD) matrix. These methods provided detailed insights into vectorial coherence properties, extending the understanding of coherence phenomena in optical systems. The first chapter lays the groundwork for the research by introducing the fundamentals of light coherence, polarization, and their significance in interferometry. It categorizes light sources into coherent and incoherent types, elaborating on their unique characteristics and applications. The challenges associated with fully coherent light are highlighted, emphasizing the advantages of low-coherence light. The chapter also delves into the concept of optical vortices, their generation, and detection techniques. Furthermore, it outlines the primary objectives of the thesis, focusing on advancing experimental methods for characterizing scalar and vectorial coherence and leveraging these methods for generating and analyzing coherence vortices.

Chapter 2 introduces a novel approach for generating and detecting optical vortices using lithographically fabricated pinhole masks. The experimental setup, based on a Mach-Zehnder interferometer, is designed to quantitatively measure the amplitude and phase components of vortex beams. By arranging pinholes in spiral structures, the study demonstrates the generation of versatile orbital angular momentum (OAM) modes. This approach simplifies vortex generation and offers tunability, enabling practical applications in areas like optical communication and particle manipulation.

In chapter 3, a novel method for measuring the 2×2 CSD matrix, which captures the coherence and polarization properties of light. The chapter introduces a Sagnac radial shearing interferometer combined with a phase-shifting technique to experimentally determine the CSD matrix elements. Detailed analysis of beams with various polarization states, such as unpolarized and spatially depolarized light, highlights the interplay between coherence and polarization. This chapter establishes the theoretical and experimental framework for studying vectorial coherence in complex optical systems.

Chapter 4 discusses a significant achievement of this work *i.e.*, the successful generation and characterization of coherence vortices in low-coherence light, a phenomenon where the two-point correlation function exhibits phase singularities. The research employs lithographically fabricated binary pinholes to modulate the spatial coherence of an incoherent source. The experimental results reveal the presence of helical phase structures and doughnut-shaped intensity profiles in the coherence function, confirming the generation of coherence vortices. Unlike conventional vortices typically associated with fully coherent beams, this study demonstrated the feasibility of creating vortices characterized by phase singularities in low-coherence light. This work bridges the gap between the properties of fully coherent and partially coherent light in vortex formation. Extensive MATLAB simulations were conducted to validate the experimental results, ensuring reliability and consistency in the findings.

In chapter 5, we explored the use of advanced digital devices such as spatial light modulators (SLMs) and digital micromirror devices (DMDs) for generating coherence vortices. SLMs enable high-resolution phase modulation, while DMDs offer binary amplitude modulation with fast response rates. These devices allow for precise control over the light field, facilitating the creation of vortices with varying TCs and helical phase profiles. The integration of theoretical modeling, simulations, and experiments demonstrates the versatility and practicality of these digital tools for manipulating light coherence.

By addressing the challenges associated with low-coherence light, this research provided a foundation for future exploration in optical systems, offering insights that could influence diverse applications, from advanced imaging techniques to optical communication systems. This structured presentation not only provides a comprehensive overview of the research but also emphasizes its contributions to advancing the understanding and application of low-coherence light in optical systems.

Therefore, in conclusion this study provides a comprehensive exploration of low-coherence light and its role in addressing challenges in optical measurement and interferometry. Through innovative experimental techniques, it highlights the ability of low-coherence light to overcome limitations of fully coherent sources, particularly in generating and analyzing coherence vortices. By successfully integrating advanced devices like SLMs and DMDs, the research showcases the versatility of these tools in crafting exotic light structures. Ultimately, this work emphasizes the significance of low-coherence light and coherence vortices, particularly in their applications for imaging and communication, paving the way for future advancements in optical science.

6.2 Future Work

The findings of this research open multiple avenues for further exploration and expansion. Each chapter of this thesis lays a strong foundation for future work, offering new perspectives and methodologies in the domain of optical science. Below are key areas of potential exploration that extend the research presented in this work:

- In this research, we developed interferometric methods to measure coherence and analyze coherence vortices. A promising direction for future work is the development of non-interferometric single-shot techniques. These approaches can overcome limitations associated with interferometric setups, such as environmental sensitivity and alignment complexities, making the measurement process more robust and versatile. By leveraging emerging digital imaging technologies and novel mathematical reconstruction methods, single-shot techniques could enable real-time applications in dynamic systems.

- Chapter 2 and 4 introduced the generation of optical and coherence vortices using structured pinhole apertures. This technique, while demonstrated with light waves, holds immense potential for application to matter waves such as electrons and neutrons. Matter-wave vortices can exhibit unique topological properties governed by quantum mechanics, opening up avenues for advancements in quantum information processing, particle beam manipulation, and high-resolution microscopy.
- The engineering of coherence properties provides a pathway for advancements in 3D imaging and optical communication. By tailoring spatial coherence, it is possible to improve depth resolution and noise suppression in holographic and tomographic systems. In communication, coherence engineering can optimize signal transmission and robustness in scattering or turbulent media. Future work can focus on designing sources and optical setups that exploit these engineered properties to address real-world challenges.
- While this research focused on second-order coherence and its manifestations, the exploration of triple-order coherence offers an intriguing extension. Triple-order coherence, involving correlations among three points in a field, provides deeper insights into the structure and interactions of light.