学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

A Study on Uncoupled Heterogenous Multimode Multicore Fiber of Two-Ring Core Layout with 125 μm Cladding Diameter
（125 μm クラッド径を有する 2 リングコア配置非結合型異種マルチモードマルチコアファイバに関する研究）

Space division multiplexing (SDM) is a proposed solution to boost capacity in optical communication, moving beyond conventional single-mode single-core fibers (SM-SCF). Multi-core fibers (MCFs), which consist of several cores enclosed within a single fiber cladding, have undergone extensive research and are considered a viable option for SDM transmission.

Few-mode multicore fibers (FM-MCFs) are a type of optical fiber technology that combines the use of multiple cores within a single fiber with the capability to support a few modes in each core. This design allows for increased data transmission capacity and efficiency compared to conventional SM-SCF. This technology is seen as a potential solution for scaling up the spatial channel count (SCC) by integrating multiple modes with multiple cores. Research has delved into MCFs with increased cladding diameters to accommodate more cores. Notably, some FM-MCFs with SCC surpassing 100 have been reported, featuring cladding diameters larger than 300 µm. However, the industry standard 125-µm cladding diameter is often preferred, especially in situations requiring tight bends, due to its superior mechanical reliability. Moreover, MCFs with this standard cladding diameter are compatible with existing optical cables, connector interfaces, and conventional optical components. They also benefit from established splicing and cabling technologies, which significantly reduce overall manufacturing costs.

One significant challenge in MCFs is inter-core crosstalk (XT), which causes signal distortion and imposes limitations on transmission distance, capacity, and modulation formats. Various approaches have been introduced to mitigate XT, including cores with low refractive index trench structures. These structures aim to enhance mode confinement or reduce mode field overlap. Still, they often involve complex and expensive fabrication processes due to their micrometer-sized features and the need for a significant amount of fluorine dopant.

Alternatively, heterogeneous MCFs (Hetero-MCFs), which consist of non-identical cores, have been proposed to achieve lower XT. Slight variations in core radii and refractive indices in Hetero-MCFs can significantly reduce XT. Compared to homogeneous MCFs (Homo-MCFs), where all cores are identical, non-identical cores in Hetero-MCFs can be more densely packed within a limited cladding diameter. Simple heterogeneous step-index (SI) cores offer a potential solution to reduce fabrication complexity and costs while maintaining sufficiently low XT.

Therefore, this study highlights the utilization of non-identical SI cores in the design of FM-MCFs within the standard 125-µm cladding diameter. This strategy is expected to increase the SCC, potentially reducing fabrication complexities and costs while achieving a higher SCC than previously reported 125-μm cladding MCFs.

This thesis is organized as follows:

Chapter 1 describes the background and motivation.

Chapter 2 is centered around elucidating the analytical expression for the mode coupling coefficient between non-identical SI cores, a key element in this paper. We outline the methodology for estimating XT between such non-identical cores, demonstrating its application in the estimation of XT within heterogeneous step-index multicore fibers (Hetero-SI-MCF). The expressions introduced are then utilized to exemplify the calculation of XT between modes essential for this study, employing the case of a conventional Hetero-SI-MCF designed with a standard 125 μm cladding diameter.

Chapter 3 proposes a two-ring core layout to modify conventional Hetero-SI-MCFs. By reducing the outer cladding thickness (CT) of cores with a higher core refractive index, we enlarge the core pitch (Λ), achieving lower XT values. The improvements in the two-ring core layout of Hetero-SI-MCFs are discussed and compared to those of their conventional counterparts. With the two-ring core allocation, the standard cladding diameter is demonstrated to support 2LP-mode (3 modes) 6 cores and 2LP-mode 8 cores with sufficiently low XT for long-haul transmission in the C-band, respectively.

Chapter 4 introduces the concept of double-cladding structure to mitigate the loss of outer cores in conventional Hetero-SI-MCFs. The outer layer of cladding, with a higher refractive index than the standard fiber cladding, occupies the outermost part of the cladding. It allows further expansion of the Λ for lower XT values. This proposed double-cladding MCF demonstrates that the standard cladding diameter can support 2LP-mode 10 cores with low XT for C-band transmission.

Chapter 5 highlights potential avenues for subsequent research within the scope of this study, particularly concentrating on the C+L-band and the 4LP-mode (6 modes) phases. The discourse extends to assessing the viability and practicality of undertaking further investigations and explorations centered around these specific wavelength bands and mode configurations. The outcomes of the brief analysis in this chapter underscore the favorable applicability of the two-ring core layout within the C+L-band and in the context of the 4LP-mode.

Chapter 6 provides summaries of the key findings and contributions presented in this thesis.