学　位　論　文　内　容　の　要　旨

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学　位　論　文　題　名

A Study on Design of heterogeneous step-index single-mode multi-core fibers with the standard cladding diameter of 125-μm

（標準クラッド外径異種ステップインデックス型シングルモードマルチコアファイバの設計に関する研究）

Space division multiplexing (SDM) has been proposed to overcome the capacity limitation of the existing optical communication system over the conventional single-mode single-core fiber (SM-SCF). Multi-core fibers (MCFs), in which multiple cores are packed in a single-fiber cladding, have been studied intensively, and the single-mode MCFs (SM-MCFs), which have the great advantage of upgradability from the existing equipment and require no complex signal processing of optical multiple-input multiple-output (MIMO) process, are regarded as a promising implementation of SDM transmission.

The inter-core crosstalk (XT), which leads to signal distortion, is a severe issue in MCFs because it limits the transmission distance, transmission capacity, and modulation format. To suppress the XT, cores with a low refractive index structure such as trench-assisted (TA) cores, hole-assisted (HA) cores, and rod-assisted (RA) cores are presented, their basic idea is to enhance the mode confinement or reduce the mode field overlap by these low refractive index area. However, because these structures are all micrometer-sized structures and a large amount of fluorine dopant is required during the fabrication process, the fabrication becomes complex and expensive. On the other hand, heterogeneous MCF (Hetero-MCF) which contains non-identical cores are proposed to realize low XT, because the slight differences in the core radii and core refractive indices can make XT go down drastically. As compared with the homogeneous MCF (Homo-MCF) where all the cores are identical, non-identical cores can be more closely packed in a limited cladding diameter. Thus, using the simple heterogeneous step-index (SI) cores is a potential means to reduce the fabrication complexity and cost while achieving sufficiently low XT.

In addition, many researches accepted MCFs with a cladding diameter of larger than the standard 125-μm cladding diameter for realizing large core count while maintaining sufficiently low XT. However, since the mechanical reliability evidently degrades as the cladding diameter increases, the standard cladding diameter is preferable for use in the tight bend situations. It is also known that MCFs with the standard cladding diameter enable the utilization of the existing optical cables, connector interfaces, and conventional optical components, and also, the already mature splicing and cabling technologies utilized for conventional single-core fibers can be applied to fabricate MCFs with the same cladding diameter, effecting the reductions in the cost.

Therefore, In this study, we focus on using the non-identical SI cores to design MCFs within the standard cladding diameter of 125-μm, which can be expected to reduce the fabrication complexity

and cost, and further increase the core count as compared to the 125-μm cladding MCFs reported so far.

This thesis is structured as follows:

In chapter 2, we derive an analytical expression for mode-coupling coefficients between non-identical SI cores, which has a particular simple form that can be easily calculated using mathematical tools. Next, we introduce the estimation of XT between non-identical cores, some equations are reviewed. We then verify the validity of the derived analytical expression, facilitating its application to the XT estimation in heterogeneous step-index multi-core fibers (Hetero-SI-MCFs). Lastly, using the derived analytical expression, the feasibility of designing the conventional Hetero-SI-MCFs within the 125-μm standard cladding diameter is discussed.

In chapter 3, we propose a novel core allocation to modify the conventional Hetero-SI-MCFs, where we shorten the outer cladding thickness (T_{C}) of those cores with higher core refractive index, resulting the enlargement of core pitch (D) for achieving lower XT values. The improvements in the modified Hetero-SI-MCFs as compared to the conventional Hetero-SI-MCFs are discussed. Using the proposed core allocation, it has been shown that the standard cladding diameter supports six and eight-core with sufficiently low XT for long-haul transmission for C- and O-band, respectively, and it also supports eight and ten-core with acceptable XT for transmission of several kilometers for C- and O-band, respectively.

In chapter 4, we propose an outer trench (OT) layer to suppress the loss of outer cores in the conventional Hetero-SI-MCFs. OT layer has a relatively low refractive index as compared to the standard fiber cladding and occupies the outermost part region of the fiber cladding, which enables us to allocate cores to a relatively thin outer cladding thickness. Using the proposed OT layer, it has also been shown that the standard cladding diameter supports eight-core with sufficiently low XT for O-band transmission

In chapter 5, summaries of this thesis are presented.