学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

A study on heterogeneous trench-assisted single-mode multi-core fiber and few-mode multi-core fiber
（異種トレンチ型シングルモードマルチコアファイバとフューモードマルチコアファイバに関する研究）

For the last twenty years, the optical communication technologies have seen an increase in transmission capacity per fiber by three orders of magnitudes, achieving several Tbit/s transmissions. If the data traffic continues to increase with 40% – 70% per year, a capacity increase by three or five orders of magnitudes should be anticipated for the next twenty years. This means that in twenty years, the backbone transmission capacity should support well over Pbit/s per fiber and the core network should support Ebit/s throughput where at home, Tbit/s access handling 3D super-high definition videos will be a reality. There are three kinds of “multi-” (3M) technologies to achieve extremely large transmission capacity and throughput, which are “multi-mode control”, “multi-core fiber”, and “multi-level modulation”. They were proposed by the collaborative study group “EXAT (EXtremely Advanced Transmission)” in Japan.

Therefore, how to cope with the exponentially increasing demand for transmission capacity per fiber is a hot topic nowadays. At present, several multiplexing technologies such as space-division multiplexing (SDM) using multi-core fiber (MCF) and mode-division multiplexing (MDM) using few-mode fiber (FMF) are being intensively investigated to solve the above-related issue in the current conventional optical communication systems. For MCF, 305-Tb/s SDM transmission using a 19-core fiber has been reported and 1.01-Pb/s SDM transmission using a 12-core fiber has also been proposed. For FMF, the fabrication of a 4-mode fiber that exhibits low bend losses, low mode coupling and low inter- and intra-mode nonlinear effects has been reported. Furthermore, differential mode delay managed transmission lines for wide-band WDM-MIMO system have also been reported. Recently, the combination of multi-core and few-mode design has been presented to further increase the capacity of fiber.

In this study, we propose a sort of heterogeneous trench-assisted MCF (Hetero-TA-MCF) to obtain much lower crosstalk, in which there are not only identical cores but also non-identical cores and the cores are more closely packed in a definite space. What’s more, two non-identical cores deployed in the fiber are not only to decrease the crosstalk but also to make the fiber insensitive to the bending extent. The trench layer is deployed around each core to realize lower inter-core crosstalk even with small core pitch. After adjusting the location and thickness of trench layer, we can find a relative optimum design scheme for the Hetero-TA-MCF. Besides the MCF, we also design a kind of Hetero-TA-FM-MCF with low differential mode delay (DMD) and large effective area (A_{eff}). After analyzing the relationship among the parameters of profile, we can propose the optimum scheme for Hetero-TA-FM-MCF too. In addition, to evaluate a superior MCF or FMF, the discussion of inter-core crosstalk under bent condition is also an important aspect during the design process. Therefore, how to calculate the inter-core crosstalk for bent MCF and FMF by using an analytical method is a big issue.

This thesis is structured as follows.

In chapter 1,the backgroud and motivation are described.

In chapter 2, we introduce the derivation of mode-coupling coefficient (MCC) based on perturbation theory, and then calculate the MCC between two adjacent trench-assisted cores by using analytical method and finite element method. Additionally, we also introduce a special approach for the MCC calculation between two identical cores based on mode interference.

In chapter 3, we introduce the calculation method for inter-core crosstalk in the bent fiber based on coupled-mode theory and coupled-power theory.

In chapter 4, we describe and explain the design methods for the cores, trench layers and core number in multi-core fibers (MCFs) in detail through analyzing the characteristics of the heterogeneous trench-assisted multi-core fiber (Hetero-TA-MCF). According to such method, we propose relative optimal design schemes for such Hetero-TA-MCF, inside which cores are arranged in one-ring structure. This Hetero-TA-MCF is a kind of bend-insensitive MCF with high density of cores and ultra-low crosstalk.

In chapter 5, we propose a kind of heterogeneous multi-core fiber (Hetero-MCF) with trench-assisted multi-step index few-mode core (TA-MSI-FMC) deployed inside. After analyzing the impact of each parameter on differential mode delay (DMD), we design a couple of TA-MSI-FMCs with large A_{eff} for each mode and meanwhile make sure low DMD in each core over C+L bands. After analyzing how the position of trench structure affects the DMD and DMD slope for wavelength, we present a relative optimal design scheme for the Hetero-TA-MSI-FM-MCF. At last, we propose two kinds of strategies for the application of fiber.

In chapter 6, concusions of this thesis are discribed.