Realization of Low Crosstalk 8-Core Heterogeneous Fibre in C-Band with 125 μm Cladding Diameter

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Abstract *A trench-assisted heterogeneous 8-core fibre with cladding of 125 μm is designed using a genetic algorithm. The attenuation of the fibre is 0.3dB/km @1550nm, and the crosstalk is suppressed to -50 dB/10 km @1550nm, while the coating loss remains below 0.0004 dB/km in design.*

Introduction

Multi-core fibre (MCF) design is crucial in developing space division multiplexing (SDM) technology for fibre optic communication systems. Uncoupled MCFs with low inter-core crosstalk and compatibility with existing standard single-mode fibre (SSMF) and SMF-based equipment have gained attentions [1-3]. SDM technology using MCFs, FMF, and multimode fibre can bridge the future capacity gap of short distance communication.

The existing uncoupled MCFs in standard cladding diameter have 4 cores to 8 cores, which can achieve several hundred Gbps to Tbps. 7-core fibre can achieve a speed of 700 Gb/s over 1 km and 10 km [4]. Morever, 8-core fibres have a larger capacity which can reach Tbps, has attracted extensive research. The existing research on 8-core fibres mainly focuses on the O-band and homogeneous fibres. Their crosstalk and coating losses were experimentally measured. To maintain lower crosstalk, they used larger core pitch, resulting in greater coating loss[3,8]. Recently, a heterogeneous fibre was designed using a particle swarm optimization algorithm, which ensured low core crosstalk and coating loss. However, its excellent results were only achieved in simulations [6].

In this work, we propose and demonstrate a new 8-core trench-assisted heterogeneous fibre with standard cladding working in the C-band. We employ an AI-based automatic method to optimize multiple targets across various fibre structures simultaneously. Simultaneously optimizing the coating loss and crosstalk of heterogeneous eight core optical fibres through genetic algorithm (GA). The circular 8-core fibre designed using this method has significantly reduced crosstalk compared to homogeneous 8-core fibres, while also offering ample space to optimize coating loss without affecting dispersion (D). A pair of 8-core fibre FIFO with insertion loss of less than 3 dB was fabricated, and the crosstalk of the designed 8-core fibre was measured. The test results corroborated the simulation results, thereby validating the feasibility of using heterogeneous circular 8-core optical fibre for communication in the C-band. Complete design, fabrication, and characterization of a C-band heterogeneous 8-core fibre have been achieved for the first time.

Design methodology and analysis

Trench-assisted design is an effective way to reduce the mode field area of optical fibres, leading to improved optimization of fibre crosstalk and coating loss. However, it's found that existing processes were especially difficult to achieve both low core crosstalk and low coating loss at standard cladding diameters for homogeneous fibre. Recent research on heterogeneous optical fibres offers the possibility of addressing this problem [5,6].

For heterogeneous fibres, the crosstalk variation follows a similar pattern as that of homogeneous fibres when the bending radius is less than the critical bending radius. However, when the bending radius is larger than the critical bending radius, the crosstalk of the fibre decreases rapidly and stabilizes at a low level. This low crosstalk value is dependent on the refractive index difference between the heterogeneous fibre core and the correlation length. Notably, in the context of heterogeneous fibres, the effective refractive index (n_{eff}) and its difference (Δn_{eff}), core pitch (Λ), coupling coefficient (κ), propagation constant (β), difference of propagation constant ($\Delta\beta$), correlation length (d), and fibre length (L) are all relevant parameters. These characteristics and variations in crosstalk are graphically represented in Eq. (1) and Eq. (2).

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$$R_{pk} = \frac{n_{eff}}{\Delta n_{eff}} \Lambda \tag{1}$$

$$XT = \begin{cases} \dfrac{2\kappa_{pq}\kappa_{qp}R}{\beta\Lambda} L & R \leqslant R_{pk} \\ \dfrac{2\kappa_{pq}\kappa_{qp}}{\Delta\beta^2 d} L & R \leqslant R_{pk} \end{cases} \tag{2}$$

Fig. 1 depicts the schematic diagram of the simulated optical fibre structure, with a standard cladding diameter of 125 μm, a core pitch of 26 μm, and an outer layer thickness of 31 μm. We optimized five parameters, including the core radius, trench location, and refractive index of the fibre core and trench. According to production accuracy, parameter settings are presented in Tab.1. The parameters r1, r2, and r3 represent the core radius, in-trench radius, and out-trench radius, respectively. Δ_{core} and Δ_{trench} refer to the relative refractive-index difference between the core and cladding, and trench and cladding, respectively. Considering the fabrication process and the subsequent application, we aim to make the heterogeneous core structure as similar as possible.

For multi-parameter simulation, more efficient GA are used to optimize the fibre structure. By generating an initial population of 40 groups, each consisting of the 5 parameters mentioned above, and calculating their coating loss allocation fitness. Through heredity, crossover, and variation, an offspring population was generated, and individuals with higher fitness were selected to replace those with lower fitness based on the fitness value calculated by the fitness function. After multiple cycles, a suitable fibre structure was obtained. The simulation results optimized by the GA and adjusted according to the production process are presented in Tab. 2, where we obtained a fibre structure that maintains low crosstalk and coating loss simultaneously.

After analyzing and studying the simulation results, we found that during the GA search for low coating loss, the fibre core index and trench index always converge towards values significantly different from the cladding index. The radius of the fibre core and the outer radius of the trench also converge towards smaller and larger values, respectively. Among these parameters, the

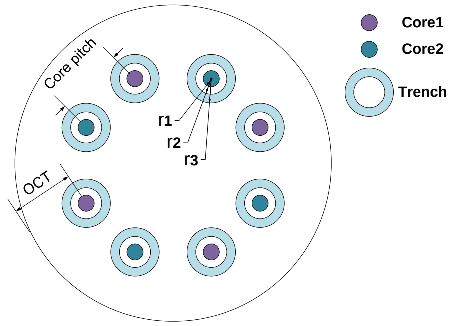

Fig. 1: Schematic diagram of 8-core fibre structure.

Tab. 1: Fibre parameters.

Parameters	Min	Max
r1 [μm]	4.0000	11.0000
r2 [μm]	4.0000	11.0000
r3 [μm]	4.0000	11.0000
Δ_{core}	0.40%	0.52%
Δ_{trench}	-0.80%	0.00%

Tab. 2: Heterogeneous fibre simulation results.

Parameters	Core p	Core q
R_{clad} [μm]	125	
R_{core} [μm]	4.1	
$r_{in\text{-}trench}$ [μm]	6.1591	
$r_{out\text{-}trench}$ [μm]	11	
Δ_{core}	0.42%	0.52%
Δ_{trench}	-0.70%	
R_{pk} [cm]	2.82	
R [cm]	14	
XT [dB/10km]	-51.8763@ d=0.05m	
	-64.8866@ d=1m	
CL [10^{-5}dB/km]	34.347	1.5506
D [ps/(nm·km)]	17.6123	22.5945

radius of the fibre core has the greatest influence on coating loss. Additionally, the refractive index difference between the cores of heterogeneous fibres is the main factor affecting crosstalk.

Measurement

Based on the simulation results in Tab. 2, we have fabricated a trench-assisted heterogeneous 8-core fibre. The plane structure diagram is shown in Fig. 2. To measure the crosstalk of the heterogeneous fibre we produced, we fabricated a pair of 8-core fibre FIFO with insertion loss below 3 dB. Fig. 4 illustrates the measurement setup where a laser beam is injected into a single-mode fibre connected to an 8-core fibre ring through the coupler, and the output is detected by a single-mode fibre. The measured crosstalk results are summarized in Tab. 3.

Compared to previous studies, which is shown in Fig. 3, the dashed line represents the simulated results, while the solid line represents the actual measurement values [3,6-8]. Heterogeneous fibres demonstrate significant superiority in terms of crosstalk and coating losses compared to homogeneous fibres operating in the O-band. Our research not only achieved better performance compared to the latest research on heterogeneous optical fibres, but also achieved a breakthrough from theory to practice due to the simplified fibre structure, which is more conducive to the manufacturing process.

Meanwhile, the attenuation of the fibre we measured is 0.3 dB/km at 1550 nm.

Conclusions

A trench-assisted circular 8-core heterogeneous fibre was designed using GA. Core radius and pitch were found to be key factors affecting coating loss and crosstalk. A larger outer radius of trench and refractive index differences between core/cladding and trench/cladding led to lower coating loss. The designed fibre had ultra-low inter-core crosstalk at 1550 nm between -64.8866 and -51.8763 dB/10km, with coating loss below 0.0004 dB/km. After manufacturing and experimental characterization, crosstalk was measured up to 10 km, with a maximum value of -52.9 dB/10km, which is consistent with the simulation results. Our complete design, manufacture, and characterization of a C-band heterogeneous 8-core fibre represents a significant milestone. This indicates that the performance parameters of heterogeneous 8-core fibres can achieve excellence in the C-band, and have significant potential for future short-range, high-capacity optical communication scenarios.

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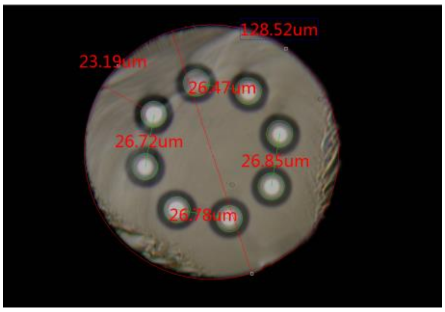

Fig. 2: Plane structure diagram of 8-core fibre.

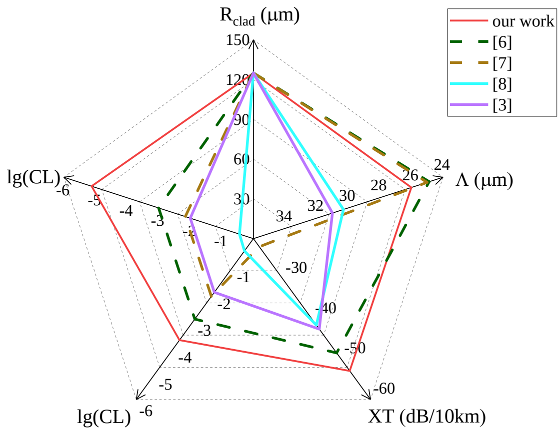

Fig. 3: Comparison of performance of 8-core optical fibres.

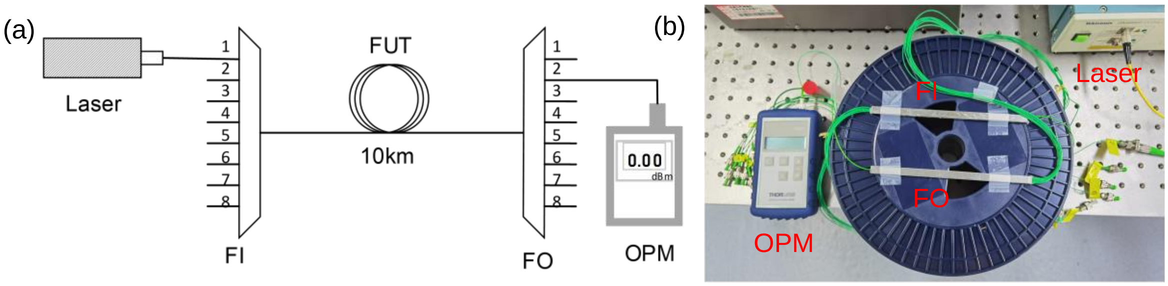

Fig. 4: 8-core optical fibre crosstalk measuring device

(a) measurement schematic diagram, (b) experimental device.

Tab. 3: Crosstalk measurement (dB/10km).

Core number	1	2	3	4	5	6	7	8
1	-5.7	-56.1	-64.8	-69.1	-56.1	-57.7	-60.6	-53.7
2	-57.2	-5.41	-59.6	-63.1	-61.1	-57.0	-55.0	-58.0
3	-65.0	-56.3	-5.86	-61.6	-64.8	-65.2	-57.2	-59.8
4	-72	-64.2	-59.0	-5.53	-52.9	-61.5	-62.1	-66.9
5	-65.7	-60.1	-71.8	-55.4	-7.15	-58.6	-59.0	-66.8
6	-56.4	-56.8	-61.3	-57.2	-59.4	-6.08	-60.9	-55.7
7	-63.4	-63.5	-58.3	-66.3	-57.5	-54.5	-6.89	-57.9
8	-56.1	-59.2	-59.2	-56.2	-62.8	-60.3	-55.5	-6.89

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