

Core-selective Variable-ratio Coupler for Multicore Fiber Applications

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Abstract We present a multifunctional fibre device based on side-polished core-selective multicore fibre couplers and demonstrate spatial path routing by using the couplers as a variable optical power splitter and reconfigurable spatial channel add/drop multiplexer. ©2023 The Author(s)

Introduction

Uncoupled multicore fibres (MCFs) are engaged our interest as one of the most promising candidates to be the next generation optical fibre for spatial-division multiplexing (SDM) because uncoupled MCFs can be converted to the conventional fibres via fan-in/fan-out (FIFO) devices and allowed us to use the conventional fibre components^[1]. In particular, MCFs with the standard-cladding diameter of 125 μm are expected that can be fabricated with comparable reliability to the standard single-mode fibre (SMF)^{[2],[3]}. Within the cladding diameter, four cores can be reasonably accommodated especially in C-band whilst keeping the cladding thickness and isolating from the inter-core crosstalk^{[4],[5]}. The applicability of four-core fibre (4CF) has been demonstrated from short-reach applications to ultra-long haul transmission experiments with optimised core designs^{[6]–[10]}. However, excess loss from FIFO devices would degrade the system performance per core compared to the conventional SMF system^[11]. Therefore, we have proposed a FIFO-less architecture with directional fibre couplers based on a side-polishing technique for pump combiners and tap couplers^{[12]–[15]}.

In this paper, we present side-polished 4CF couplers with translation mechanics for variable coupling ratio. Moreover, we prototype a 90° rotatable LC adapter to select connecting cores between two 4CFs instantaneously. The couplers are shown to be used for configuring multifunctional fiber components, such as core-selective variable optical attenuator (VOA) and add/drop multiplexer, without FIFO devices.

Core-selective variable-ratio 4CF coupler

We fabricated four variable-ratio couplers using a 4CF^{[12],[16]–[18]}. One of the couplers is shown in Fig. 1a, which has a micrometer to shift the distance between coupled cores in an SMF and

MCF. We chose a pure-silica-core 4CF as an MCF, and we, therefore, selected a pure-silica-core single-core fibre as an SMF to harmonise the effective refractive indices of propagating modes at 1550 nm in both fibres. The four cores were arranged in the standard-cladding diameter as a square lattice with the pitch of 43 μm . The 4CF was rotationally aligned as one of cores in MCF being close to the SMF core as shown in Fig. 1b. The fibres were fixed on quartz substrates and polished their cladding glasses to bring two cores closer together. Note that the coupled core in MCF was randomly chosen in the fabrication process. Since the core arrangement was circularly symmetric, the coupled core can be selected by splicing the 4CF with rotational alignment even after polishing process. Here, we implemented instantaneous rotational function with a specially designed LC-type adapter, in which connector key slots were designed at every 90° rotation angle (Fig. 1c). In total, four key slots were formed on a single side of the adapter at the angle of 0°, 90°, 180°, and 270°. The rotation angle of 0° was defined at the fixed key slot on the other side. The LC connector key was aligned to two diagonal cores (Fig. 1d). By using the LC adapter, we can choose an MCF core to be worked as a coupler. Figure 1e shows an example of cascaded setup. The couplers were connected by monitoring its output power to be functional on each core, resulting in the rotation angles of connectors were 270°, 270°, 0°, and 180° for Core 1, Core 2, Core 3, and Core 4, respectively.

Coupling ratio characterisation

To characterise the coupling ratio and its variation, we used a set of FIFO device, which were connectorised with LC-type connector as same with the 4CF couplers. The excess loss on each coupler was estimated as <1.0 dB including a connector loss. All measurements were

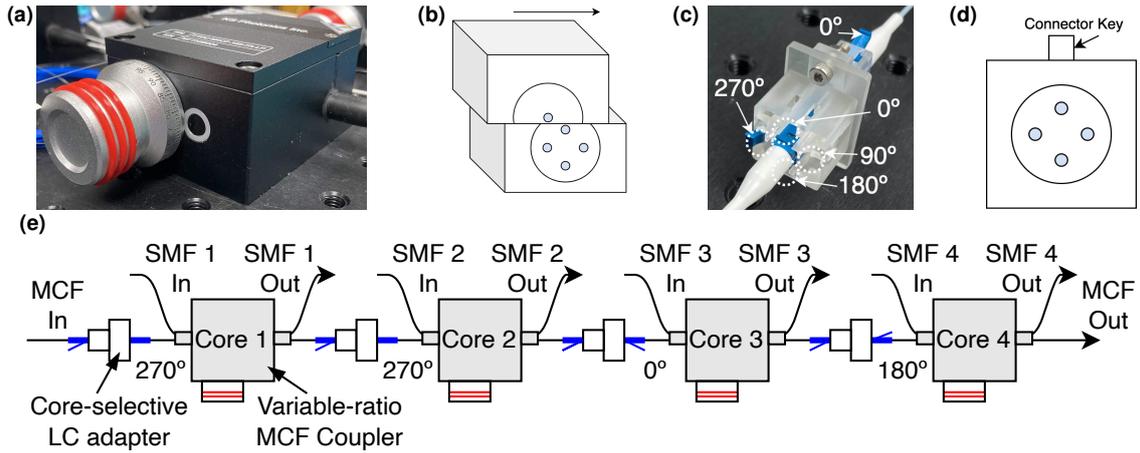


Fig. 1: Core-selective variable-ratio MCF coupler. (a) One of fabricated variable-ratio couplers, (b) translation mechanics, (c) core-selective LC adapter, (d) connector key, and (e) a cascaded configuration of variable-ratio 4CF coupler.

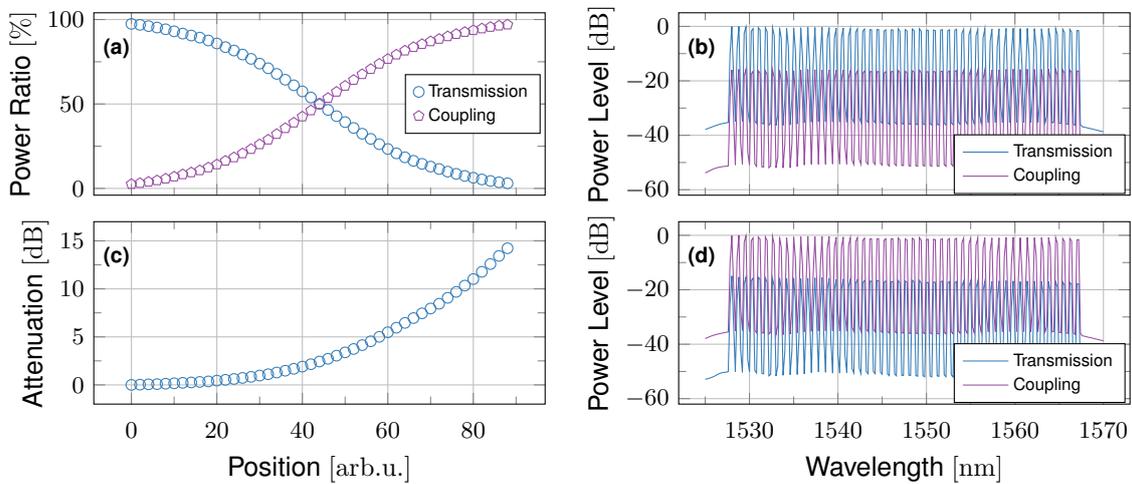


Fig. 2: (a) Power ratio characteristics and (c) attenuation levels for different translation positions. Optical spectra with 0.1-nm resolution at translation positions of maximum (b) transmission and (d) coupling.

conducted with the cascaded configuration in Fig. 1e. As probe light, a wavelength-division multiplexed optical signal was emulated with spectrally-shaped amplified spontaneous emitting light from an erbium-doped fibre amplifier. The emulated number of channels and channel spacing were 50 channels and 100 GHz, respectively. The wavelength range was 1527-1565 nm. The flatness of peak power level was within 1 dB. Figure 2a shows the coupling and transmission ratios as a function of the position from 0 to 88 in unit of the micrometer when inputting the WDM signal to Core 1. The coupled and transmitted signal was observed at the output of SMF 1 and MCF via FIFO, respectively. The coupling and transmission power ratios were calculated from measured optical power at each output port. The transmission and coupling ratios at the position of 0 were 97% and 0%, respectively. These ratios were changed at the position of 88 were 0 to 98%, respectively. From the transmission power, the at-

tenuation range was estimated up to 15 dB as in Fig. 2c. This indicates that the coupler could be used as a core-selective VOA with the dynamic range of 15 dB.

Optical spectra at the micrometer positions of 0 and 88 were shown in Figs. 2b and 2d, respectively, where the transmission and coupling ratios were maximised. For both cases, the spectral shapes were preserved after sweeping the micrometer position. The wavelength dependency of the coupler was significantly suppressed across the C-band.

Spatial path reconfiguration

By using the cascaded 4CF couplers, examples of spatial path reconfiguration were demonstrated^[19]. In Figs. 3a and 3b, spatial paths and its output power ratio matrix are shown at maximum transmission for all cores of the 4CF. The power matrix was normalised for total output power on each input. From the core-to-core power ratio, the inter-core crosstalk can be es-

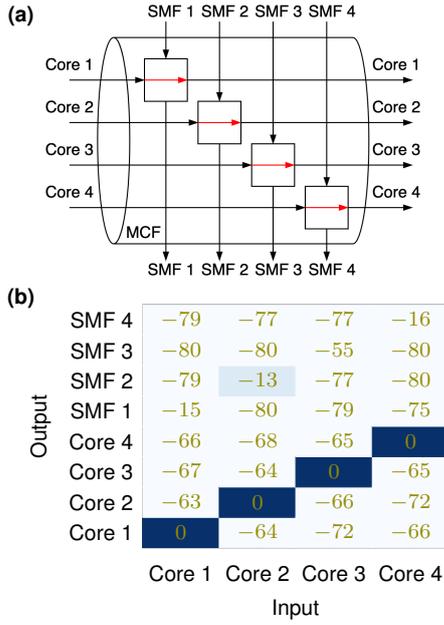


Fig. 3: (a) Spatial paths and (b) its power ratio matrix in dB when maximizing transmission on MCF.

timated as less than -60 dB. The output power contrasts on each input depend on the difference between effective refractive indices of two coupled cores. In Fig. 4, spatial paths and its power ratio matrix are shown under the same condition with Fig. 3. In this case, the lowest contrast was observed on SMF 2. Fig. 5 shows an example of applications using the core-selective variable-ratio MCF coupler, where SMF 1 and SMF 2 were worked as add/drop ports on Core 1 and Core 2, respectively. Simultaneously, SMF 3 and SMF 4 were used for a 50% power splitter and 20% tap coupler, respectively. Power ratio for this scenario was summarised in Fig. 5b. Entirely, the matrix shows a intended contrast over 10 dB for the target configuration.

Conclusion

We have fabricated side-polished-based variable-ratio couplers on a four-core fibre (4CF) and successfully demonstrated various multicore fibre (MCF) applications of core-selective variable optical attenuator, splitter/combiner, and add/drop multiplexer without fan-in/fan-out devices. The coupling ratio could be swept from 0 to 98% with low excess loss of <0.5 dB including connector loss. Moreover, since the coupler was based on optical fibre only, inter-core crosstalk was suppressed at the level of < -60 dB even after concatenating four couplers via LC connectors and adapters. Furthermore, we have shown that the LC adapter could be used to select a core by forming the key slots at every 90° rotation an-

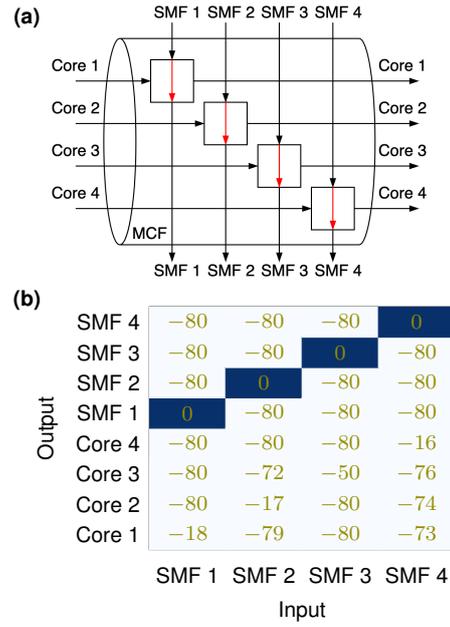


Fig. 4: (a) Spatial paths and (b) its power ratio matrix in dB when maximizing transmission on SMFs.

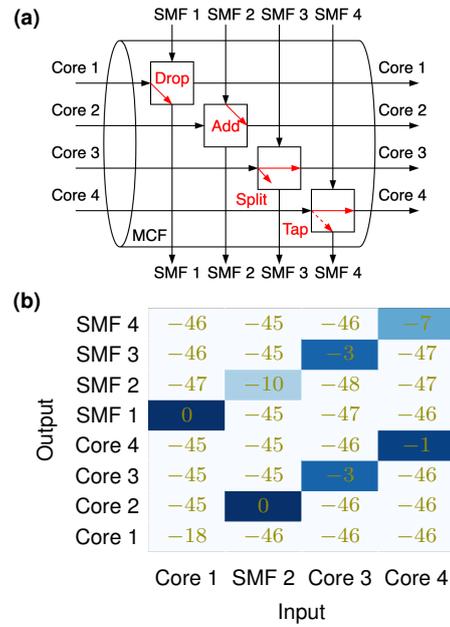


Fig. 5: (a) Optical paths and (b) its power ratio matrix in dB when applying different functions on each core.

gle. This connector would potentially improve the productivity of the MCF coupler because the user can reconfigure the coupler combination instantaneously and the manufacturer can ignore core identification in the coupler fabrication.

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