Compact 32-Core Multicore Fibre Isolator for High-Density Spatial Division Multiplexed Transmission

Yongmin Jung(1), Shaiful Alam(1), Yusuke Sasaki(2) and David J. Richardson(1)

(1) Optoelectronics Research Centre, University of Southampton, Southampton, UK, ymj@soton.ac.uk
(2) Advanced Technology Laboratory, Fujikura Ltd., 1440, Mutsuzaki, Sakura, Chiba, 285-8550 Japan

Abstract *We present a fully integrated 32-core multicore fibre isolator with low insertion loss (average loss <0.8dB, core-to-core variation <2dB) and low inter-core crosstalk (<-40dB).*

Introduction

The possibility of using a single optical amplifier to simultaneously amplify multiple spatial channels propagating in a space division multiplexed (SDM) transmission fibre has been the topic of considerable research interest in recent years[1,2]. Both core and cladding-pumped configurations have been demonstrated however the cladding-pumped scheme looks the most promising in terms of providing cost, energy and space saving benefits and currently appears to be emerging as the preferred route for recent SDM amplifier development[3,4]. Importantly, the cladding-pumped configuration incorporating a side coupling pump delivery approach offers a convenient route towards a fully integrated SDM amplifier system. Here, the pump radiation can easily be coupled into the active fibre through a fully-fiberized pump coupler and the SDM amplifier can be directly spliced to the SDM transmission fibres. The critical next steps to scale this integrated amplifier approach to higher core (or mode) count fibres are obvious and the relevant high density core (or mode) SDM amplifier components are essential to fulfil the benefit of high-density SDM transmission.

In this paper, we build and experimentally characterize a fully integrated 32-core multicore fibre isolator using micro-optic optical fibre collimators (i.e. fibre optic collimation and focusing assemblies). This is an important platform already used widely in single mode fibre optic components such as optical isolators, circulators, gain flattening filters, WDM couplers, switches and variable optical attenuators. Over the past year we have been working to extend this concept to multicore (and indeed also few mode) fibres[5], providing an array of new and practical packaged components with performance in terms of function and insertion loss comparable to the equivalent existing single mode fibre devices, whilst at the same time ensuring low levels of inter-core cross-talk. Detailed device characterization and analysis of the 32c-MCF isolator is discussed in terms of the average insertion loss (IL), core-to-core IL variation and cross-talk (XT) amongst the cores.

Fabrication of 32c-MCF isolator

Fig. 1(a) shows a schematic diagram of a representative 32c-MCF collimator assembly consisting of a cylindrical micro-optic lens and a MCF ferrule, fitted in a ferrule sleeve. Compact fibre optic collimators usually use GRIN lens or C-lens elements to transform the emergent light from an input 32c-MCF into a collimated free-space beam that can then be refocused into another length of MCF using a second identical

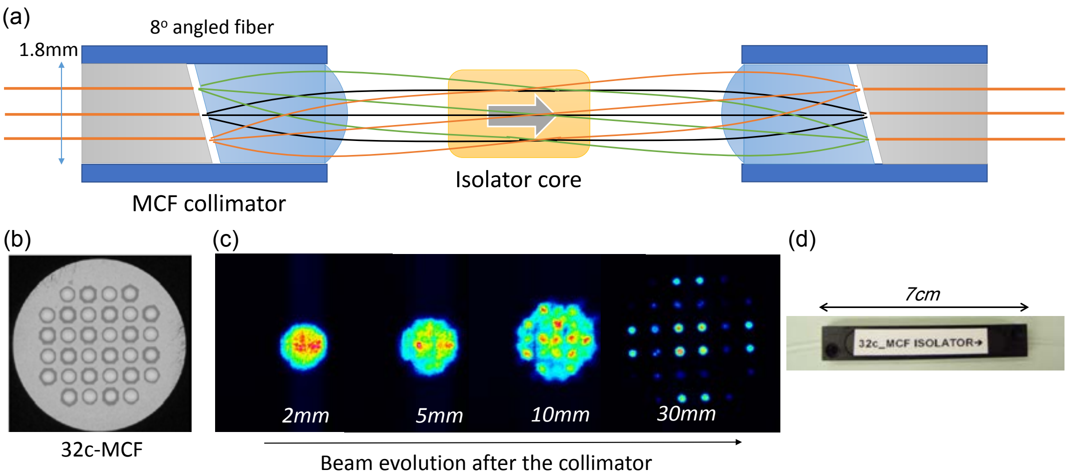

Fig. 1: (a) Schematic of a 32c-MCF collimator assembly incorporating an optical isolator as a functional element. (b) The cross-section of 32c-MCF, (c) the measured beam profile as a function of distance from the collimator and (d) the fully integrated and packaged isolator.

assembly in reverse. Optical elements can then be inserted into the free space beam path (e.g. a bulk isolator in our experiment) to provide in-line functionality. Fig. 1(b) shows a cross-section of the 32c-MCF used in our isolator which is a heterogeneous, trench-assisted MCF incorporating a square lattice core arrangement to reduce the inherent inter-core XT of the fibre. The core pitch is 29µm and the cladding diameter is 243µm. The measured inter-core XT of the fibre was less than -55dB/km and the fibre has recently been used in high-density 32-core MCF transmission experiments over 1600km[6].

To optimize the alignment of the MCF collimators, we first illuminate all 32-cores of the MCF using a single low-coherence ASE source. To enable this, the single mode source output fibre was first spliced to a short section (~3mm) of coreless fibre (i.e. pure silica rod fibre) with the purpose of expanding the beam size and which was then spliced to the 32c-MCF. The launched optical power varies from core to core but it nevertheless allows stable and efficient simultaneous light coupling into all fibre cores. The other end of the MCF was angle-cleaved at 8° to reduce Fresnel reflections, inserted into the glass ferrule and fixed into place with UV curable adhesive. Next the MCF ferrule was inserted into the ferrule sleeve and the distance between the C-lens and fibre ferrule was carefully adjusted to achieve an array of high quality collimated beams. As shown in Fig, 1(c), spatial interference patterns were observed in the near field from the collimator but clean thirty-two spatial mode beams were observed in the far field which remain collimated over relatively long distances (up to 50mm) from the collimator. A pair of MCF collimators was built and mounted on a multi-axis precision micro-stage (offering translation, tilt and rotation adjustments) to align the collimators. Importantly, the MCF collimators intrinsically require rotational alignment and the far field intensity distribution from the collimator was examined using a visible He-Ne laser for rough angular alignment of the MCF collimator. We next developed a compact air-gap device based on two such collimators, configured such that we could insert and fix in place different functional elements (e.g. an isolator core in this experiment) to provide for robustly packaged MCF components. A final packaged 32c-MCF isolator is shown in Fig. 1(d).

Characterization of 32c-MCF isolator

To characterize the integrated 32c-MCF isolator, all fibre cores were again illuminated by a single ASE source as described previously and the near field distribution of the fibre was investigated with a 2-dimentional power

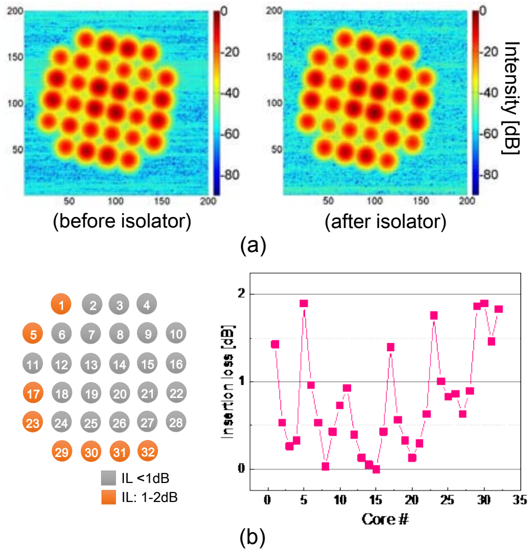

Fig. 2: (a) Measured 2-dimensional spatial beam distribution before and after the 32c-MCF isolator obtained by a power sampling method. (b) The measured core-to-core IL variation of the isolator with ±0.2dB measurement error.

sampling method. A CCD camera can be used to observe the near field distribution of the fibre but we performed a single mode fibre probe scanning method in the near field of the fibre to obtain a better dynamic range power distribution measurement across the fibre cross-section. The scan area was 250µm x 250µm sampled on a 200 by 200 step grid in the near field plane using an SMF28 fibre with an MFD of 10.4µm. The resulting intensity distribution is plotted on a logarithmic scale and its contour plot is shown in Fig. 2(a). 32 clean spatial beams from the individual cores were clearly observed and the noise floor (due to scattered light trapped in the fibre cladding) was less than -60dB compared to the maximum beam intensity (which means that the measurable dynamic range is more than 60dB). By comparing the spatial intensity distribution before and after our fabricated isolator, we can quantitatively evaluate the core dependent insertion loss of the device. As shown in Fig. 2(b), the average insertion loss was ~0.8dB and the core-to-core variation was less than 2dB. Note this also includes a loss contribution from two extra splices between MCFs and we expect that the actual isolator loss and core IL variation will be lower. The left figure of Fig. 2(b) illustrates the measured insertion loss associated with a given core. The outer cores have relatively larger insertion losses than the inner cores which may be due to a slight angular orientation misalignment of the MCF splices and/or collimator assembly. However, one side of the outer cores shows a slightly higher insertion loss which may be due to beam clipping as a result of the limited (1mm x 1mm) clear aperture of the isolator core. Using slightly different lens choices and by adopting bulk components with a slightly larger clear aperture, we can expect to further improve the isolator performance, especially in terms of core-to-core IL variation.

Secondly, in order to estimate the crosstalk (XT) between fibre cores we carefully excited

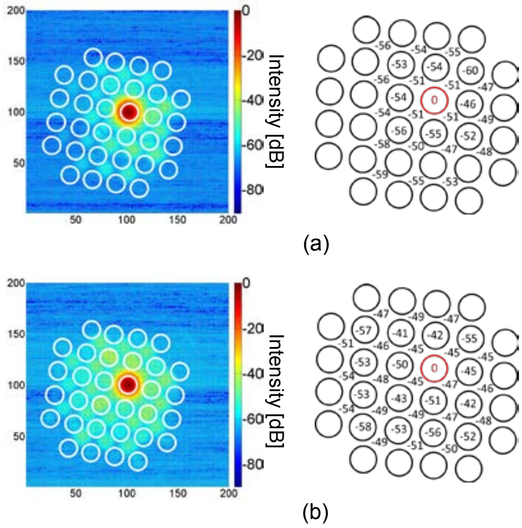

Fig. 3: Measured inter-core crosstalk contour map (a) before and (b) after 32c-MCF isolator.

one of the cores in the central region using a spliced single mode fibre. As shown in Fig. 3(a), the XT between the neighboring cores was less than -50dB from the SMF-MCF splice itself. Interestingly, an unexpected level of beam intensity was also observed in the middle of core lattice. It is due to light guidance by the pure silica region surrounded by fluorine doped index trenches as evident from the fibre cross-section in Fig. 1(b). The light guidance from this region can be suppressed by bending the fibre tightly but a noise floor of around -50dB was still observed from a 20m section of MCF. Some of the core mode profiles exhibit an LP_{11} beam feature due to the higher order mode guidance in short lengths of this fibre (the effective cutoff wavelength is 1530nm for a 1km length of the fibre). Incorporation of the 32c-MCF isolator increased the neighboring core XT slightly but it was still less than <-40dB.

Thirdly, the excited core of the MCF was then spliced to another SMF pigtail and the optical isolation and back reflection were investigated. As shown in Fig. 4, the peak isolation was around 43dB at 1559nm and an optical isolation exceeding 32dB is obtained over the entire C-band. We also measured the back reflection for the 32c-MCF isolator and a value of -32dB was obtained over the full C-band due to the angled fibre facet. Whilst at present we have tested only one of the cores we expect that all other cores will exhibit a similar level of optical isolation and back reflection. With anticipated access to 32-core fan-in/fan-out devices a complete set of core characterization measurements should be possible in the near future.

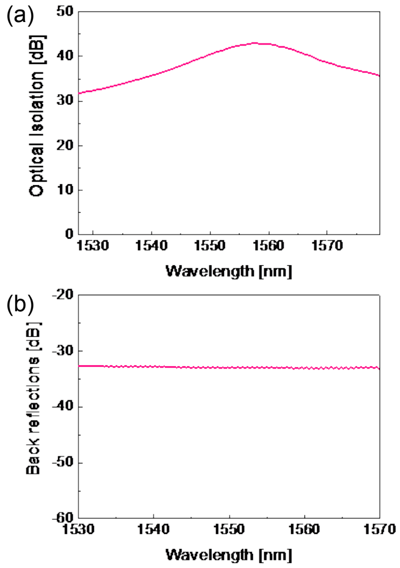

Fig. 4: (a) Optical isolation and (b) back reflections measured from the 32c-MCF isolator.

Conclusions

We have successfully realized an integrated optical isolator for 32-core fibre. The initial results look most encouraging with an average insertion loss of ~0.8dB, core-to-core variation of ~2dB and an inter-core crosstalk of less than -40dB. Optical isolation exceeding 32dB was obtained over the full C-band and back reflection was less than -32dB. These results indicate that conventional free space optical isolator technique can be integrated into MCF based subcomponents such that isolation can be achieved on all cores simultaneously with near identical performance for all cores. The approach can be applied to other optical components such as circulators, beam splitters, WDM filters, routing switches and so on.

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