Ultra Broadband Coupler Based on Dual-Concentric-Core Photonic Crystal Fibre

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Abstract

An original arrangement of air-holes and pure silica is proposed to design ultra broadband fibre couplers. Very high energy transferred superior to 92% on more than 700nm is demonstrated.

Introduction

Optical couplers have attracted significant interest in many domains varying from the most popular telecom networks to sensor and laser applications more recently. In the literature, fibres composed of "twin-core" represent the majority of the existing fibre couplers due to their strong theoretical coupling coefficients [1]. However, the drastic manufacturing tolerances limit their actual performances [2]. In addition, this collinear configuration of two cores gives rise to serious problems of connectivity with conventional fibres. One interesting solution deals on the fibre couplers based on dual-concentric-core, first highlighted by Boucouvalas *et al*. with MCVD demonstration [3]. In this paper, we propose, for the first time, to translate this configuration into the microstructured technology, allowing higher design flexibility, in order to significantly improve the optical coupling performances. Moreover, the unconventional chromatic dispersion behaviour in such fibre [4] is also investigated for potential nonlinear applications.

Modelling of the optical coupler

Regarding [3], in order to design a broadband optical coupling, the equivalent refractive index profile must be symmetric. This assumption implies a diameter of central core closed to the thickness of the ring core with refractive index identical. This design cannot be obtained by using the traditional triangular lattice structure because it then requires sub-micron air-holes size (incompatible with the fabrication stage). In consequence, a hybrid design is proposed combining a hexagonal arrangement for the first layer of air-holes (Λ for the pitch and d_1 for the diameter of the air-holes) and circular for the following ones (d_2 for the diameter of the air-holes), as shown by the Figure 1. Other designs are also under investigations. Simulations are based on a full-vector finite-element-method to optimise the geometrical dimensions. Typical parameters give $d_1 = 3\mu m$, $d_2 = 2\mu m$ and $\Lambda = 5\mu m$ for a phase matching wavelength fixed at 1550nm (λ_0 defined as propagation constants of fundamental elementary modes are equal).

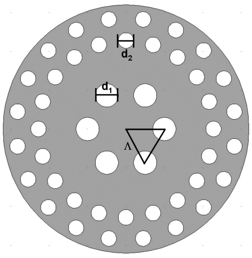

Figure 1 : Transverse section of the proposed dual-concentric-core fibre coupler.

The coupled mode theory [5] is applied to evaluate the fraction of energy transferred (F^2) from the central core to the ring core, defined by :

$$F^2 = \frac{1}{1+\left(\frac{\Delta\beta}{2K_0}\right)^2}$$

with spectral variation $\Delta\beta=\beta_1-\beta_2$ and the coupling coefficient at phase matching wavelength λ_0: $K_0=(\beta_I-\beta_{II})/2$. Consequently, F^2 is maximum at λ_0.

Note: β_1 and β_2 correspond to the propagation constants of the fundamental mode of each core considered separately; β_I and β_{II} correspond to the propagation constants of the two first fundamental modes (or supermode) of the complete structure.

The result is reported on the following Figure 2:

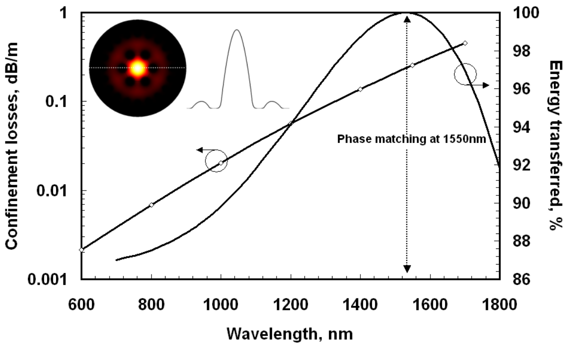

Figure 2 : Confinement losses and fraction of energy transferred versus the wavelength. Inset : norm of the electric field of the fundamental supermode at 1550nm.

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Opposite to the particular behaviour of classical dual-concentric-core fibre [4], the coupling bandwidth has been enlarged. In consequence, a very high fraction of energy transferred is obtained higher than 92 % over 700nm (1100nm to 1800nm) centred at λ_0. Using the propagation constants of the supermodes, a beat length of 2.74mm is found. Moreover, the confinement losses versus the wavelength were calculated by introducing a perfectly matched layer. With two air-holes layers on the limit, 0.25dB/m losses are achieved in the C-band, corresponding to a good trade off between stack process complexity and acceptable losses. Notice that the addition of a third air-holes layer reduce the confinement losses by more than a factor 100.

Fabrication and characterization of the coupler

Thanks to the modelling, a first dual-concentric-core coupler has been performed by the stack and draw method. The scanning electron microscope (SEM) of the realized fibre coupler is reported on the Figure 3.

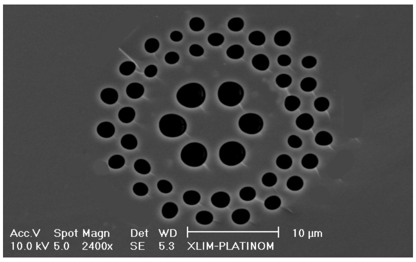

Figure 3 : SEM of the actual dual-concentric-core fibre coupler (zoom on the microstructured zone).

A small disorder in the external layers is noticed but without notable consequences. The other parameters are in good agreement with the simulation results.

An ASE source emitting in the C-band is launched into 35cm-long piece of the realized fibre coupler. The injection and detection are made only into the central core by intermediate SMF-28. A periodic beat of energy between the two cores is observed versus the wavelength as indicated on the Figure 4.

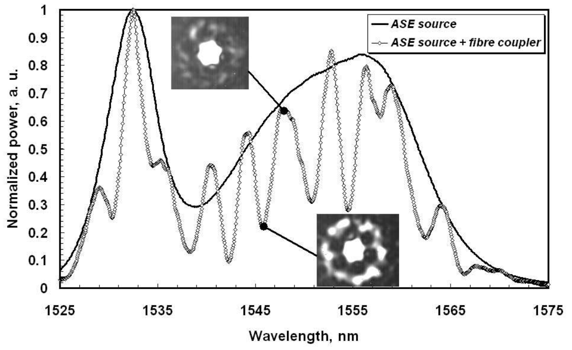

Figure 4 : Comparison of the spectrum of the ASE source with/without the fabricated fibre coupler. Inset : near field pattern at the output of the coupler.

A tiny over modulation is noticed due to the unpolarized light injected. This first experiment confirms qualitatively the transfer of energy between the two cores. Complementary measures are in progress and will be presented at the conference.

Prospects for nonlinear applications

The chromatic dispersion behaviour of such fibre couplers is also highlighted. Different scaling factors (k) are applied on the previous design (4µm instead of 3µm for d_1) and results are reported on the Figure 5.

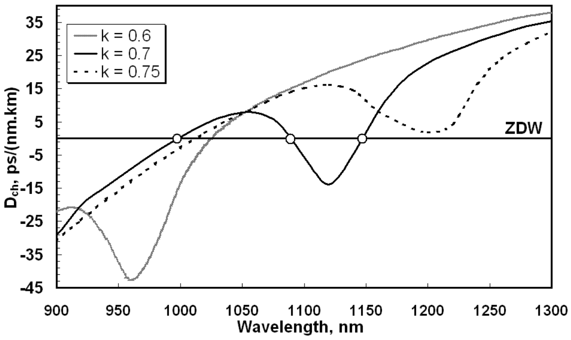

Figure 5 : Chromatic dispersion evolution of the fundamental supermode versus the wavelength for different scale factors (ZDW indicated for k = 0.7).

Consequently, the shift of λ_0 towards shorter wavelengths allows the apparition of multiple zero-dispersion wavelength (ZDW). This control could be very attractive for nonlinear applications.

Conclusions

In conclusion, an original arrangement of air-holes and pure silica has been proposed to design ultra broadband photonic crystal fibre couplers. Very high energy transferred fraction superior to 92% on more than 700nm has been theoretically demonstrated and qualitatively confirmed by a first realization.

Moreover, due to the unconventional chromatic dispersion behaviour, optimisation of the structure is under investigation for nonlinear applications.

References

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