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Compact spatial mode filter based on a MMI coupler

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A compact integrated optical spatial mode filter based on a single MMI coupler is presented, which can be used to suppress unwanted first order modes. The MMI filter measures 134 x 8 μm, which, to our knowledge, is the smallest device size reported sofar. The average measured excess loss is 0.5 ± 0.2 dB, and the optimum suppression ratio is better than 23 dB.

Introduction

In general, devices are designed to operate optimally for the fundamental waveguide mode. However, in many cases the waveguide width is chosen such that it supports more than one mode in order to relax fabrication tolerances. Occurance of first-order waveguide modes will degrade device operation, and therefore excitation of these modes should be avoided. This can be achieved by optimising the fibre-chip coupling, but it is very difficult to maintain this over a long period of time. Therefore, a - preferably compact - spatial mode filter is desirable at the input of the device. Such a filter can be realised by an adiabatic asymmetric Y-junction [1], which is, however, difficult to fabricate due to the stringent requirements on the lithographic resolution necessary to obtain a sharp intersection angle. Additionally, this device is relatively long.

A compact solution to this problem is the application of a single MMI coupler, which is easy to fabricate because only one single etching step is needed, as demonstrated by Leuthold et al. [2]. The device was realised in a weekly guiding waveguide structure, and had a suppression of the -18 dB. In this paper we present a mode filter fabricated in a strongly guiding raised-strip waveguide, which has the potential for high suppression ratio.

Operation principle

The principle of a MMI-based spatial mode filter lies in the fact that symmetric and antisymmetric modes applied at the input are differently mapped onto output waveguides, as shown schematically in figure 1, and can be explained as follows. When using a centre-fed MMI coupler, N_1-fold images of the input field are obtained at $L_{MMI,1} = 3L_\pi/4N_1$ [3,4,5]. This length equals the length of a N_2xN_2 power splitter-combiner $L_{MMI,2} = 3L_\pi/N_2$, if we choose $N_1 = 1$ and $N_2 = 4$. For the fundamental mode excitation, the two center input waveguides are considered as one, of which the width is twice the width of the separate waveguides. The coupler now acts as a 1x1 MMI coupler, and the input field will be imaged at the centre output waveguide. For first-order mode excitation, we consider the input waveguide as a combination of two separate waveguides that touch each other, but neither of them lies at the centre of the MMI coupler. This assumption may be used, because the distance *a* between a pair of input or output waveguides (see figure 1) is a parameter which can be chosen freely [3,4]. The coupler now acts as a 4x4 MMI coupler of which only at the two center input waveguides fields are applied. Then the first-order field is split into two separate zero-order fields. Inherently to a first-order mode, these fields are in counter phase, i.e. one of which has an additional phase term term $e^{-j\pi}$. From table 1 (columns with $i = 2$ and $i = 3$; inputs $i = 1$ and $i = 4$ are not used) it can be seen directly that as a result of this c phase term *constructive* interference will occur in the outer output waveguides 1 and 4, and *destructive* interference in the centre output waveguides 2 and 3.

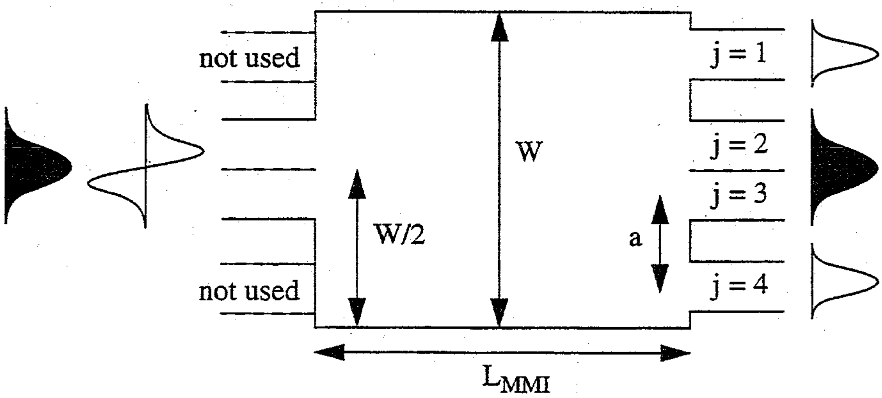

Figure 1. Schematic diagram of a MMI-based spatial mode filter, including mapping characteristics for zero-order mode (filled) and first-order mode (open).

$\varphi_{j,i}$	$i = 1$	$i = 2$	$i = 3$	$i = 4$
$\varphi_{1,i}$	π	$3\pi/4$	$-\pi/4$	π
$\varphi_{2,i}$	$3\pi/4$	π	π	$-\pi/4$
$\varphi_{3,i}$	$-\pi/4$	π	π	$3\pi/4$
$\varphi_{4,i}$	π	$-\pi/4$	$3\pi/4$	π

Table 1. The phase relations for a single 4x4 MMI-coupler.

Due to the balanced power distribution over both input fields, which is inherent to first-order fields, there is absolutely no residual power coupled into the centre output waveguides, as long as the length and width are realised as designed. Figure 2 shows simulation results obtained with Beam Propagation Method (BPM) analysis illustrating the operation of the spatial mode filter.

Experimental results

A MMI-based spatial mode filter has been fabricated in a large-core and low-contrast waveguide structure, consisting of a 2.2 µm thick InGaAsP(λ_g = 1.02 µm) guiding strip on an InP substrate. The centre input and output waveguide is 3.0 µm wide and the outer output waveguides are 2.0 µm wide. The MMI coupler measures 134 x 8 µm, which is the smallest reported so far.

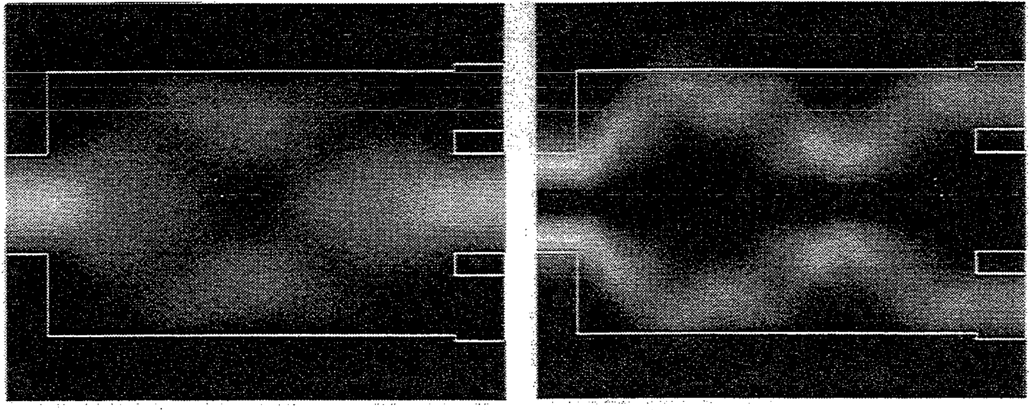
(a) (b)

Figure 2. Simulated filter operation obtained with BPM analysis: zero-order mode excitation (a), and first-order mode excitation.

In order to be able to excite the zero-order mode as well as the first-order mode in a controlled manner, a lateral offset was inserted in the input waveguide, as shown in figure 3. In this way the amount of power in the first-order mode can be selected accurately by a proper choice of the offset value.

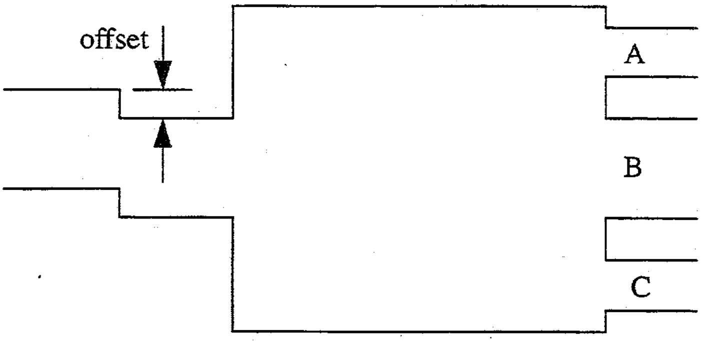

Figure 3. Lateral offset in the input waveguide in order to control the excitation of the fundamental and first-order modes more accurately.

This offset introduces and additional excess loss, which is depicted as the dashed line in the graph of figure 4. The average excess loss with respect to the additional coupling loss introduced by the offset, was measured to be 0.5 ± 0.2 dB. The first measured excess loss in the graph shows a larger deviation from the dashed line, which is due to damage in the input waveguide. Also shown in this graph is the suppression ratio which is defined as P_A/P_B ($= P_C/P_B$), in which P_A, P_B, P_C are the field intensities in outputs A, B, and C, respectively. The optimum suppression ratio was measured for a zero offset in the input waveguide, and is better than -23 dB.

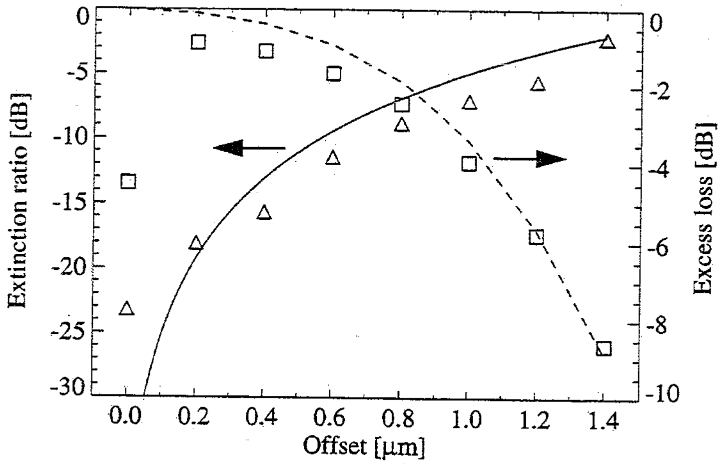

Figure 4. Measured filter response: first-order suppression ratio (triangles) and excess loss (squares) as a function of the offset applied at the input waveguide. The lines denote the simulated suppression ratio (solid) and excess loss (dashed).

Conclusions

A compact integrated optical spatial mode filter based on a single MMI coupler is presented. The MMI filter is 134 µm lond and 8 µm wide, which, to our knowledge, is the most compact device reported sofar. The average excess loss with respect to the coupling loss introduced by the lateral offset, was measured to be 0.5 ± 0.2 dB. The optimum suppression ratio is better than -23 dB. The device may be used in a wide variety of applications due to its ease of fabrication because only one single etching step is needed.

References

[1] W.K. Burns and A.F. Milton, "Mode conversion in planar dielectric separating waveguides", *IEEE J. Quantum Electron.*, QE-11 (1), pp. 32-39, 1975.

[2] J. Leuthold, R. Hess, J. Eckner, P.A. Besse, and H. Melchior, "Spatial mode filter realized with multimode interference couplers", *Opt. Lett.*, 21 (11), pp. 836-838, June 1996.

[3] M. Bachmann, P.A. Besse, and H. Melchior, "General self-imaging properties in NxN multi-mode interference couplers including phase relations", *Appl. Opt.*, 33 (18), pp. 3905-3911, June 1994.

[4] P.A. Besse, M. Bachmann, and H. Melchior, "Phase relations in multi-mode interference couplers and their application to generalized integrated Mach-Zehnder optical switches", in *Procs. 6th Eur. Conf. on Int. Opt. (ECIO'93)*, Neuchatel, Switzerland, pp. 2.22-2.23, April 18-22, 1993.

[5] L.B. Soldano and E.C.M. Pennings, "Optical multi-mode interference devices based on self-imaging: principles and applications", *J. Lightw. Tech.*, 13 (4), pp. 615-627, April 1995.