Multi-Mode Interference for Wavelength Demultiplexing

(Student paper)

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This paper presents a two-channel wavelength division demultiplexer based on Multimode Interferometer with two multimode regions to separate 1532.68 and 1596.34 nm wavelengths into distinct ports with a loss of approximately 3 dB. The device was simulated and analysed using industry software with built-in solvers. Designed for a Silicon on Insulator Photonic Platform, this design boasts a simple geometry and compact size.

Keywords: *Photonic Integrated Circuits, Wavelength Demultiplexing, Multimode Interferometer, NG-PON2*

INTRODUCTION

The telecommunications industry is one of the sectors that has made significant investments in the application of Photonic Integrated Circuits technology. Since the utilization of fiber and lasers, Photonics has been an integral part of the infrastructure, allowing the unprecedented quantity of information exchanged today. PIC technology is used as a cost-effective solution that combines increased transmission capacity with advantages as a smaller weight, volume, and power consumption [1]. PIC technologies use is widely spread in Passive Optical Networks (PONs). There are several PON standards in use in today's world, working with different wavelength bands, which adds a degree of complexity to the integration of the standards that operate inside the same legacy infrastructure. The telecom industry uses wavelength multiplexing and demultiplexing so that several wavelength channels are transmitted through the same optical link without the need to change or lay a new connection. Demultiplexing can be achieved in PICs using different components, such as ring resonators, arrayed waveguide gratings (AWGs), Bragg gratings, or multimode interference waveguides, among others. Due to the small size and simple design of multimode interferometers (MMIs), PICadvanced explored the possibility of a demultiplexing component made by a MMI to separate the wavelengths used in Next Generation PON2 (NG-PON2) (narrow band option for upstream). This standard is currently in deployment and is part of technology portfolio worked at PICadvanced [2]. To exclude the necessity of adding bends (the case of side ported MMIs [3]), the design was constrained to have outputs along the same axis. The additional bends were going to have an unwanted impact on the footprint needed for the component and on the circuit design complexity.
A 1532.68/1596.34 nm wavelength demultiplexer was created using a multimode waveguide with two multimode regions and inputs and outputs along x- axis. The purpose of this design was to investigate the possibility of simultaneously recovering single and multiple images of the input field for different wavelengths or different wavelengths.

Multimode Interferometer

MMI takes advantage of the phenomenon of interference occurring among the modes propagating inside the wider area of the component. Inside the multimode region, the input field is replicated at a specific length, being this repetition called a single image. Between single image and input field there is an interference pattern where the input field is replicated in N-folded images, as can be seen in Fig. 1.

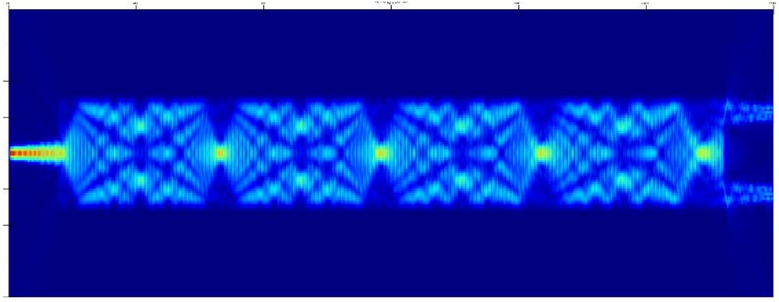

Fig. 1. Propagation Pattern in an MMI, obtained using FDTD solver.

In Fig. 1. it is possible to see the propagating pattern where the repetition of the input field is formed at a length that can be estimated by the following equation [4]:

$$\boldsymbol{L} = \frac{3}{4}\boldsymbol{L_{\pi}} = \frac{3}{4}\frac{4n_f W_{e0}^2}{3\lambda_0} \tag{1}$$

In equation (1), λ_o is the wavelength of propagation, W_{e0} is the width of the mode, and n_f is the strip effective index calculated using effective index method [4] [5]. C band single images are going to appear at a higher length than the one from L band. Typically, the offset between wavelengths is explored by changing the input field y-axis position, creating a pattern where consecutive single images are going to occur at mirrored position by the y-axis. If the multimode region is long enough this offset is going to accumulate, allowing for the occurrence of single images for different wavelengths, at the same length but at different y-axis position, ultimately enabling the separation of the wavelengths into different waveguides. The length at which this happens can be calculated by:

$$\boldsymbol{L_{DEMUX}} = \boldsymbol{p}\left(3\boldsymbol{L_{\pi}^{\lambda_b}}\right) = (\boldsymbol{p}+\boldsymbol{q})\left(3\boldsymbol{L_{\pi}^{\lambda_a}}\right) \tag{2}$$

where *p* is an integer and *q* are an odd integer [6]. The values are dependent on the beat length ratio, which is dependent on wavelength. If the wavelengths are far apart in the electromagnetic spectrum the values are going to be much smaller than when the wavelengths relatively close.

While this approach allows for the recollection of the full single image it also requires a great multimode region length, so that the offset accumulates till there is an x-axis superposition and at the same time y-axis mirroring. In the design of photonic chips, component size is an important limitation/constrain as bigger components mean a lower level of integration, driving up the cost by component of the circuit. Being a technology in development the cost is still elevated when compared with electronics.

To reduce the size of MMIs used for demultiplexing and taking advantage of the offset between single images, the MMI we developed in this paper recovers part of the single image in one of the output waveguides and uses a second multimode region (slot) where multiple images are recovered. The light going through the second multi-mode region suffers a second mode interference, and an image is recovered in a different output waveguide.

RESULTS

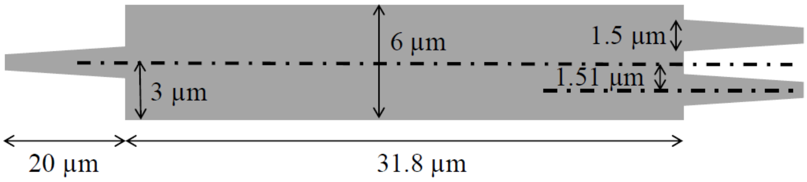

Fig. 2. 3 dB splitter original design **[7]**.

The starting design was based on a 3 dB splitter made in Si/SiO$_2$ Strip waveguide system from Cornerstone Photonics [7]. The position of the input was changed to the edge and the second multimode region was added as can be seen in Fig. 3.

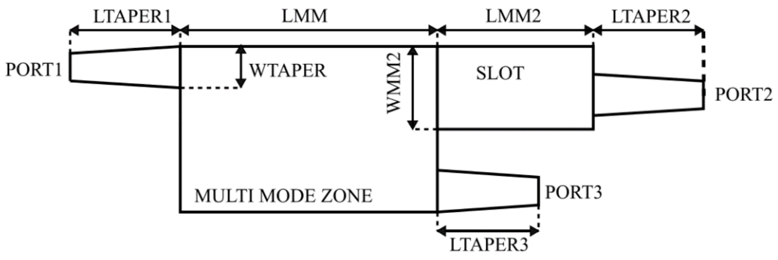

Fig. 3. Slot MMI schematic design.

Using EME sweep tool it was possible to determine a length at which Port3 (bottom output in Fig. 3.) recovers part of the L band single image and the slot recovers part of the C band multiple images. The length of the slot is also swept to determine the ideal length in which it recovers the light into Port2 (upper output in Fig. 3.). The simulation results are presented in Table 1.

Wavelength (nm)	S_{21} (a.u)	S_{31} (a.u)	ER (dB)	IL (dB)
1532.69	0.06119	0.4923	9.055	3.078
1596.32	0.6021	0.001035	27.65	2.203

Table 1. Transmission results and parameters for the two wavelengths at the beginning of the C and L band, in a Slot MMI with a 6 µm multimode region width.

As the footprint of the component is an important constraint, a second slot MMI was designed with a multimode region width of 5 µm. In accordance with expression (1), reducing the width, the length at which the single image appears is going to be smaller, enabling the modelling of a smaller component. The results for this smaller width component are presented in Table 2:

Wavelength (nm)	S_{21} (a.u)	S_{31} (a.u)	ER (dB)	IL (dB)
1532.69	0.01839	0.5009	14.35	3.002
1596.32	0.5657	0.1168	6.853	2.474

Table 2. Transmission results and parameters for the two wavelengths at the beginning of the C and L band, in a Slot MMI with a 5 µm multimode region width.

DISCUSSION

Width (µm)	Multimode Region Length (µm)	Slot Length (µm)
5	193	55.8
6	273.1	103

Table 3. Dimensions of the Slot MMis with 5 and 6 µm of width.

A 1532.68/1596.34 nm wavelength demultiplexer based on a multimode waveguide with two multimode regions and x-axis inputs and outputs was demonstrated for application in NG-PON2. The component was designed for Si/SiO_2 platform made by Cornerstone Photonics and is being produced using multi-project wafer for testing and validation of simulation results (both designs present on Table 3). The simulations show losses bellow 3 dB and smaller lengths compared to the traditional application method, proving the feasibility of reducing the footprint of MMIS for demultiplexing. This work is supported by the European Regional Development Fund (FEDER), through the Competitiveness and Internationalization Operational Programme (COMPETE 2020) of the Portugal 2020 framework [Project POWER with Nr. 070365 (POCI-01-0247-FEDER-070365)].

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