Performance Analysis of 1310/1490 Nm Demultiplexer based on Multimode Interference Coupler for PON

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Abstract: The design and analysis of a 1310/1490-nm demultiplexer based on Multimode Interference (MMI) coupler for Passive Optical Networks (PON) has been studied in this paper. Numerical simulations with finite difference Beam Propagation Method (BPM) have been utilized to optimize the operation of the proposed demultiplexer. The device has been designed with optimized width and MMI length and its analysis has been done based on extinction ratio and Insertion loss. Restricted interference has been used to reduce the size of the device. The device has been solely designed using 1310 nm as upstream and 1490 nm as downstream of data for Passive Optical Network communication system.

1 INTRODUCTION

Fiber-to-the-home Passive Optical Networks are one of the evolving telecommunication networks that uses wavelength multiplexing/demultiplexing to have point to multipoint fibers to the end points. They are used for ultra-high speed internet communication for home entertainment and industrial demands (Fan et al., 2009). Few standards, which were earlier used are Broadband Passive Optical Networks (BPONs) set by ITU and Ethernet Passive Optical Networks (EPONs) set by IEEE and are based on time division multiplexing. A currently widely used standard is Gigabit Passive Optical Networks (GPON) set by ITU, which uses three wavelength channels for multiple applications including 1310 nm for upstream of data with a bit rate of 1.25 Gb/s, 1490 nm for downloading of voice and data with a bit rate of 2.5 Gb/s and 1550 nm is reserved for video broadcasting (Cale et al., 2007; Filka, 2010). Video service of PON could be upgraded to digital form of signal using internet protocol television (IPTV) but the transmission type is unicast (FOA 2014; Horvath et al., 2015). This negates the need of separate wavelength for video and same wavelength can be used for downloading video ie.1490 nm in case of IP Protocol.

Devices based on multimode interference support large number of modes due to which there has been a growing interest in its application and effects in the field of integrated optics (Soldano and Pennings, 1995). MMI based demultiplexers have attracted much attention because of its compact size, low loss, larger fabrication tolerances and the broad bandwidth properties and hence they are increasingly used for wavelength demultiplexing (Chack et al., 2015; 2014; Jerabek et al., 2013; Shi et al., 2007; Paiam et al., 1995). This paper presents a simple design of a demultiplexer to separate wavelengths 1310 nm and 1490 nm at two different ports such that it can be used by a GPON system for uploading and downloading. The device length and width have been optimized with the help of Beam propagation method based simulations.

2 DEVICE DESIGN AND ANALYSIS

A multimode section supporting many modes reproduces input field profile in single or multiple images at periodic intervals along the direction of propagation of the guide and it is called as" Self-imaging" (Soldano and Pennings, 1995). Using the concept of self-imaging, we have designed our device with material InGaAsP as core layer of waveguide and InP as cladding layer (Adachi and Sadao, 1982; Chack et al., 2015). InP-based optical power splitters are of great advantage to photonic integration in 1550 nm optical communication systems compared with

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other material, such as AlGaAs/GaAs and SOI (Li et al., 2011). As an experimental design, we have taken these materials for analysis at 1310 nm and 1490 nm to have high optical power operation. In this work, we have chosen the simulation parameters given below in Table 1. The theory and properties of MMI devices has been described below. Beat length (L_π) for a multimode section of waveguide is defined as

$$L_\pi = \pi / (\beta_0 - \beta_1), \quad (1)$$

where β_0 and β_1 are the propagation constants of fundamental and first order modes, respectively (Paiam et al. 1995). In order to reduce device size, restricted interference has been used in which modes 2,5,8…are not excited in multimode waveguide. In restricted resonance mechanism at MMI length of $L_{MMI} = k.L_\pi$, a direct or mirrored image of the input field is formed if n is an even or odd integer, respectively. The MMI width is adjusted to satisfy the total length of MMI region as

$$L_{MMI} = n.\ L_\pi\,(1310) = (n+1).\ L_\pi\,(1490) \quad (2)$$

where n is an integer.

Further, if the MMI section of the device satisfies the relation in Eq. 2, the wavelengths 1310 nm and 1490 nm can be successfully separated by choosing a suitable width and length of MMI section. The width of the MMI section is chosen using the ratio of beat lengths at 1310 nm and 1490 nm for transverse electric polarization. The beat length ratio, which corresponds to the ratio of two integers is generally taken and width corresponding to that ratio is chosen. Figure 1 shows that beat length ratio corresponding to width 3.4 µm is 1.1 and hence integer n is taken as 10 and (n+1) =11 so that (n+1)/n=1.10.

Now from Eq. 2, we have $L_\pi^{1310}/L_\pi^{1490}$ =n/n+1 which results in $L_{MMI} = 10L_\pi^{1310} = 11L_\pi^{1490}$. For TE polarization, the calculated value of L for 1310 nm and 1490 nm are 50.32 µm and 45.84 µm respectively at width of 3.4 µm. Hence L_{MMI} for 1310 nm and 1490 nm are 503.20 µm and 504.21 µm respectively.

Figure 2 clearly depicts the structure of the proposed demultiplexer where the width of the MMI section has been optimized at 3.4 µm. The width of input and output waveguides has been taken to be 0.8 µm. Initially input and output waveguides are taken at a lateral shift of around $W_{MMI}/3$. Input waveguide is at an offset of 1.1 µm. Two output waveguides are separated by distance 1.4 µm. The complete structure has been first optimized at MMI length of 449 µm. The designed device is shorter in length in compression the existing similar device with tapered geometry (Chang et al., 2010).

Table 1: Parameter for demultilpexer MMI structure.

Parameter	Value
Guide Refractive index	3.290
Cladding Refractive index	3.167
I/O waveguide width	0.8 µm
λ_1	1490 nm
λ_2	1310 nm
MMI width	3.4 µm
MMI length	449 µm
Polarization	TE
BPM	Solver Paraxial
Engine	Finite Difference
Boundary Condition	TBC

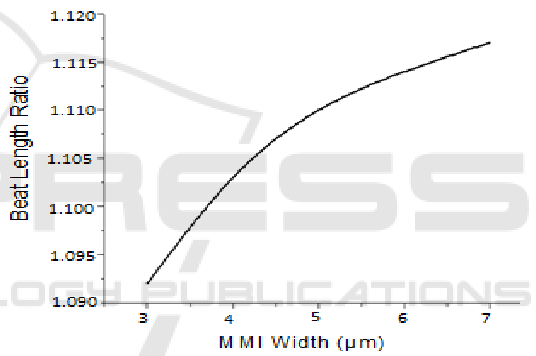

Figure 1: Calculated beat length ratio ($L_\pi^{1310}/L_\pi^{1490}$) as a function of MMI width for TE polarization.

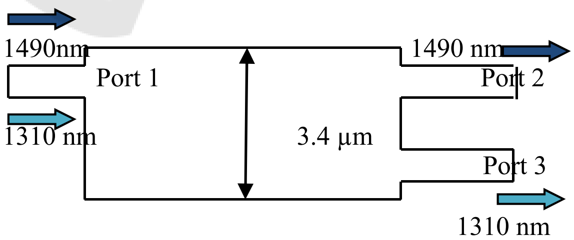

Figure 2: Schematic diagram of the proposed demultiplexer.

3 RESULTS AND DISCUSSTION

From Fig. 3, it can be observed that wavelength 1310 nm is obtained at port 3 with highest optical intensity while wavelength 1490 nm is obtained at port 2 with highest optical intensity at MMI length of 449µm for separation distance between output waveguides to be 1.4 µm and input lateral offset as 1.1 µm. Further, to measure the performance of device, Extinction Ratio and Insertion Loss has been calculated using the relations:

$$\text{Extinction Ratio} = 10 \log (P_d / P_u) \quad (3)$$

$$\text{Insertion Loss} = -10 \log (P_d / P_i) \quad (4)$$

where P_d is the power from desirable output waveguide, P_i is the power in input waveguide and P_u is the power from undesirable output waveguide (Shi et al., 2007). From fig. 4, it is clear that optimized length is 449 µm.

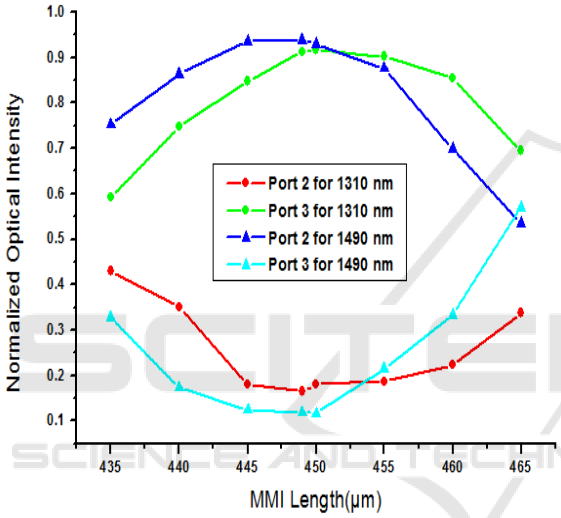

Figure 3: Normalized field distribution versus MMI Length for λ=1310 nm and 1490 nm wavelength for TE polarization.

Two dimensional simulations of field distribution for TE polarization can be seen in Fig. 5, where 1490 nm get separated at port 2 and 1310 nm at port 3. We have also optimized the output by varying the gap size between output waveguides and simultaneously changing the corresponding lateral offset of input waveguide. From fig. 6, we can observe that the output has been optimized at a gap size of 1.3 µm or a lateral shift of 1.05 µm.

Table. 2 and Fig. 6 show that the insertion loss for both the wavelengths is below 1dB and and extinction ratio for 1310 nm and 1490 nm are around 17 dB and 20dB at optimized MMI length of 449 µm. TM beat lengths were also calculated but the optimized MMI length was different as compared to its TE counterpart. For TM mode, optimized MMI length was found to be 440µm. This shows that optimum value for both polarizatios are different and hence we have optimized our designed demultiplexer only for TE polarization.

Table 2: Output Powers (normalized to input power) of two output ports of the proposed demultiplexer at two wavelengths.

Wavelength (nm)	**Extinction Ratio (dB)**	**Insertion Loss (dB)**
1310	16.93	0.924
1490	20.17	0.546

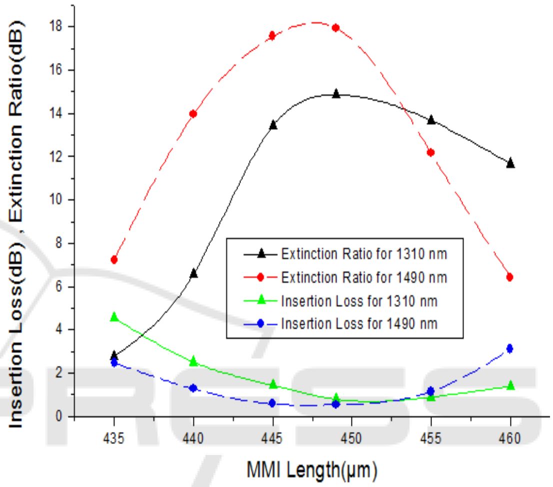

Figure 4: Simulation performance for TE mode as a function of MMI length.

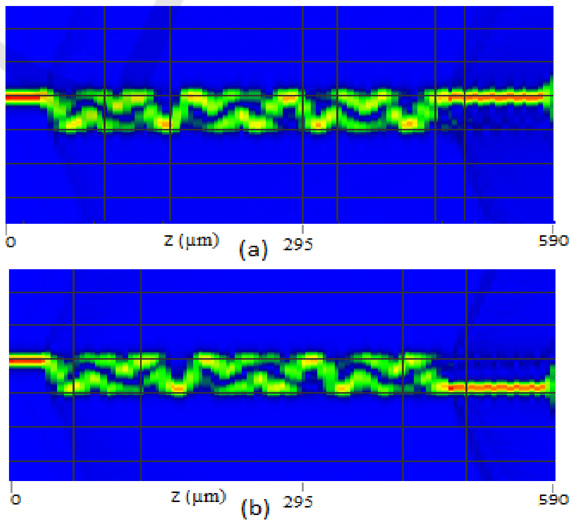

Figure 5: 2-D simulations of the field distribution (a) port 2 for wavelength 1490 nm and (b) port 3 for wavelength 1310 nm.

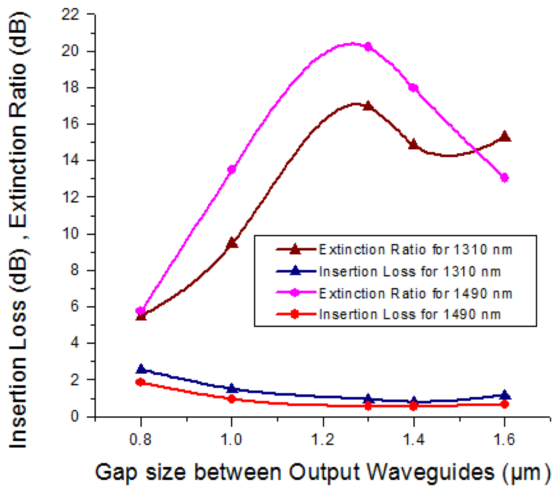

Figure 6: Simulation performance for TE mode as a function of branching separation distance (Gap size) between output waveguides.

4 CONCLUSIONS

A 1310/1490 nm wavelength demultiplexer has been proposed based on conventional MMI structure. It has been shown that separation distance between output waveguides and the lateral offset of input waveguide affect the simulation output and we optimized the branching separation distance at 1.3 µm to achieve maximum output optical field for demultiplexer. The present simulation based on finite difference beam propagation shows that the proposed demultiplexer has good performances such as a low insertion loss and a high extinction ratio at 1310 nm wavelength, which has been found to be IL= 0.924 dB and extinction ratio = 16.93 dB, respectively, and at 1490 nm wavelength, IL= 0.546 dB and extinction ratio = 20.17 dB, respectively, for quasi-transverse-electric (quasi-TE) polarization. The 1310/1490 nm wavelength demultiplexer may be an important key component in application of Passive Optical Network communication system in near future.

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