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Performance evaluation of Multimode Interference Coupler with parabolic and exponential shaped coupling region

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***Abstract*— Several studies have suggested that multimode interference coupler with exponential taper structure is advantageous as compared to parabolic taper structure. This paper shows a comparative study of 1×2 MMI coupler with exponential and parabolic taper structure using 2D finite difference beam propagation method (BPM). We have found that for the proposed design over the same dimension, performance of MMI coupler with exponential taper structure is better as compare to parabolic taper structure. On the other hand effective refractive index (Neff) is also studied in comparison with width and wavelength for both exponential and parabolic tapered MMI coupler**

***Index Terms*—Multimode interference (MMI) coupler, Self-imaging, effective refractive index, parabolically and exponentially tapered waveguide**

I. INTRODUCTION

In recent years, MMI devices gained popularity because of their advantageous properties such as compact size, polarization intensity, low crosstalk and excellent fabrication tolerances. Further in many applications MMI devices are used such as couplers, spillers, combiners and optical switches [1]. MMI couplers can split power among more than two waveguides. Good performance of MMI coupler is reported when these couplers are constructed using materials like InP, SiO2, InGaAs and GaAS. The MMI device generally consists of three parts such as input ports (or left ports), a MMI area and output ports (or right ports). Practical MMI device is usually an M-input and N output device with tapered functions. MMI devices are based on self-imaging technique. Whereas self-imaging is the phenomena in which at periodic intervals, input field profile reproduces itself in single or multiple image along the direction of propagation of waveguide[2-4].Main drawback of MMI coupler is that its size increases if we try to reduce its losses. Size of MMI coupler can be reducing by introducing taper structure such as parabolic taper structure in it [5]. In this paper another taper structure called as exponential taper structure [13] for MMI coupler is also presented and it has been shown that exponential taper structure can further reduces size of MMI coupler than that of parabolic taper structure. In order to realize comparative results of MMI coupler using parabolic and exponential taper structure beam propagation method [6] is used in the simulation which is a powerful technique to investigate linear and nonlinear light wave propagation phenomena in waveguides. This paper provides a comparison between exponential and parabolic taper structure. We discussed basics of MMI coupler and self-imaging phenomenon further in theory section we have discussed two designs of each parabolic and exponential taper structure and parameters like effective refractive index (Neff), losses and wavelength are presented for both of the designs. Finally based on the comparison done, a conclusion is drawn between both the taper structures.

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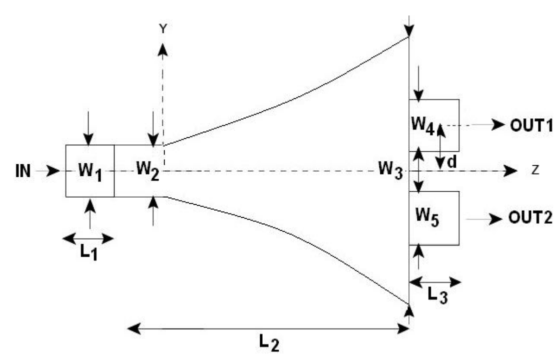
II. MULTIMODE INTERFERENCE COUPLER

Design (i) of 1×2 MMI coupler has been shown in figure 1. Whereas 1×2 MMI coupler consists of one single mode input waveguide, one multimode and two single mode output waveguides. Where figure 1(a) showing MMI coupler with exponentially tapered waveguide and figure 1(b) is MMI coupler with parabolically tapered waveguide. Dimension for exponential and parabolic tapered MMI couplers are kept same. In design (i) d represents offset for output waveguides from the center of taper structure. where W1 represents width of input waveguide and W4 and W5 are width of output waveguides which are 5 µm where W2 andW3 are start and end width of exponential and parabolic taper structure which is 5 µm and 20 µm and L1, L2 and L3 represents length of input waveguide, tapered structure and output waveguide where length of input and output waveguide is same which is 50 µm and length of tapered structure is 160 µm respectively whereas depth of input and output waveguides, parabolic and exponential taper structure is 0.4 µm. Figure 2 showing 3D plot of refractive index profile for both parabolic and exponential tapered MMI coupler. For design (i) losses (normalized) and effective refractive index (Neff) is analyzed with respect to wavelength (λ). Material used in design (i) is InGaAs whose refractive index is 3.3832.



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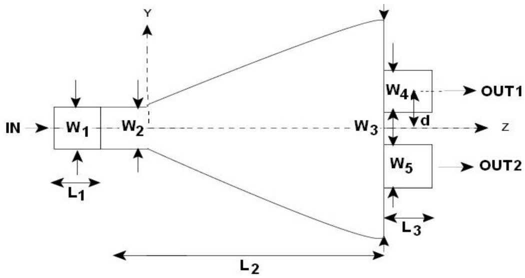

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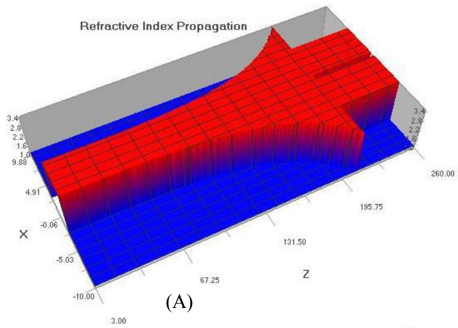

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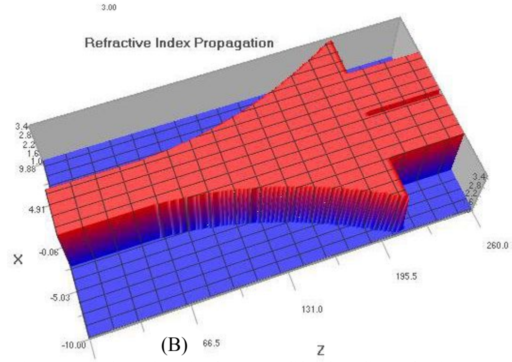

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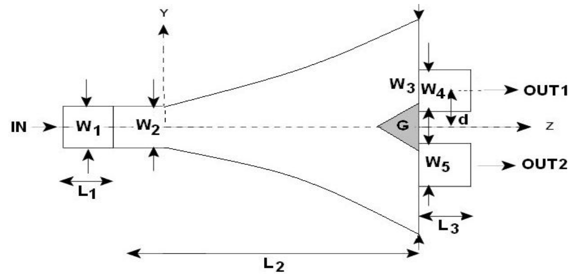
Fig. 2, Refractive index profile for first design 2(a) exponentially tapered and 2(b) parabolically tapered MMI coupler.

Next proposed design is shown in figure 3. Design (ii) is the result of modification in design (i) in which a linear taper structure is included in parabolic and exponential taper structure in order to reduce losses and increase separation between two output ports and due to which offset for output waveguide also increases. Linear taper structure is situated at the end of the taper structure and present at the center with 0 offset. As design (ii) have a material whose refractive index is higher than refractive index of material used in linear taper structure hence light wave entering through input waveguide in exponential or parabolic taper structure instead of travelling straight through linear taper structure light ray will change its direction or appear to bend and tends to travel through output waveguide which is of same refractive index and in this way linear taper structure in design (ii) act as a gap. Hence signal travelling from multimode exponential and parabolic taper structure concentrate more in output waveguide. Figure 3(a) showing linear taper structure within the exponentially tapered MMI coupler and figure 3(b) is a linear taper structure in parabolically tapered MMI couple.



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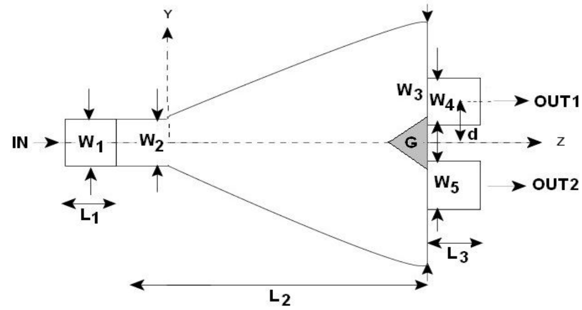
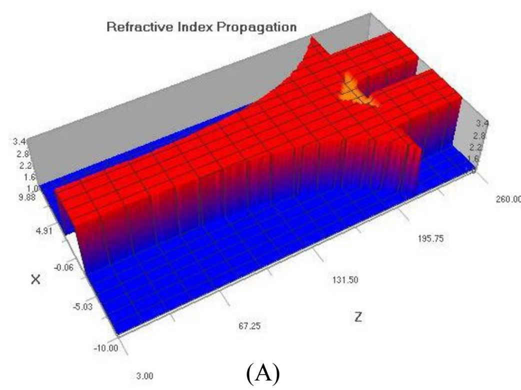


(B)

Figure 3 Schematic diagram of design (ii) for 1×2 MMI coupler 3(a) exponentially tapered waveguide with linear taper structure 3(b) parabolically tapered waveguide with linear taper structure.

Dimension for exponential and parabolic tapered MMI couplers with linear taper structure are same. In design (ii) G stands for gap and represents linear taper structure whose, Start and end width is 6.5 µm whereas length is 20 µm. d represents offset for output waveguides. Other dimension such as W1, W2, W3, W4 and W5 which represents width of input waveguide, starting and end width of exponential and parabolic taper structure and width of output waveguides. L1, L2 and L3 which represents length of input waveguide, tapered structure and output waveguide and depth are same as design (i) respectively. Figure 4 showing 3D plot of refractive index profile for both parabolic and exponential tapered MMI coupler with linear taper waveguide. Material used in design (ii) is same as used in design (i) whereas material used in linear taper waveguide in design (ii) is InP whose refractive index is 3.1662 which is less than InGaAs. For design (ii) losses at output waveguide is analyzed with respect to different wavelength.



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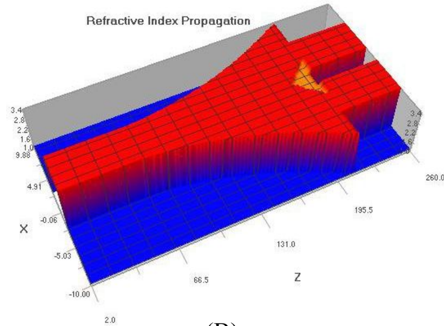

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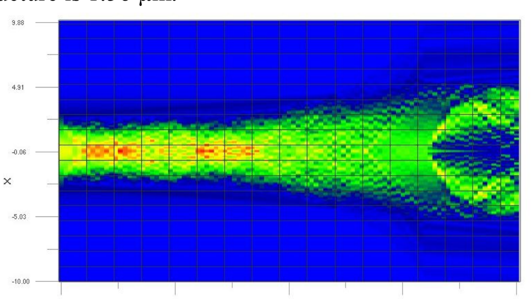
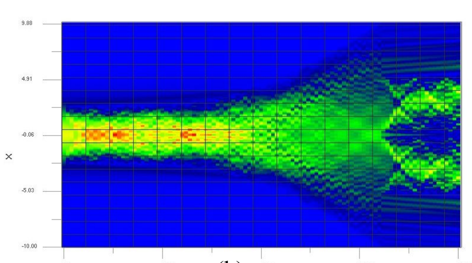
Fig. 4, Refractive index profile for second design 2(a) exponentially tapered and 2(b) parabolically tapered MMI coupler with linear taper structure.

III. SIMULATION AND RESULTS

In order to analyze comparison between the performances of exponentially tapered and parabolically tapered structure, we illustrate the particular case of 1×2 MMI coupler which is simulated with 2-D beam propagation method (BPM) which is based on the finite difference method. For both of the proposed designs in simulation transverse electric (TE) mode is considered whereas free space wavelength for design (i) is 1.56µm and for design (ii) is 1.54 µm. In addition perfectly matched layer (PML) approach is used which defines the truncation of the computation domain by layers without any reflection [8, 9]. Where starting field mode is Gaussian field. Offset for design (i) is selected as 2.7 µm and for design (ii) offset is 3.6 µm. for both the designs rest of the parameters are same as mentioned above. Figure 5 showing plot of optical field propagation of design (i) for both parabolic and exponential taper structure when wavelength for both the structure is 1.56 µm.



(a)



(b)

Fig. 5, 2-D plot of optical field propagation of design (i) for 5(a) exponentially tapered structure and 5(b) parabolically tapered structure.

Characteristics curve in figure 6 shows normalized losses in design (i) with respect to wavelength. Following curve showing that losses in MMI coupler with exponential taper structure is small as compare to MMI coupler with parabolic taper structure over the different wavelength.

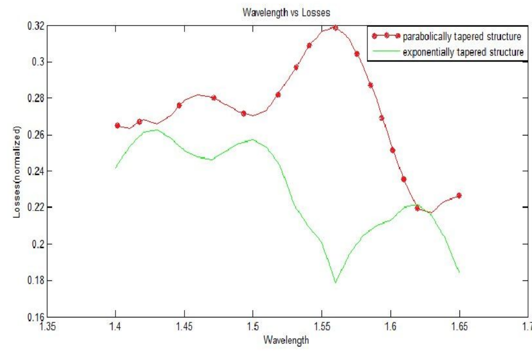
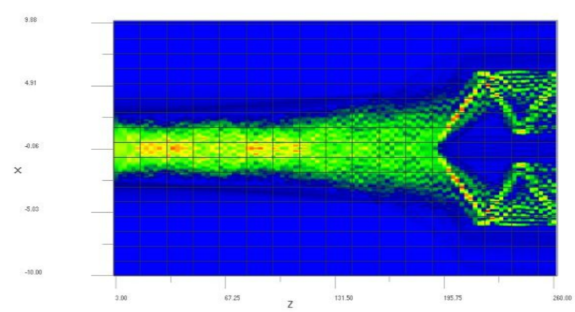
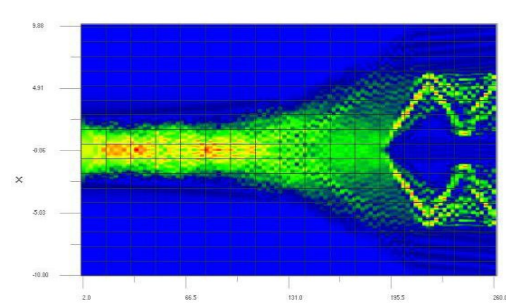


Fig. 6, plot of normalized losses versus wavelength for design (i)

According to simulation results at the wavelength of 1.56 µm minimum normalized losses in MMI coupler with exponentially tapered waveguide is 0.178 and over the same wavelength losses (normalized) in MMI coupler with parabolically tapered waveguide is 0.319 respectively. Further we have analyzed variation in effective refractive index (Neff) with respect to wavelength (λ) for design (i) and it has been found that effective refractive index (Neff) with respect to wavelength in MMI coupler with exponential taper structure slightly decreases as compare to MMI coupler with parabolic taper structured waveguide. Figure 7showing plot of optical field propagation for design (ii) when wavelength for both exponentially and parabolically tapered MMI coupler with linear taper structured waveguide is 1.54 µm.



(a)



(b)

Fig. 7, 2-D plot of optical field propagation of MMI coupler 7(a) exponentially tapered waveguide with linear taper structure and 7(b) parabolically tapered waveguide with linear taper structure

Again in figure 8 characteristic curves for design (ii) showing losses at output with respect to different wavelength for both parabolically and exponentially tapered MMI coupler with

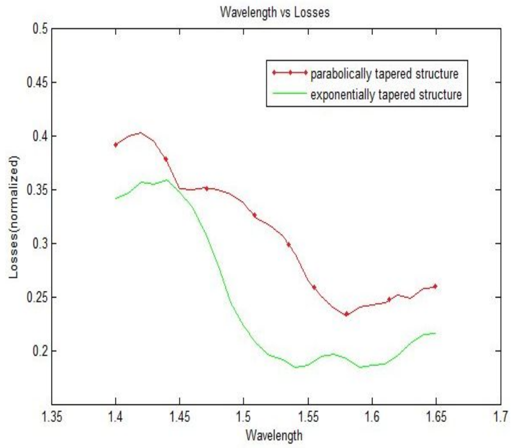


Fig. 8, plot of normalized losses versus wavelength for design (ii)

linear taper structured waveguide as shown in figure 3. In design (ii) we observed that at the same dimension over different wavelength, losses in exponentially tapered MMI coupler with linear taper structured waveguide is less as compare to parabolically tapered MMI coupler with linear taper structured waveguide. Further simulation results are showing that in design (ii) minimum loss (normalized) in exponentially tapered structure is 0.185 at the wavelength of 1.54 µm on the other hand loss (normalized) in parabolically tapered structure over the same wavelength is 0.289.Whereas minimum normalized loss in parabolically tapered structure is 0.235 at the wavelength of 1.58 µm on the other hand loss (normalized) in exponentially tapered structure over the same wavelength is 0.192 respectively.

CONCLUSION

We presented two, 1×2 MMI coupler designs in order to draw a comparison between exponentially and parabolically tapered structure. Through simulation result it was found that effective refractive index (Neff) with respect to wavelength (λ) decreases in exponentially tapered coupler because of its less effective area as compare to parabolic taper area. Further we have investigated that losses in exponential taper structure is less as compare to parabolic taper structure. Size of MMI coupler can be reduce with exponentially tapered waveguide further it can be more compact and have low losses as compare to MMI coupler with parabolically tapered waveguide.

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