Chapter 7:

Double S-Bend Geometry for Compact MMI Coupler

Introduction

Mathematical Model of Double S-bend structure for Multimode Interference Couplers

Results and Discussion

Conclusion
7.1. Introduction

Although grating assisted tooth shaped geometry provides lower coupling length than that of conventional structures such as TMI and MMI couplers of Photonic Integrated Devices (PID) due to having more number of multiple reflections in grating assisted tooth shaped (GATS) structures; GATS structure shows more radiation losses in the coupling region due to having large number of grating period. It is also seen in chapter-5 that overall length \((L_x + 2L_T)\) of multimode interference (MMI) coupler including coupling length \(L_x\) and longitudinal access waveguide length \(L_T\) is less than that of two mode interference (TMI) coupler as \(L_T\) of MMI coupler is lower than that of TMI coupler for a bending loss of 0.1 dB [1]. From the previous works [2]-[5], it is also found that the tapered structures of MMI coupler provides lower coupling length but there is radiation loss due to the leakage of higher order modes at tapered portion of the structure. It is seen in chapter-6 that the fabrication of grating assisted geometries require higher resolution fabrication process and techniques. So much effort should be given to reduce the coupling length by using other possible design structures such as double S-bend structure [6]-[7]. On the other hand, optical guided-wave devices often contain tapered structures [8]-[12] to achieve a highly efficient power coupling between two different optical devices.

In the current chapter, a double S-bend structure based on general interference has been proposed for MMI coupler. The proposed structure has been designed and implemented by using silica waveguides with SiON core for reduction of device length. The coupling characteristics of the proposed double S-bend MMI (DB-MMI) structure is compared with conventional MMI structure. The optimal value of the longitudinal access waveguide length and beat length for the double S-bend assisted MMI (DB-MMI) coupler is also determined and compared with the previous results for double S-bend TMI (DB-TMI) coupler [6]-[7]. The fabrication tolerance and its effect on power imbalance of the proposed tapered MMI coupler are studied and compared with other tapered MMI couplers [3]-[4].
7.2. **Double S-Bend**

![Diagram of Double S-Bend MMI coupler](image)

**Fig. 7.1:** 2x2 double S-bend MMI coupler with bending angle \( A^0 \), width \( W_{mm} \), access waveguide width \( a \) and thickness \( b \) (a) 3D view (b) 2D MMI structure containing \( x \) and \( z \) axis

Fig-7.1(a) shows the schematic 3D view of a double S-bend MMI (DB-MMI) coupler consists of a double S-bend coupling region of longitudinal length, \( L \) and width, \( W_{mm}=2a+b \) (where \( h \) is the gap between two access waveguides near to MMI region and \( a= \)width of access waveguide), two single mode S-bend input access waveguides (Waveguide-1 and Waveguide-2) of core width \( a \), thickness \( b \) and two output S-bend access waveguides (Waveguide-3 and Waveguide-4) of same core size.
respectively. The height (H) and longitudinal coupling length (L) of S-bend structure in double bend MMI (DB-MMI) coupling region is \( S \sin A \) and \( S \cos A \) respectively (where \( S \) is S-bend length, \( A \) is angle made by S-bend with Z-direction). The refractive index of core and surrounding cladding layer are \( n_1 \) and \( n_2 \) respectively. When the input power \( P_1 \) is launched into lower most input S-bent access waveguide, the output powers \( P_3 \) and \( P_4 \) are obtained as bar state power and cross state power respectively.

Fig.-7.1(b) shows the 2D view of the double bend MMI (DB-MMI) coupler as shown in Fig.-7.1(a). Since the lateral dimension (along x-axis) in DB-MMI region is \( \sim \) more than two times larger than the transverse dimension (along y-axis) as shown in Fig.-7.1(b) and transverse dimension \( b \) is chosen to be for single mode normalized frequency \( V \leq 2.3 \) \([where, V = \frac{2\pi b}{\lambda} \sqrt{n_1^2 - n_2^2} \)]\( )\), the waveguide structure is to be single mode in transverse direction and has the same transverse behavior everywhere in the MMI region. So it is assume that the modal analysis can be studied by using two dimensional (2D) structures in which lateral (along x-axis) and longitudinal (along z-axis) characteristics are considered. The input field profile \( H(x, 0) \), incident on DB-MMI coupler is composed of mode field distribution of all excited modes and represented in 2D approximation as follows,

\[
H(x, 0) = \sum_{i=0}^{r-1} b_i H_i(x)
\]  

(7.1)

where \( i = 0, 1, 2, \ldots, (r-1) \) denotes the order of guided modes and \( b_i = i^{th} \) mode field excitation coefficient of DB-MMI coupler. The mode excitation coefficients are evaluated from Fourier series coefficients of odd periodic functions. \( H_i(x) \) is mode field distribution of \( i^{th} \) order mode of DB-MMI region at \( z=0 \). Based on the phase differences of excited modes at the end of the coupling region, the optical power is either transferred to the output waveguides or lost out at the end of multimode channel waveguide. Again the mode fields at the output access waveguides of width \( a \), thickness \( b \) are assumed to be single mode where only fundamental mode is
excited. The composite mode field of the output waveguides is the sum of the contribution of all the modes guided in DB-MMI section which can be express as,

$$H_M(x,z) = \sum_{i=0}^{r-1} C_{M,i} H_i(x) \times \exp\left[j(\beta_0 - \beta_i) L \sec A\right] e^{-2a \sec A}$$  \hspace{1cm} (7.2)$$

where \( \alpha \) is the bending loss coefficient depends on bending angle A [7], [13] and \( C_{M,i} \) is the field contribution coefficient of \( i^{th} \) mode for M-th output access waveguide (M=3 for the 3\textsuperscript{rd} access waveguide and M=4 for the 4\textsuperscript{th} access waveguide), that determined by using simple effective index method (SEIM) based on sinusoidal modes [14]-[17] as discussed in the chapter-3. The \( \beta_0 \) and \( \beta_i \) are propagation constants of zero\textsuperscript{th} (fundamental) mode and \( i^{th} \) order mode respectively.

The normalized coupled power transferred to the 3\textsuperscript{rd} and 4\textsuperscript{th} output access waveguides can be define as,

$$\frac{P_3(x,L)}{P_3(x,0)} = \left| \frac{H_{1,3}(x,L \sec A)}{H_{1,3}(x,0)} \right|^2$$  \hspace{1cm} (7.3)$$

$$\frac{P_4(x+a+h,L)}{P_4(x,0)} = \left| \frac{H_{2,4}(x+a+h,L \sec A)}{H_{2,4}(x,0)} \right|^2$$  \hspace{1cm} (7.4)$$

where,

$$H_{1}(x,L \sec A) = \sum_{i=0}^{r-1} C_{3,i} H_i(x) \times \exp\left[j(\beta_0 - \beta_i) L \sec A\right] e^{-2a \sec A}$$  \hspace{1cm} (7.5)$$

$$H_{2}(x+a+h,L \sec A) = \sum_{i=0}^{r-1} C_{4,i} H_i(x+a+h) \times \exp\left[j(\beta_0 - \beta_i) L \sec A\right] e^{-2a \sec A}$$  \hspace{1cm} (7.6)$$

The \( C_{3,i} \) and \( C_{4,i} \) are the field contribution coefficients of \( i^{th} \) mode for output access waveguide-3 (M=3) and waveguide-4 (M=4) respectively which are determined by using simple effective index method (SEIM) based on sinusoidal modes as discussed in chapter-3 with a consideration \( n_3 \rightarrow n_1 \) (h\( \neq 0 \)), we have

$$\frac{C_{M,i}}{C_0} = \frac{\pi^2}{16b^2a^2} \times \exp\left[-hk(n^2-\eta_1^2)\right] \times \exp\left[hk(n^2-\eta_2^2)\right] \times \exp\left[-b(n^2-\eta_2^2)\right]$$  \hspace{1cm} (7.7)$$

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where for TE mode,

\[
C_0 = \frac{0.4}{F_c} \times \frac{(n_i^2 - n_{\text{eff(TE)}}^2) \sqrt{n_{\text{eff(TE)}}^2 - n_2^2}}{n_{\text{eff(TE)}} (n_1^2 - n_3^2) \left[ W_{\text{mmi}} + \frac{2}{k_0 \sqrt{n_{\text{eff(TE)}}^2 - n_2^2}} \right]}
\]

\[
F_c = \frac{3(1 + 0.2h)}{[13.5 + 185(\beta_0 - \beta)]h}
\]

\[
n_{\text{eff(TE)}} = \beta_{\text{TE (i)}} \left( \frac{\lambda}{2\pi} \right)
\]

Similarly, for TM mode,

\[
C_0 = \frac{0.4}{F_c} \times \frac{(n_i^2 - n_{\text{eff(TM)}}^2) \sqrt{n_{\text{eff(TM)}}^2 - n_2^2}}{n_{\text{eff(TM)}} (n_1^2 - n_3^2) \left[ W_{\text{mmi}} + \frac{2}{k_0 \sqrt{n_{\text{eff(TM)}}^2 - n_2^2}} \right]}
\]

\[
F_c = \frac{3(1 + 0.2h)}{[13.5 + 185(\beta_0 - \beta)]h}
\]

\[
n_{\text{eff(TM)}} = \beta_{\text{TM (i)}} \left( \frac{\lambda}{2\pi} \right)
\]

As shown in Fig.-7.1(b), the transition length (\(L_T\)) of the S-bend access waveguide (along z direction) can be obtained as follows,

\[
L_T = \sqrt{\left( H_T - \frac{h}{2} \right) \left[ 4R + \frac{h}{2} - H_T \right]}
\]

\[
R^2 = \left( \frac{L_T}{2} \right)^2 + \left( R - \frac{H_T}{2} + \frac{h}{4} \right)^2
\]

where \(R\), \(H_T\) and \(h\) are the bending radius, height and coupling gap between two access waveguides respectively. The double S-bend loss \((T_s)\) in dB for the DB-MMI region can be approximated as

\[
T_s = 4.343\alpha L \sec(A)
\]
where $\alpha$ is the bending loss coefficient that depends on bending angle $A$ and propagation constant ($\beta$).

### 7.2.1 Coupling Characteristics of DBMMI Coupler

![Graph showing coupling characteristics vs longitudinal beat length](image)

**Fig.-7.2:** Normalized Coupling Power characteristics vs Longitudinal Beat Length of double S-bend multimode interference coupler (dashed lines) with bending angle $A=22^0$, $26^0$, $30^0$ and conventional MMI coupler ($A=0^0$, dotted line) for $h=4$ $\mu$m, $a=b=1.5$ $\mu$m, wavelength~$1.55$ $\mu$m, $\Delta n=1.45$ and $\Delta n=5\%$ respectively.

Fig-7.2 shows the normalized coupling power distribution ($P_2/P_1$ and $P_3/P_1$) versus longitudinal coupling length ($L_z$) of TE polarization determined by using (7.1) and (7.3)-(7.10) for the proposed DB-MMI coupler with different bending angles, $A=22^0$, $26^0$ and $30^0$ for $h=4$ $\mu$m, $a=b=1.5$ $\mu$m, wavelength=1.55 $\mu$m, cladding index=1.45 and $\Delta n=5\%$ respectively. The normalized coupled power distributions of
conventional MMI coupler (A=0°) is also estimated and represented by dotted line in the figure. The black dot and cross signs in the figure represents the experimental points (which is discussed later in section-7.4) for conventional MMI coupler (A=0°) and DB-MMI coupler (A=26°) respectively, matching well with theoretical curves. It is found that the longitudinal beat lengths (L₁) for conventional MMI and proposed DB-MMI structure are ~80 μm and ~67 μm respectively. It is observed (not shown in the figure) that for TM mode, the theoretical value of longitudinal beat length (L₁) is estimated as ~83.08 μm which is 0.24 % more than that of TE mode for the proposed structure showing the polarization independent characteristics. It is also found that the number of guided modes in DB-MMI region of width (2a+h)=7 μm is eight. In the figure, the peak normalized coupling power in case of the DB-MMI coupler decreases with bending angle (A). This is due to radiation loss at the S-bending region of the proposed structure and as bending angle increases, the bending radiation loss increases. It is seen from the figure that the peak coupling power for DB-MMI coupler with A=26° is close to that with A=30°. So we have chosen A=26° for further study of DB-MMI coupler.

7.2.2 Beat Length of DBMMI Coupler

The longitudinal beat length of the proposed DB-MMI coupler with A=26° is ~67 μm which is 19% less than that of conventional MMI coupler. We have also estimated light propagation which is obtained by using optiBPM software (version 9.0) for DB-MMI coupler with A=0° (conventional), 22°, 26° and 30° as shown in Fig-7.3. It is seen from the figure that the longitudinal beat lengths of DB-MMI coupler with A=0°, 22°, 26° and 30° are obtained as ~80 μm, 69 μm, 67 μm and 65.2 μm respectively which are almost close to those obtained theoretically from coupling characteristics obtained by SEIM based on sinusoidal modes as shown in Fig-7.2. It is also confirmed from the figure that the bending loss in conventional MMI coupler
is lower than that of the proposed DB-MMI coupler but the bending loss for DB-MMI coupler with $A=22^\circ$ is close to that with $A=26^\circ$.

Fig-7.3: Beam propagation results of DB-MMI coupler with $W_{\text{mmi}}=7$ μm, $a=b=1.5$ μm, $\lambda=1.55$ μm, $n_2=1.45$ and $\Delta n=5\%$ for (a) conventional ($A=0^\circ$), (b) $A=22^\circ$, (c) $A=26^\circ$ and (d) $A=30^\circ$ respectively.

7.2.3 Double S-Bend Loss

Fig.-7.4 shows the S-bend loss versus H obtained by using (7.14)-(7.16), (where H is height of S-bend in MMI region) for fundamental mode and higher order modes which are excited in MMI region of the proposed structure with $A=20^\circ$, $b=4$ μm, $a=1.5$ μm, wavelength~1.55 μm, cladding index~ 1.45 and $\Delta n=5\%$ respectively. It is seen that S-bending loss for fundamental mode is lowest whereas that for the higher order mode is highest. This is due to more confinement of fundamental mode.
than higher order modes. Since the fundamental mode carry most of the power in MMI region, higher bending loss of higher order mode will not contribute much in the overall bending loss in comparison to TMI coupler. It is also seen that the double S-bend loss increases with H and almost saturates at $H = 11.5 \, \mu m$. So we have chosen $H = 11.5 \, \mu m$.

![Graph](image)

**Fig.-7.4**: Double S-Bend loss versus $H$ of the proposed DB-MMI structure with bending angle $A=26^\circ$ for $h=4 \, \mu m$, $a=b=1.5 \, \mu m$, cladding index~1.45 and $\Delta n \sim 5\%$.

### 7.2.4 Fabrication Tolerances and Polarization Dependence of DBMMI Coupler

Since realization of designed device structure with the exact designed parameters is tricky, it is necessary to study its performance degradation with an unwanted deviation of waveguide parameters during fabrication process. Fig.-7.5 shows the plot of power imbalance in dB [\(=10 \log_{10}(P_3/P_2)\)] versus fabrication tolerance ($\pm \delta w$) of double bend MMI width obtained by using the equations (7.3) and (7.4) with $a=b=1.5 \, \mu m$, index contrast~5 % and cladding index~1.45 for 3dB conventional MMI coupler of $L_{eff}/2 \sim 40 \, \mu m$, 3dB parabolic tapered structure [3] of
L_d/2~23 \mu m, 3dB tooth shaped grating assisted MMI coupler [1] with L_d/2~20 \mu m, 3dB proposed DB-MMI coupler of L_d/2~33.5 \mu m and A=26^0. In all cases, a minimum value of power imbalance is obtained at \( \delta w=0 \mu m \).

\[ \text{Fig. 7.5: Power imbalance characteristics versus MMI width tolerance (}\delta w\text{) for conventional (solid line), proposed structure and parabolic tapered (at the middle) 3dB MMI coupler with cladding index~1.45, h~4 \mu m, } \Delta n~5\%, a=b=1.5 \mu m \text{ and wavelength~1.55 } \mu m. (\ast )\text{- experimental point of 3dB conventional MMI structure, (+)\text{- experimental point of the proposed 3dB DS-MMI coupler with } A=26^0.} \]

Although the longitudinal coupling length of tooth shaped grating assisted structures [1], [18]-[19] is lower than that of the proposed structure, the increase of power imbalance in the former case [18][19] is more than that of the proposed DB-MMI structure due to having more number of designed parameters. The rate of increase of power imbalance with respect to MMI width tolerance \( \frac{\partial}{\partial (\delta w)} \text{[Power} \]
Imbalance (dB) for GA-MMI coupler, conventional MMI coupler, DBMMI coupler are approximately obtained as 0.18 dB/μm, 0.26 dB/μm and 0.25 dB/μm respectively. The black dots and cross signs in the figure represents experimental points (which is discussed later in the section-7.4) of conventional and the proposed structure respectively, that matches well with theoretical curves.

Fig-7.6 shows power imbalance versus wavelength for a~1.5 μm, b~1.5 μm, h~4.0 μm, A=26°, index contrast ~5 % and cladding index~1.45 respectively. In the figure, the dotted line indicates the curve for 3 dB DB-MMI coupler of coupling length ~33.5 μm and the solid line shows for 3 dB conventional MMI coupler of coupling length ~40 μm.

![Power Imbalance vs Wavelength](image)

**Fig-7.6:** Power Imbalance characteristics versus wavelength variation for double band assisted MMI coupler (dotted line), tooth shaped grating assisted MMI coupler (dashed line) and conventional MMI coupler (solid line) with a=1.5 μm, b=1.5 μm, h~4.0 μm, A=26°, index contrast ~5 % and cladding index~1.45.
It is observed from the plot that in both cases minimum power imbalance is obtained at $\lambda \sim 1.55 \mu m$ and it is symmetrically increased in both sides of $\lambda \sim 1.55 \mu m$. The increase of power imbalance for double band MMI coupler is sharp in comparison conventional MMI coupler. The dashed line in the figure represents the variation of power imbalance versus wavelength for GA-MMI coupler. The dependence of power imbalance on fabrication tolerance and wavelength for DB-MMI coupler is almost close to that for conventional MMI coupler.

![Graph showing normalized coupling power distribution for DB-MMI coupler](image)

**Fig-7.7:** Normalized coupling power distribution of DB-MMI coupler for both TE-mode (solid line) and TM-mode (dashed line) with $h=4.0 \mu m$, $A=26^0$, $a=b=1.5 \mu m$, cladding index $\sim 1.45$, $\Delta n=5\%$ and $\lambda \sim 1.55 \mu m$ respectively.

Fig-7.7 shows the normalized coupling power distribution versus longitudinal coupling length of DB-MMI coupler for both TE-mode (solid line) and TM-mode (dashed line) with $h=4.0 \mu m$, $A=26^0$, $a=1.5 \mu m$, $b=1.5 \mu m$, cladding index $\sim 1.45$, $\Delta n=5\%$ and $\lambda \sim 1.55 \mu m$ respectively. It is found that for TM-polarization the value of longitudinal beat length ($L^*_x$) is $\sim 0.24 \%$ more than TE-polarization. The polarization dependence of DB-MMI coupler is slightly more than conventional MMI/TMI
couplers because the number of waveguide parameters in the double band geometry is more than that of conventional structures.

7.3. Dependence of h on \( L_T \) and Longitudinal Beat Length of DBMMI Coupler

In \( N \times N \) photonic matrix switching applications [20][21], it is required to keep maximum access waveguide bending loss of 0.1 dB due to large scale integration. Keeping same access waveguide bending loss, the reduction of longitudinal access waveguide length (\( L_T \)) is studied with increase of coupling gap (h) by using (7.14)-(7.16) for the proposed DB-MMI coupler with \( A=26^\circ \), \( a=b=1.5 \ \mu \text{m} \), index contrast≈5%, cladding index≈1.45, \( H_T=7 \ \mu \text{m} \) and \( R=200 \ \mu \text{m} \) as shown in Fig.-7.8. The cross signs in the figure represents the experimental values of \( L_T \) and longitudinal beat length (\( L'_T \)) for fabricated DB-MMI coupler.

![Figure 7.8](image)

**Fig.-7.8:** Dependence of h on longitudinal beat length and access transition length (\( L_T \)) of the proposed DB-MMI structure with bending angle \( A=26^\circ \) for h=4 \( \mu \text{m} \), \( a=b=1.5 \ \mu \text{m} \), wavelength≈1.55 \( \mu \text{m} \), cladding index≈ 1.45 and \( \Delta n≈5 \% \). The cross sign represents \( L_T \) and longitudinal beat length of fabricated DB-MMI coupler.
The Fig-7.8 also shows the variation of longitudinal beat length with h. It is seen that as h increases longitudinal beat length of DB-MMI region increases whereas L_T decreases with increase of h and the optimum value for h is obtained at the crossing point of the curves (h~4 μm), at which the value of the L_T and L_π are ~63 μm and 67 μm respectively. The device length of the proposed DB-MMI coupler is obtained as (2L_T+L_π)~193 μm. In the figure, the h=0 μm corresponds to the double S-bend two mode interference (DB-TMI) coupler reported by previous authors [6]-[7]. The device length of the DB-TMI coupler is obtained as ~214.2 μm (where L_T~88 μm and L_π~38.2 μm) which is 10 % more than that of the proposed DB-MMI coupler.

7.4. Design Device Parameters

<table>
<thead>
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<th>Design Parameters</th>
<th>DB-MMI Coupler</th>
<th>DB-TMI Coupler</th>
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<tr>
<td>Core waveguide width (a), μm</td>
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<tr>
<td>Core waveguide Thickness (b), μm</td>
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<td>Longitudinal coupling length (L_λ), μm</td>
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<tr>
<td>Access Waveguide length (L_T), μm</td>
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<tr>
<td>Total device length (L_λ+2L_T), μm</td>
<td>193</td>
<td>214.2</td>
</tr>
</tbody>
</table>
Table-7.1 shows the design parameters that is considered for the designed of double band multimode interference (DB-MMI) coupler. For comparison device parameters of DB-TMI coupler are also mentioned in the table.

7.5. Fabrication and Experimental Results

The proposed DB-MMI couplers of width ~7 μm and coupling lengths~ 69 μm, 67 μm, 65 μm for bending angle, A=22°, 26°, 30° respectively and conventional MMI couplers of coupling lengths~80 μm with h=4 μm, a=b=1.5 μm are fabricated by using SiO₂-SiON material[22]-[32] with Δn=5 %. On the top of a silicon substrate, the embedded waveguide including the MMI section and access waveguides of core (SiON) width ~1.5 μm were formed by a combination of plasma enhanced chemical vapour deposition (PECVD), photolithography [28] and reactive ion etching (RIE) [28] process steps as details are discussed in chapter-6. The top cladding layer (SiO₂) of thickness ~3 μm is deposited using PECVD method[27]-[32].

**Fig-7.9:** Power loss measurement set-up
Fig.-7.9 shows the experimental set-up that is used for the measurement of optical power loss of the fabricated devices and the flow chart of fabrication process steps adopted for the development of the proposed device is shown in Fig.-7.10 (details are discussed in previous chapter-6).

Fig.-7.10: Flow chart of fabrication process steps
Fig-7.11: SEM images and corresponding beam spot measurements of (a), (c) conventional MMI coupler of longitudinal coupling length ~79.9 μm, Λ=0° and (b), (d) proposed DB-MMI coupler of longitudinal coupling length ~67.2 μm and Λ=26°.

Fig-7.11(a) shows the SEM photograph of conventional MMI coupler of coupling length ~79.9 μm whereas Fig.-7.11(b) shows SEM image for DB-MMI coupler of coupling length ~ 67.2 μm respectively. The coupling into and out of the devices was made by using tapered and polarization maintaining fibers with focusing lenses, aligned to the chip and tunable stabilized laser diode by six-axis micrometer stages. The output power was detected by the movable germanium p-i-n detector attached with power meter of a minimum detectable power of 100 pW. The output field of waveguide-3 and waveguide-4 are monitored. Further, the waveguide propagation losses are obtained ~ 0.15 dB/cm which is measured for a single planar waveguide of length ~2 cm (with SiON as the core surrounded by silica cladding layer); whereas the fiber to chip loss per facet is less than 1.1 dB that are determined using the relation -10log[(P_{out}/P_{in})]. Fig.-7.11(c) shows beam spot of output access waveguide-4 of conventional MMI coupler recorded by CCD camera at distance 10 cm whereas Fig.-7.11(d) shows the beam spot of access waveguide-4 of DB-MMI coupler recorded by CCD camera at a distance of 10 cm from access waveguide-4. The measured values of cross state and bar state coupling power for the proposed and conventional MMI structure as shown in Fig.-7.2, Fig.-7.5 and Fig.-7.8
are matching well with theoretical curves. The longitudinal beat length \(L^1\) and longitudinal access waveguide length of the proposed MMI coupler for \(A=26^\circ\) obtained experimentally are also close to theoretical values as given in Fig.-7.8. The total device length of the fabricated cross coupling DB-MMI coupler is obtained as \((2L+L_a)=193.2 \, \mu\text{m}\) which is less than that of conventional MMI coupler \((2L+L_a)=213.9 \, \mu\text{m}\). The power imbalance for the proposed DB-MMI coupler and conventional MMI coupler with \(w_m=6.9 \, \mu\text{m}, 7 \, \mu\text{m}\) and \(7.1 \, \mu\text{m}\) is studied experimentally and it is seen that these results are very much close to those obtained theoretically as shown in Fig.-7.5. The accuracy of all these results is within 10%.

7.6. Conclusion

In this chapter, a double S-bend multimode interference (MMI) coupler is proposed and designed for the reduction of coupling length. The coupling characteristics of the proposed structure has been studied theoretically by using simple effective index method based sinusoidal modes and compared with those of the conventional MMI structure experimentally. Both the longitudinal access waveguide length and beat length of the double S-bend MMI (DB-MMI) coupler are optimized at access waveguide gap \(h=4 \, \mu\text{m}\). The designed DB-MMI coupler and conventional MMI coupler are realized with silica waveguides using SiON as the core layer. It is seen both theoretically and experimentally, that the device length of the DB-MMI coupler is \(~19\%\) and \(10\%\) less than that of a conventional MMI coupler and existing DB-TMI coupler [6]-[7] respectively. The variation of power imbalance on fabrication tolerance of the proposed geometry is almost close to that of the conventional MMI coupler and less than that of other MMI structures.

References:


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