Chapter 5

Optically controlled, tunable power splitter based on SPTMI waveguide coupler

Contents

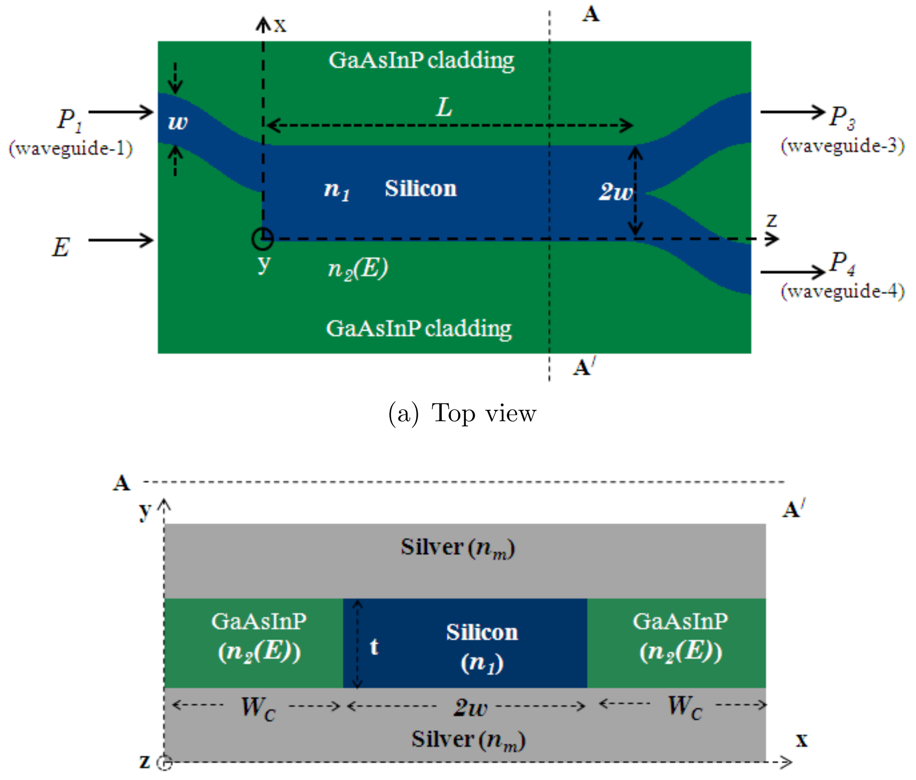
5.1 Introduction

Compact optical power splitters are indispensable components of integrated optical processor for distribution of power among its building blocks. In this direction, tunable optical power splitters are useful for dynamical redistribution and efficient management of optical power in various optoelectronic devices. All-optical control of splitting ratio has become essential for faster operation of these devices. During the last decade, there has been considerable progress in the research for optical power splitter devices. There have been many approaches to implement optical power splitters such as branching waveguide with microprism [92], MMI couplers [93–96], microelectromechanical system [97], mode converters [98], surface plasmonic waveguide [31, 52, 57, 99, 100, 102–106, 132] etc. But in most of them, the splitting ratio is either fixed [31, 52] or manually tuned [92, 96, 98]. Although some reported works could provide tunability, these works have some disadvantages such as larger device size [93, 94, 97, 98], only selective splitting ratio [95, 103], narrow tuning range [92], necessity to vary device size or length to achieve variation of power splitting ratio [57, 102, 105] etc.

In this chapter, we have proposed a compact 3dB optical power splitter with optically-tunable splitting ratio, based on the surface plasmonic two-mode interference (SPTMI) waveguide coupler discussed in chapter 3. Using a single 1×2 SPTMI structure, splitting of input optical power is achieved. The splitting ratio of the proposed power splitter depends on the energy of optical pulse applied at the GaAsInP cladding of the SPTMI waveguide coupler. By increasing the energy of applied optical pulse, tunability of the proposed power splitter is achieved and the splitting ratio of the power splitter can be varied from the 3dB coupling.

5.2 Optical power splitter based on surface plasmonic TMI waveguide

Fig-5.1 shows the schematic view of our proposed optical power splitter based on SPTMI waveguide coupler which is discussed in chapter 3. The proposed structure consists of a two-mode coupling region of core width $2w = 0.48\mu m$, core thickness $t = 5.0\mu m$ and length L and one single mode input access waveguide and two single mode output access waveguides having core width $w = 0.24\mu m$ and core thickness $t = 5.0\mu m$. The core material is silicon with refractive index



(a) Top view

(b) Cross sectional view along $AA^/$

Figure 5.1: Two dimensional schematic view of the optical power splitter based on 1×2 SPTMI waveguide coupler.

n_1 and the claddings are made up of GaAsInP (refractive index $n_2(E)$) on the left and right side and silver (refractive index n_m) on upper and lower side. The input power P_1 is launched into TMI region through input access waveguide-1, whereas optical pulse of energy E and width T_P is applied at the GaAsInP cladding. The output power at access waveguide-3 and waveguide-4 are obtained as P_3 and P_4 respectively.

When an input power is incident at the input access waveguide-1, SPP fundamental and first order modes are excited in the coupling region and those excited modes propagate along the coupling region with different phase velocities. The complex propagation constants of the fundamental mode ($\beta_0(n_2(E))$) and first order mode ($\beta_1(n_2(E))$) can be expressed as

$$\beta_0(n_2(E)) = \beta_0^r(n_2(E)) + j\beta_0^{im}(n_2(E)) \tag{5.1}$$

$$\beta_1(n_2(E)) = \beta_1^r(n_2(E)) + j\beta_1^{im}(n_2(E)) \tag{5.2}$$

where, $\beta_0^r(n_2(0))$ and $\beta_1^r(n_2(0))$ are the real parts of propagation constant of fundamental mode and first order mode respectively and $\beta_0^{im}(n_2(0))$ and $\beta_1^{im}(n_2(0))$

are the imaginary parts of propagation constant of fundamental mode and first order mode respectively. The phase difference of the two propagating SPP modes at $z = L$ at the end of the coupling region is given by

$$\Delta\Phi_T(0) = [\beta_0^r(n_2(0)) - \beta_1^r(n_2(0))]L \tag{5.3}$$

As discussed in section 3.4.3 of chapter 3, the normalized power coupled to the output access waveguides can be expressed as

$$\frac{P_3}{P_1} = \cos^2\left(\frac{\Delta\Phi_T(0)}{2}\right)\exp[-2(\beta_0^{im}(n_2(0)) - \beta_1^{im}(n_2(0))L] \tag{5.4}$$

$$\frac{P_4}{P_1} = \sin^2\left(\frac{\Delta\Phi_T(0)}{2}\right)\exp[-2(\beta_0^{im}(n_2(0)) - \beta_1^{im}(n_2(0))L] \tag{5.5}$$

The dependence of normalized cross state power (P_4/P_1) and bar state power (P_3/P_1) of the 1×2 SPTMI waveguide coupler based optical power splitter on the length L of two-mode coupling region is shown in Fig-5.2 for $2w = 0.48\mu m$, $t = 5.0\mu m$, $n_1 = 3.5$, $n_2(0) = 3.17$, $n_m = 0.394 + 8.2j$ and $\lambda = 1.33\mu m$. It is seen

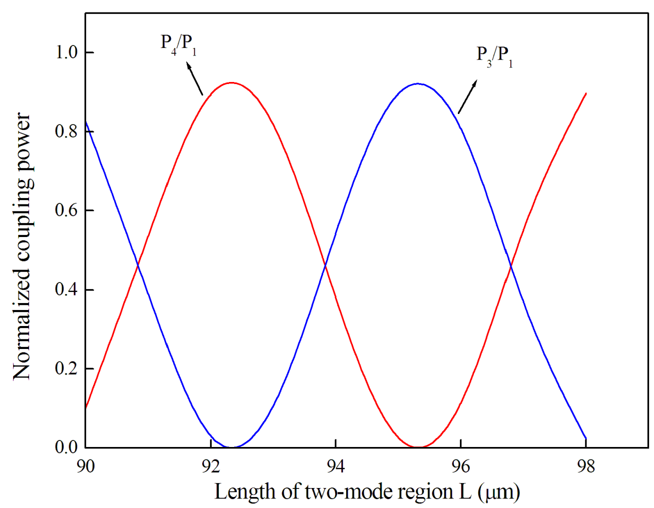


Figure 5.2: Variation of normalized coupling power for SPTMI based optical power splitter versus length of two-mode region with $2w = 0.48\mu m$, $t = 5.0\mu m$, $n_1 = 3.5$, $n_2(0) = 3.17$, $n_m = 0.394 + 8.2j$ and $\lambda = 1.33\mu m$

that for $L = 92.35\mu m$, all the power in the two mode coupling region is coupled to the waveguide-4 (cross port) and no power is coupled to the waveguide-3 (bar port). This corresponds to cross state coupling of the device. For $L = 93.85\mu m$, almost equal power is coupled to both the cross state and bar state output waveguides (3dB coupling) and the splitting ratio is $\sim 50\% : 50\%$. For

$L = 95.35\mu m$, the device shows bar state coupling where, all the power in the two-mode coupling region is coupled to the waveguide-3 (bar port) and no power is coupled to the waveguide-4 (cross port).

Considering values of L in the range from $L = 92.35\mu m$ to $L = 95.35\mu m$, any desired value of splitting ratio can be obtained from 1% : 99% to 99% : 1% (considering P_3/P_4) and from 99% : 1% to 1% : 99% (considering P_4/P_3). Fig-5.3 shows the variation of the splitting ratio (P_3/P_4) of SPTMI based optical power splitter with respect to length of two-mode coupling region (L) with $2w = 0.48\mu m$, $t = 5.0\mu m$, $n_1 = 3.5$, $n_2(0) = 3.17$, $n_m = 0.394 + 8.2j$ and $\lambda = 1.33\mu m$ for L variation in the range from $L = 92.35\mu m$ to $L = 93.9\mu m$.

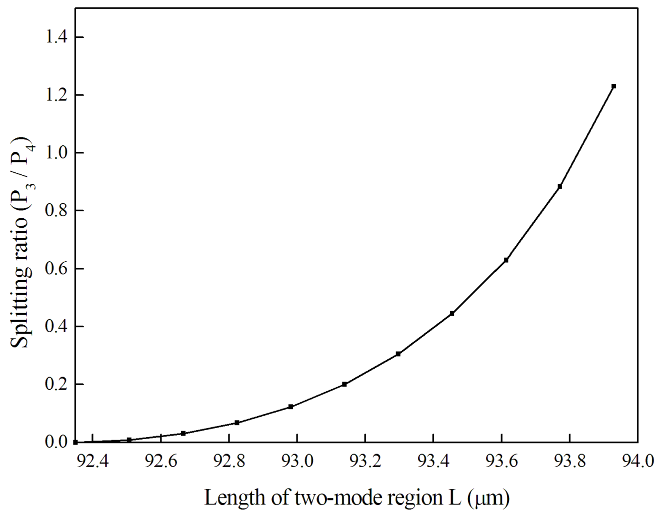


Figure 5.3: Variation of splitting ratio (P_4/P_3) of SPTMI based optical power splitter versus length of two-mode region with $2w = 0.48\mu m$, $t = 5.0\mu m$, $n_1 = 3.5$, $n_2(0) = 3.17$, $n_m = 0.394 + 8.2j$ and $\lambda = 1.33\mu m$

It is seen from the Fig-5.2 and Fig-5.3 that equal amount of power is transferred to bar state output waveguide-3 (P_3/P_1) and cross state output waveguide-4 (P_4/P_1) corresponding to a length of $L = 93.85\mu m$ and a power splitting ratio of almost 50% : 50% is obtained. Thus, the 1×2 SPTMI waveguide coupler behaves as a 3dB power splitter for $L = 93.85\mu m$.

On the other hand, the 1×2 SPTMI waveguide coupler functions as an optical power splitter with splitting ratio 10% : 90% for two-mode region length given by $L = 92.9\mu m$ and an optical power splitter with splitting ratio 1% : 99% for two-mode region length given by $L = 92.5\mu m$.

5.3 Optical pulse dependent variable splitting ratio in 3dB Optical power splitter

When an optical pulse is applied to the GaAsInP cladding of the SPTMI waveguide coupler based 3dB optical power splitter, refractive index modulation of GaAsInP cladding occurs. The change in refractive index of GaAsInP cladding with application of optical pulse of energy E and width T_P can be given as [124]

$$\Delta n_2(E) = n_2(E) - n_2(0) = \frac{n_{nl}E}{1.605 A_{clad} T_P} \tag{5.6}$$

where, $n_2(0) = 3.17$ is the refractive index of GaAsInP cladding in the absence of optical pulse energy, $n_{nl} = -2 \times 10^{-3} \mu m^2 W^{-1}$ is the nonlinear coefficient of GaAsInP and A_{clad} is the effective area of GaAsInP cladding on which the optical pulse is applied.

Due to this nonlinear change of cladding refractive index, an additional phase change is introduced between the SPP fundamental and first order modes propagating through the two-mode region, the magnitude of which depends on the energy of optical pulse. The phase difference between the two SPP modes after application of optical pulse of energy E can be written as

$$\Delta\Phi_T(E) = [\beta_0^r(n_2(E)) - \beta_1^r(n_2(E))]L \tag{5.7}$$

As already discussed in section 3.4 of chapter 3, above equation for the phase difference between the two SPP modes after application of optical pulse energy can be written as

$$\Delta\Phi_T(E) = [\beta_0^r(n_2(0)) - \beta_1^r(n_2(0))]\, L + \frac{2\pi L}{\lambda}\left[\Delta n_{1,r}^{eff}(E) - \Delta n_{0,r}^{eff}(E)\right] \tag{5.8}$$

The first term of above equation gives the phase difference of SPP modes without application of optical pulse energy, whereas the second term gives the additional phase difference introduced as a result of application of optical pulse of energy E.

The normalized power at the bar port and cross port of the 1×2 SPTMI waveguide coupler can be expressed as

$$\frac{P_3}{P_1} = \cos^2\left(\frac{\Delta\Phi_T(E)}{2}\right)\exp[-2(\beta_0^{im}(n_2(E)) - \beta_1^{im}(n_2(E))L] \qquad (5.9)$$

$$\frac{P_4}{P_1} = \sin^2\left(\frac{\Delta\Phi_T(E)}{2}\right)\exp[-2(\beta_0^{im}(n_2(E)) - \beta_1^{im}(n_2(E))L] \qquad (5.10)$$

It is evident from equation (5.9) and (5.10) that as the energy E of applied optical pulse increases, the normalized cross state power and normalized bar state power will vary periodically with the peak power decreasing exponentially.

Fig-5.4 shows the variation of normalized cross state power (P_4/P_1) and bar state power (P_3/P_1) of the 3dB optical power splitter based on 1×2 SPTMI waveguide coupler with respect to energy of optical pulse (E) applied at the GaAsInP cladding, with the device parameters $2w = 0.48\mu m$, $t = 5.0\mu m$, $L = 93.85\mu m$, $n_1 = 3.5$, $n_2(0) = 3.17$, $n_m = 0.394 + 8.2j$ and $\lambda = 1.33\mu m$ and for $A_{clad} = 2.0\mu m^2$, $2.5\mu m^2$ and $3.0\mu m^2$. In the absence of optical pulse at GaAs-

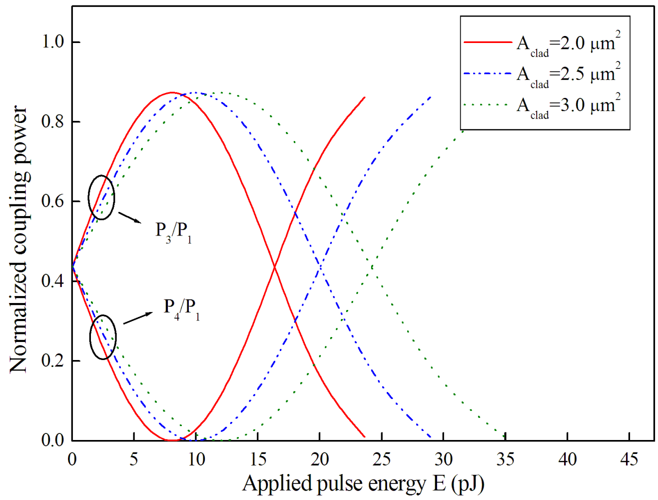


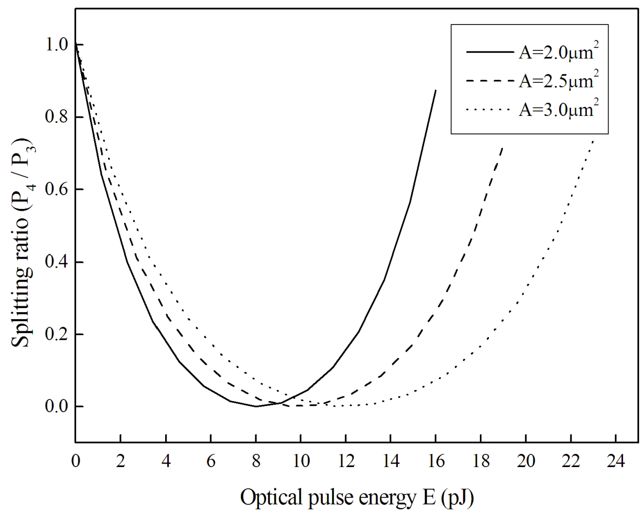
Figure 5.4: Normalized cross state power (P_4/P_1) and bar state power (P_3/P_1) versus energy of applied optical pulse for SPTMI waveguide coupler based 3dB optical power splitter with $2w = 0.48\mu m$, $t = 5.0\mu m$, $L = 93.85\mu m$, $n_1 = 3.5$, $n_2(0) = 3.17$, $n_m = 0.394 + 8.2j$ and $\lambda = 1.33\mu m$

InP cladding, power in the two-mode coupling region is transferred equally to the output access waveguide-3 and output access waveguide-4 ($P_3/P_1 \approx P_4/P_1$) which corresponds to a 3dB coupling state. Thus for $E = 0$, the device gives a 50% : 50% power splitting ratio. When an optical pulse is applied at the GaAsInP cladding and the energy is gradually increased, power transferred to output access waveguide-3 (P_3/P_1) increases and power transferred to output access waveguide-4 (P_4/P_1) decreases. The energy of applied optical pulse required for P_3/P_1 to reach a maximum and P_4/P_1 to reach zero, i.e., to change the 3dB coupling state to bar state coupling is $E = 8pJ$ for $A_{clad} = 2.0\mu m^2$. The energies of optical pulse required to change the 3dB coupling state to bar state coupling for $A_{clad} = 2.5\mu m^2$ and $3.0\mu m^2$ are $E = 10pJ$ and $12pJ$ respectively. To ensure compactness of the device and lower power consumption, we have taken $A_{clad} = 2.0\mu m^2$ as the effective cladding area for the SPTMI waveguide coupler. By varying the energy of optical pulse applied to GaAsInP cladding in the range from $E = 0$ to $E = 8.0pJ$, power splitting ratio variation can be obtained in the range 50% : 50% to 1% : 99% ($P_4 : P_3$) and 50% : 50% to 99% : 1% ($P_3 : P_4$).

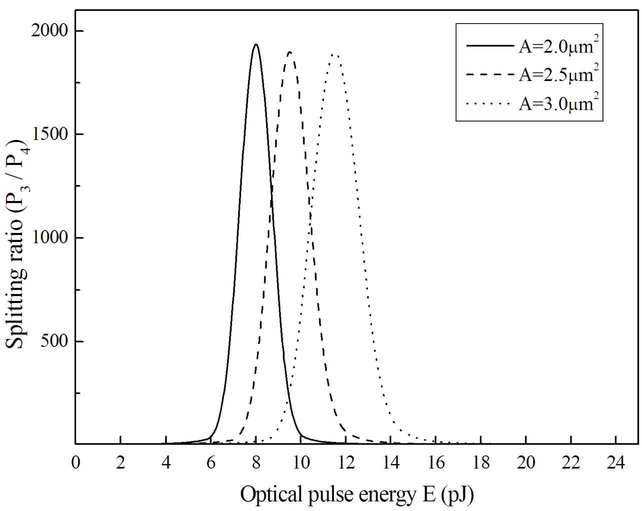
The variation of power splitting ratio (P_3/P_4 and P_4/P_3) of the 1×2 SPTMI waveguide coupler based 3dB power splitter with respect to optical pulse energy E with $2w = 0.48\mu m$, $t = 5.0\mu m$, $L = 93.85\mu m$, $n_1 = 3.5$, $n_2(0) = 3.17$, $n_m = 0.394 + 8.2j$ and $\lambda = 1.33\mu m$ and different cladding area $A_{clad} = 2.0\mu m^2$, $2.5\mu m^2$ and $3.0\mu m^2$ are shown in Fig-5.5. Fig-5.5(a) shows the variation of P_4/P_3 with respect to E, whereas Fig-5.5(b) shows the variation of P_3/P_4 with respect to E. Initially, when no optical pulse is applied in the nonlinear cladding of the SPTMI waveguide coupler, the coupler gives 3dB splitting and the power splitting ratio is 50% : 50% (seen from Fig-5.5(a) and Fig-5.5(b)). When the optical pulse energy increases gradually, variation of splitting ratio is observed with variation in the energy of optical pulse. For $A_{clad} = 2.0\mu m^2$, the splitting ratio changes gradually from 50% : 50% to 1% : 99% (considering P_4/P_3, as seen in Fig-5.5(a)) and from 50% : 50% to 99% : 1% (considering P_3/P_4, as seen in Fig-5.5(b)), when the optical pulse energy is varied in the range $E = 0 - 8pJ$. The optical pulse energy required to change the splitting ratio from 50% : 50% to 1% : 99% (P_4/P_3) and from 50% : 50% to 99% : 1% (P_3/P_4) for $A_{clad} = 2.5\mu m^2$ and $3.0\mu m^2$ are given as $E = 10pJ$ and $12pJ$ respectively (obtained from Fig-5.5).

5.4 Fabrication tolerance

Because it may be difficult to fabricate a device with exact design parameters, it is required to study the performance degradation of the device with small unwanted variations in the device parameters. We have studied the effect of fabrication tolerances of core width (δw) of the proposed 3dB optical power splitter based on SPTMI waveguide coupler, on the power transmission defined as $(P_3+P_4)/P_1$. The variation of the power transmission in dB ($10log((P_3+P_4)/P_1)$)



(a) Splitting ratio P_4/P_3 versus applied optical pulse energy



(b) Splitting ratio P_3/P_4 versus applied optical pulse energy

Figure 5.5: Variation of power splitting ratio of SPTMI waveguide coupler based 3dB optical power splitter versus optical pulse energy with $2w = 0.48\mu m$, $t = 5.0\mu m$, $L = 93.85\mu m$, $n_1 = 3.5$, $n_2(0) = 3.17$, $n_m = 0.394+8.2j$, $\lambda = 1.33\mu m$ and $A_{clad} = 2.0\mu m^2$, $2.5\mu m^2$ and $3.0\mu m^2$

with respect to deviations in core width (δw) with $2w = 0.48\mu m$, $t = 5.0\mu m$, $L = 93.85\mu m$, $n_1 = 3.5$, $n_2(0) = 3.17$, $n_m = 0.394 + 8.2j$ and $\lambda = 1.33\mu m$ for the SPTMI waveguide coupler based 3dB optical power splitter is shown in Fig-5.6. The figure also shows the power transmission in dB for a previously reported 3dB optical power splitter based on MMI coupling in Silicon hybrid plasmonic waveguide with respect to width variations [57]. It is evident from the figure that, the power transmitted to output waveguides in the proposed optical power splitter ($\sim -0.347dB$) is about 1.18 times higher than the transmission in the

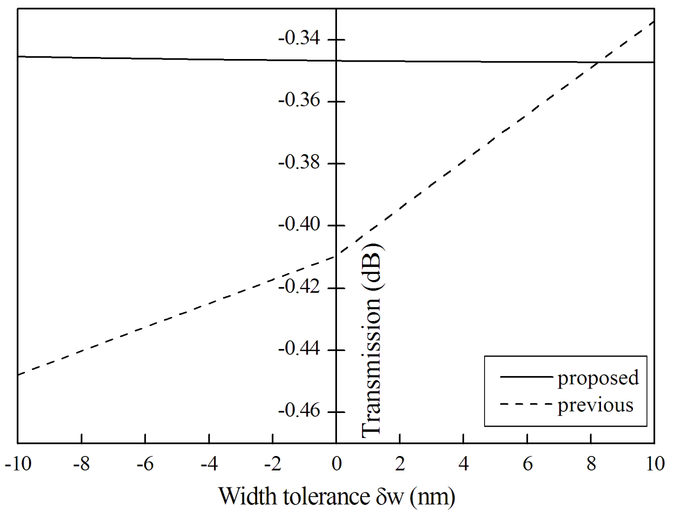


Figure 5.6: Power transmission versus width tolerance of the 1×2 SPTMI waveguide coupler based 3dB power splitter with $2w = 0.48\mu m$, $t = 5.0\mu m$, $L = 93.85\mu m$, $n_1 = 3.5$, $n_2(0) = 3.17$, $n_m = 0.394 + 8.2j$, $\lambda = 1.33\mu m$ and a previously reported device

previously reported device ($\sim -0.41dB$) [57]. Moreover, the rate of variation of transmission with respect to deviation in core width for the SPTMI waveguide coupler based splitter is less than the previously reported optical power splitter.

5.5 Design of bend of access waveguides

Fig-5.7 shows the top schematic view of the proposed 3dB optical power splitter based on 1×2 SPTMI waveguide coupler (shown in Fig-5.1) with access waveguides of transition length (L_T), bending height (H_T) and bending radius (R). As

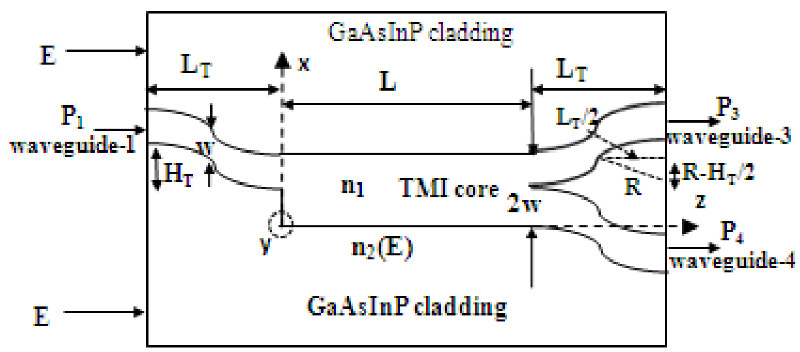


Figure 5.7: Top schematic view of 1×2 SPTMI waveguide coupler based optical power splitter showing access waveguide bends

discussed in section 3.4.4 of chapter 3, the transition length L_T can be expressed in terms of bending height H_T and bending radius R as

$$L_T \approx \sqrt{4H_T R} \tag{5.11}$$

whereas, the S-bending loss for input and output access waveguides can be expressed as

$$\text{S-bending loss} = 8.686\alpha R \cos^{-1}\left[1 - \frac{H_T}{2R}\right] \tag{5.12}$$

where α is the loss coefficient depending on R and can be estimated as $\alpha = 3.997 \times 10^{-6}$ [122].

As already discussed in section 3.4.4 of chapter 3, the bending height corresponding to a bending radius of $R = 39\mu m$ and access waveguide S-bending loss of $\sim 0.1dB$ is estimated from equation (5.12) as $H_T = 4\mu m$. Thus, considering an access waveguide S-bending loss of $\sim 0.1dB$ and taking a bending radius (R) of $39\mu m$ and bending height (H_T) of $4\mu m$, the transition length L_T of the input and output access waveguides can be estimated as

$$L_T \approx \sqrt{4 \times 4 \times 39} \approx 24.97\mu m$$

As seen from Fig-5.7, the total length of the device is the combined length of the coupling region and the transition length of the input and output access waveguides. The total device length can be estimated as

$$L_D = L + 2L_T \approx 93.85 + 2 \times 24.97 \approx 143.79\mu m$$

where, $L = 93.85\mu m$ is the length of two-mode coupling region for 3dB coupling, as mentioned in section 5.2. The total length of the device is found to be about $\sim$ 1.4 times compact than a variable optical power splitter based on mode converter [98] reported previously.

5.6 Optical power launching efficiency to the SPTMI waveguide coupler

The optical power launching efficiency can be defined as the amount of optical power emitted from the source that can be coupled into a fiber. Fig-5.8 shows the three dimensional schematic view of the proposed 3dB optical power splitter based on 1×2 SPTMI waveguide coupler (shown in Fig-5.1) consisting of two-mode coupling region of core width $2w = 0.48\mu m$, core thickness $t = 5.0\mu m$ and length $L = 93.85\mu m$ and one single mode input access waveguide and two single mode output access waveguides having core width $w = 0.24\mu m$ and core thickness $t = 5.0\mu m$. The optical power launching efficiency to waveguide core

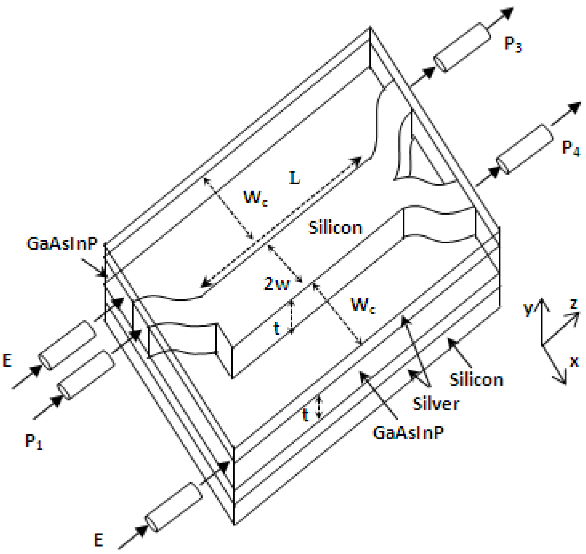


Figure 5.8: 3D schematic view of 1×2 SPTMI waveguide coupler based optical power splitter showing power launching by optical fiber

and GaAsInP cladding via optical fibers, as shown in Fig-5.8, can be estimated as follows.

Optical power launching efficiency to waveguide core

The optical power launching efficiency to waveguide core via optical fiber of core radius r can be written as [126]

$$\eta_{core} = \frac{A_{core}}{\pi r^2}(NA_{core})^2 \qquad (5.13)$$

Here, A_{core} is the cross sectional area of access waveguide core which can be estimated as $A_{core} = (0.24 \times 5.0)\mu m^2 = 1.2\mu m^2$. $NA_{core} = \sqrt{n_1^2 - n_{m,real}^2}$ is the numerical aperture of core where, $n_1 = 3.5$ and $n_{m,real} = 0.394$. Hence, the optical power launching efficiency to waveguide core via optical fiber of core radius $r = 2.2\mu m$ can be estimated as

$$\begin{aligned} \eta_{core} &= \frac{1.2}{3.14 \times 2.2^2} \times (3.5^2 - 0.394^2) \\ &= \frac{1.2}{3.14 \times 4.84} \times 12.09476 \\ &\approx 0.955 \end{aligned}$$

Optical power launching efficiency to GaAsInP cladding

The optical power launching efficiency to GaAsInP cladding via optical fiber of core radius r can be written as [126]

$$\eta_{clad} = \frac{A_{clad}}{2\pi r^2}(NA_{clad})^2 \tag{5.14}$$

where, $A_{clad} = 2.0\mu m^2$ is the effective cross sectional area of GaAsInP cladding, as discussed in section 5.3. $NA_{clad} = \sqrt{n_2(0)^2 - n_{m,real}^2}$ is the numerical aperture of GaAsInP cladding where, $n_2(0) = 3.17$, $n_{m,real} = 0.394$. Hence, the optical power launching efficiency to GaAsInP cladding via optical fiber of core radius $r = 1.8\mu m$ can be estimated as

$$\begin{aligned} \eta_{clad} &= \frac{2.0}{2 \times 3.14 \times 1.8^2} \times (3.17^2 - 0.394^2) \\ &= \frac{2.0}{2 \times 3.14 \times 3.24} \times 9.89366 \\ &\approx 0.972 \end{aligned}$$

5.7 Design summary for the 3dB optical power splitter with optical pulse controlled splitting ratio

We have designed a 3dB optical power splitter with optical pulse controlled variable splitting ratio using the surface plasmonic TMI (SPTMI) waveguide coupler discussed in chapter 3. Table-5.1 gives the design parameters of the proposed SPTMI waveguide coupler based tunable optical power splitter shown in Fig-5.7.

Table 5.1: Device parameters for 3dB optical power splitter

Device parameters	Values
Core (silicon) refractive index (n_1)	3.5
Metal (silver) cladding refractive index (n_m)	$0.394 + 8.2j$
Side (GaAsInP) cladding refractive index ($n_2(0)$)	3.17
Side (GaAsInP) cladding nonlinear coefficient (n_{nl})	$-2 \times 10^{-3} \mu m^2 W^{-1}$
Wavelength of operation (λ)	$1.33\mu m$
Core width ($2w$)	$0.48\mu m$
Core thickness (t)	$5.0\mu m$
Full width at half maximum of optical pulse (T_P)	$1ps$
Bending radius of access waveguides (R)	$39\mu m$
Bending height of access waveguides (H_T)	$4\mu m$
Transition length of access waveguides (L_T)	$24.97\mu m$
Length of coupling region (L)	$93.85\mu m$
Device length	$143.79\mu m$
Width of GaAsInP cladding (W_C)	$0.2\mu m$
Area of GaAsInP cladding (A_{clad})	$2.0\mu m^2$

5.8 Comparison of proposed SPTMI based tunable power splitter with previous works

The proposed structure has been able to address the major disadvantages in the previously reported optical power splitting devices such as larger device size and fixed or manually tunable splitting ratio. The length of the coupling region for the proposed SPTMI waveguide coupler based 3dB tunable optical power splitter is $93.85\mu m$ which is about ~ 11.5 times less than that for a previously reported variable optical power splitter based on MMI couplers with multimode waveguide holograms [93]. The device length of the proposed SPTMI waveguide coupler based 3dB tunable optical power splitter is $143.79\mu m$ which is about ~ 69.5 times less than a previously reported variable optical power splitter based on microelectromechanical system [97] and about ~ 1.4 times less than a previously reported variable optical power splitter based on mode converters [98].

In most of the previous works, the tuning of optical power splitting ratio can be achieved by variation of length of the device or the length or width of a component of the device [57, 102, 105] or by manually adjusting some other device parameters [92, 96, 98]. The optical pulse controlled 3dB power splitter proposed in this thesis does not require the variation in the device parameters for tunability of power splitting ratio, but the tunability can be achieved by increasing or decreasing the energy of optical pulse applied at the nonlinear GaAsInP cladding. As such, a dynamic and wide range of tunability is achieved. This is another advantage over previous devices which could offer only some specific values for power splitting ratio [95, 103] or a narrow range of tunability of power splitting ratio [92].

The power consumption in the 3dB power splitter with tunable splitting ratio is $\sim 0-8pJ$ which is close to optical pulse energy required for changing of the power splitting ratio. Moreover, because the recovery time of refractive index change of GaAsInP cladding with application of optical pulse is $\sim 1ps$, the operating time of the optical power splitter is almost as same as recovery time of nonlinearity in refractive index of GaAsInP i.e., of the order of picoseconds. The advantages of the proposed tunable power splitter based on 1×2 SPTMI waveguide coupler is summarized in the following Table-5.2.

Table 5.2: Comparison of proposed device with previous works

Parameter	**Proposed device**	**Comparison to previous work**
Coupling length	$93.85\mu m$	coupling length= $1080\mu m$ ($\sim$ 11.5 times) and width= $24\mu m$ ($\sim$ 27.3 times) [93]
Device length	$143.79\mu m$	$10mm$($\sim$ 69.5 times) [97]
		$200\mu m$ ($\sim$ 1.3 times) [98]
Tuning of power splitting ratio	By varying energy of optical pulse applied	Depends on device architecture [57, 102, 105]
		Manual tuning [92, 96, 98]
Tuning range	Dynamic and wide tuning range	Specific values [95, 103]

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Table 5.2 – continued from previous page

Parameter	Proposed device	Comparison to previous work
	(50% : 50% to 1% : 99% or 99% : 1%)	Narrow range [92]
Power consumption	0-8pJ	-
Operating time	Of the order of picoseconds	-

5.9 Conclusion

In this chapter, an optically-tunable 3dB power splitter has been designed using the surface plasmonic two-mode interference (SPTMI) waveguide coupler. The power splitting ratio in the 1×2 SPTMI waveguide coupler based 3dB optical power splitter depends on the energy of optical pulse applied at the GaAsInP cladding of the SPTMI waveguide coupler. By increasing the energy of applied optical pulse, tunability of the proposed power splitter is achieved and the power splitting ratio can be varied in a wide range from 50% : 50% (3dB state) to 1% : 99% or 99% : 1% by varying the energy of optical pulse from 0 to 8pJ.

The length of the coupling region of the 1×2 SPTMI waveguide coupler based 3dB tunable optical power splitter is obtained as 93.85μm which is about $\sim$ 11.5 times less than that of a previously reported variable optical power splitter [93]. The device length of the proposed 3dB tunable optical power splitter is 143.79μm which is about $\sim$ 69.5 times [97] and $\sim$ 1.4 times [98] less than previously reported works on variable optical power splitter. The proposed device is free from some major disadvantages seen in previous works such as narrow tuning range [92], selective splitting ratio [95, 103] and need of varying device parameters for tunability [57, 102, 105]. The power consumption in the device is $\sim 0 - 8pJ$, whereas the operating time is of the order of picoseconds.