InP Laterally Tapered Wide-bandwidth Optical Power Splitter

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Abstract: A new optical power splitter design utilizing laterally coupled tapered waveguides with small size, low splitting loss and arbitrary splitting ratio is designed and fabricated in InP. The splitter loss of dependence of wavelength is about 0.1dB over 100nm.

OCIS codes: (130.1750) Components, (130.3120) Integrated optics devices

Introduction:

The capability of integrating active and passive components on the same chip [1] allows the implementation of Photonic Integrated Circuits for innumerous applications. The optical power splitter is a fundamental element in PICs; in order to increase the complexity and device density of InP-based PICs, splitters with small footprint and low excess loss must be developed. Additionally, wide optical bandwidth and splitting-ratio tunability are critical.

In this paper, we report a new kind of splitter that utilizes three laterally coupled tapered waveguides. This splitter has advantages over other three-waveguide designs, due to the lateral tapering: the structure is compact and its splitting characteristic is wavelength insensitive. The operating principle and simulation and experimental results are presented next.

Power Splitter Design and Operating Principle:

The power splitter is composed of three laterally tapered, coupled waveguides as shown in Figure 1a. As the input beam of light propagates towards the pinched-off end of the input waveguide, its mode field diameter is adiabatically increased, resulting in an increasing coupling to the other two waveguides. The latter are also tapered and adiabatically transform the mode back to its original size. The optical fields in the three waveguides can be expressed by [2]

$$\vec{E} = A_1(z)\vec{E}_1 + A_2(z)\vec{E}_2 + A_3(z)\vec{E}_3 \qquad (1)$$

$$\vec{H} = A_1(z)\vec{H}_1 + A_2(z)\vec{H}_2 + A_3(z)\vec{H}_3 \qquad (2)$$

where E_1, E_2, E_3, and H_1, H_2, and H_3 are the unperturbed electric and magnetic fields of the three waveguides respectively. $A_1(z)$, $A_2(z)$, *and* $A_3(z)$ represent the change of field amplitude with distance.

Substituting the total electric and magnetic fields $\vec{E}$, $\vec{H}$ into Maxwell's equations and introducing the wave amplitudes $a_\nu = A_\nu e^{-i\beta_\nu z}$ $\nu = 1,2,3$ we obtain the coupled wave equations represented by a_ν, instead of A_ν.

$$\partial a_1 / \partial z = -i\beta_1 a_1 + iC_{12} a_2 \qquad (3)$$

$$\partial a_2 / \partial z = -i\beta_2 a_2 + iC_{21} a_1 + iC_{23} a_3 \qquad (4)$$

$$\partial a_3 / \partial z = -i\beta_3 a_3 + iC_{32} a_2 \qquad (5)$$

We assume the propagation constants of the three waveguide to be identical ($\beta_1 = \beta_2 = \beta_3$) and the coupling coefficients C_{12}, C_{21}, $C_{23,}$ C_{32} independent of z, assumptions approximately satisfied. Taking $a_1(0) = a_3(0) = 0$, equations (3), (4), and (5) have the solution

$$a_1(z) = i\frac{C_{12}}{\Delta\beta} a_2(0)\sin(\Delta\beta z)e^{-i\beta z} \tag{6}$$

$$a_3(z) = i\frac{C_{32}}{\Delta\beta} a_2(0)\sin(\Delta\beta z)e^{-i\beta z} \tag{7}$$

$$a_2(z) = a_2(0)\cos(\Delta\beta z)e^{-i\beta z} \tag{8}$$

with

$$\Delta\beta = \sqrt{C_{12}C_{21} + C_{23}C_{32}}$$

This solution shows clearly the periodic exchange of power between guide 2 to and the others. The length for complete transfer is given by

$$\Delta\beta z = \frac{\pi}{2} \tag{9}$$

Characteristics and Results:

A BPM simulation of the device is shown in Figure 1b. The waveguides are single-mode, with width 1.3μm. The width at the tapers' ends is 0.2μm. The splitter length is about 200μm. The coupling coefficients C_{12}, C_{21}, $C_{23,}$ C_{32} increase along the propagation due to the increase in mode widths caused by the tapers. The device, thus, results very short. The optical field is transformed adiabatically, resulting in very low radiation loss. Figure 2 shows the output power for one of the splitter's arms, for wavelengths between 1.5μm and 1.6μm.

a) Splitter

b) Simulation

Fig. 1. The picture of optical splitter of coupled tapered waveguides and splitting result of BPM simulation

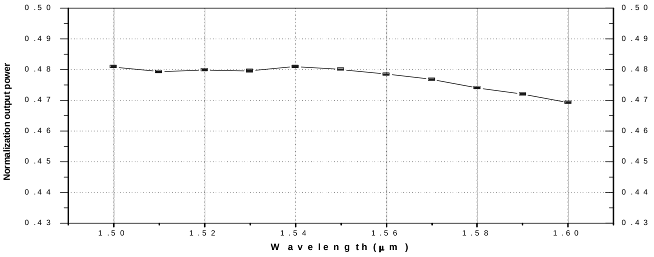

Fig. 2. Dependence of output power of 3dB splitter with coupled tapered waveguides on wavelength

The splitter loss curve is very flat over 60nm, with loss around 0.2dB. The maximum loss is about 0.3dB, thus the overall change is only 0.1dB over 100nm wavelength space.

The design described above has been fabricated as part of an SOA-based wavelength converter in InP. Figure 3 shows a near-field image of ASE light from the splitter's outputs. The ASE stems from an integrated SOA at the input. The distance between the two spots is 250µm.

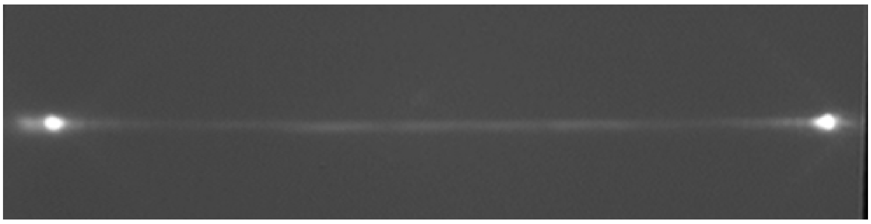

Fig. 3. The near field image of the 3dB splitter. The space between two spots is 250µm.

Summary:

A new type of optical power splitter for PIC has been developed. Since it utilizes coupled waveguide way to split and combine light, its splitting loss is very low. Tapered waveguides lead to improved power transfer from one waveguide to another, reduced coupler length, and wavelength insensitivity. It is thus a very useful element for PICs, especially in wideband application.

[1] Erik J. Skogen, Jonathon S. Barton, Seven P. DenBaars, and Larry A. Coldren, "Tunalbe Sampled-grating DBR Lasers Using Quantum-Well Intermixing," IEEE Photo. Technol. Lett., vol. 14, pp.1243-1245, Sept. 2002.
[2] Dietrich Marcuse, "Light Transmission Optics" Chapter 10. (1972).