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Singlemode 1×3 integrated optical branching circuit design using microprism

H.-B. Lin, Y.-H. Wang and W.-S. Wang

Indexing terms: Optical couplers, Integrated optics, Optical waveguides

A novel design for a symmetric singlemode 1×3 integrated optical branching circuit as a power divider using microprisms is proposed. By varying the index of the microprisms, power can be equally and efficiently transmitted to the three output ports at a large branching angle.

Introduction: Branching waveguides are important and essential components in integrated optical systems as power dividers and switch arrays. For the 1×3 optical branching waveguide structure, Belanger *et al.* [1] demonstrated that for sufficiently large branching angle, there is more power in the centre branch than the others. Many subsequent proposals have been suggested to devise symmetric 1×3 branching waveguide with equal power division. Among these works, Haruna *et al.* [2] showed the feasibility of controlling power distribution by index modification in the branches. By depositing an extra layer of dielectric cladding to cause an increase in the effective indices in the two side branches, equal power division can be attained. Hung *et al.* [3] achieved the above goal by deliberately introducing a low-index phase front accelerator region in the central region between the two adjacent branches. Previous work all met the problem that the branching angle should be restricted to extremely small values in order to avoid large excess loss. This causes great difficulties in the fabrication of such devices and tends to result in long devices. Recently, it was reported that a wide-angle low-loss waveguide bend can be achieved with the use of a microprism [4]. In this Letter, microprisms are applied to modify the wave front of incoming waves more efficiently for the facilitation of wave branching at large angles. The condition of equal and efficient power division can be fulfilled as a compromise is achieved between the effects of the microprisms and the strong coupling between the two adjacent waveguides.

Design: The configuration of the proposed three-branch waveguide is shown in Fig. 1. The proposed structure is different from the conventional structure in that a pair of microprisms are provided at the junction of the input and output waveguides. As shown in Fig. 1, the microprisms are triangular with side lengths determined by the effective width of waveguides W_{eff}, which repre

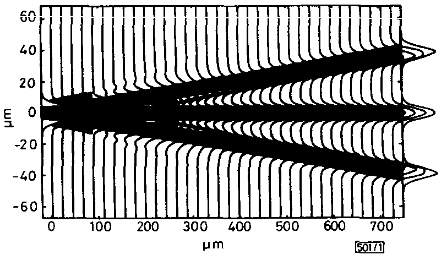

Fig. 1 *Proposed three-branch waveguides*

$\theta = 3°$, $n_p = 1.5082$

sents the fictitious boundaries enclosing the majority of power flow. The size of the microprism is determined so that most of the power of the incoming wave is included. The main cause of unequal power partition in a conventional structure is the phase mismatches occurring at the side branches which form an angle θ_0 with the propagation direction of the incoming wave. In our work, the presence of microprisms can modify the wave front of the incoming wave from planar to a shape in which the wave front is nearly perpendicular to the axis of each output waveguide. This sets the stage for wave bending at larger angles. As the wave leaves the microprism region, the incoming wave has been modified to such an extent that it has more components which closely match the corresponding eigenmodes in each output waveguide. Owing to the coupling between the centre branch and each side branch, the radiation power will be well coupled to those branches as the wave leaves the microprism region, thus preserving efficiency. We expect that, with careful selection of a microprism index n_p and a branching angle θ, the power can be equally and efficiently distributed to the three output branches.

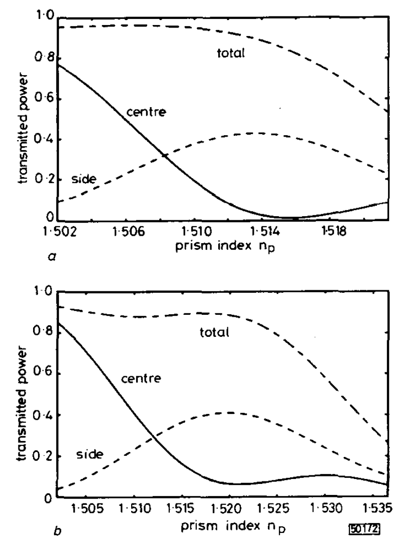

Fig. 2 *Power distributions in proposed three-branch structure as function of microprism index for $\theta = 3°$ and $\theta = 4°$*

a $\theta = 3°$
b $\theta = 4°$

Results and discussion: To demonstrate the operation of the proposed optical branching circuit design, the finite difference beam propagation method is employed for numerical simulation. The waveguides are assumed to operate in a single TE_0 mode at 1.5μm operating wavelength with refractive indices chosen as $n_f = 1.502$, $n_s = 1.5$, as shown in Fig. 1. The optical power ratio of each branch as a function of the microprism index when the branching angles are 3 and 4° are shown in Fig. 2*a* and *b*, respectively. It is apparent from those Figures that the output power of the centre and side branches can be made equal or a certain ratio by suitable choice of microprism index (this range of index values can be realised by ion exchange in glass [5]), while the total guided power is still maintained at a satisfactory level. These figures also show the feasibility of controlling the transmitted power ratio between the centre and side branches by adjusting n_p. (Banda *et al.* [6] had proposed a three-branch structure which also can adjust the output power ratio, but the maximal branching angle is as small as 1° in their demonstrations) It is noted that a larger branching angle, e.g. $\theta = 4°$ will result in a slight decrease in transmitted power. However, it offers an alternative branching circuit design, as larger angles would allow the enhancement of packing density and the elimination of crosstalk. Fig. 3 shows the intensity plot of the propagating beam in our proposed structure for $\theta = 3°$ and $n_p = 1.5082$, and the output power ratios with respect to the input powers are 32.15 and 31.86% for the central and side branches, respectively. It is obvious that input power is efficiently divided into three nearly equal parts to the corresponding output branches.

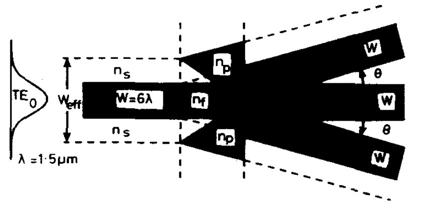

Fig. 3 *Intensity distribution for equal power division in three-branch structure with microprism*

Conclusion: We have successfully shown that the use of microprisms in the design of a large-angle low-loss 1×3 waveguide branches can be achieved. In our design, the output power ratio can be easily adjusted by a suitable choice of microprism index. Further applications of the microprism to the design of other waveguide devices will be of great interest in the future.

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160°C CW operation of InGaAs/GaAs vertical cavity surface emitting lasers

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Indexing terms: Vertical cavity surface emitting lasers, Gallium arsenide

A CW operation temperature of 160°C is demonstrated in InGaAs/GaAs double quantum well vertical cavity surface emitting lasers (VCSELs). The effect of offset-gain is considered in the design, and wet chemical etching is employed for forming the mesa structure to reduce surface recombination. A low threshold current of 5.2mA is achieved at 160°C.

Vertical cavity surface emitting lasers (VCSELs) are considered to be key components for future optical interconnection systems and optical parallel processing systems because of their potential for ultralow threshold current, efficient coupling into optical fibres and dense two-dimensional arrays. Although recent rapid progress has achieved a drastic improvement in the performance of the VCSELs [1, 2, 3] from their first oscillation [4], one of the most important factors limiting the device performance is a thermal problem. Resistance to temperature fluctuations is an important factor for practical applications. In this Letter, we report temperature insensitive VCSELs in which the effect of offset gain [5] is considered in the design and a wet etching process to reduce surface recombination is employed to form the mesa structure.

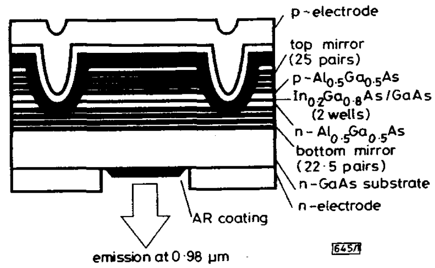

Fig. 1 *Schematic cross-section of VCSEL*

The VCSEL heterostructure was grown by molecular beam epitaxy (MBE) on *n*-GaAs substrate. Fig. 1 shows a schematic cross-section of the VCSEL structure, which consists of a pair of DBR mirrors surrounding two 8nm strained $In_{0.2}Ga_{0.8}As$ quantum wells separated by 10nm GaAs barriers. The top mirror is 25 periods of *p*-doped (Be:$2\times10^{18}cm^{-3}$) GaAs/AlAs DBR, which includes 20nm $Al_{0.5}Ga_{0.5}As$ spacers at the GaAs/AlAs interfaces to reduce series resistance [6] and a phase-matching layer to enhance the reflectivity of the top mirror. The bottom mirror is 22.5 periods of *n*-doped (Si:$2\times10^{18}cm^{-3}$) GaAs/AlAs DBR without spacers. Either side of the quantum wells and barriers are $Al_{0.5}Ga_{0.5}As$ spacers to locate the mirrors one wavelength apart. We prepared two wafers in which detunings of the cavity wavelength to the peak wavelength of the photoluminescence (PL) spectra ($\Delta\lambda = \lambda_{cavity} - \lambda_{PL}$) were −2nm (type A) and 16nm (type B), respectively. The PL peak wavelength was 980nm in the both wafers. We assumed here that the PL peak wavelength represented the gain peak wavelength.

The lasers were chemically etched through the active region to form a mesa structure, stopping at the middle of the bottom mirror, which provides both carrier and optical confinement. As an etchant, we used a low temperature $Br:HBr:H_2O$ solution to obtain a very smooth etched surface. The wet etching is a simple process and quite effective in reducing the surface recombination which degrades low threshold operation [7]. After the etching process, an SiO_2 passivation film was immediately deposited on the etched sidewall to avoid oxidation. An AuZn/Au electrode and an AuGe/Au electrode were then formed on the *p*-side and *n*-side, respectively. An SiN_x antireflection layer was deposited on the light-emission window at the bottom.