Compact design of 1×16 cascaded Y-branch splitter

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We proposed a new kind of cascade Y-branch splitter with a branching region and a fan-out region. The length of the new device are analyzed in detail and compared with ordinary ones. The results show that the new splitter can be 10%−30% shorter than the ordinary splitters. We designed and fabricated a 1×16 splitter in K+/Na+ ion-exchanged BK7 glass. The length of the new designed splitter is 30-mm, which is 85% of the length of an ordinary splitter.

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Optical power splitter is one of the most important optical devices for optical communication and optical signal processing. In recent years, the start-up of fiber CATV and FTTH projects stimulates device companies and research institutes to make greater efforts to investigate and develop high quality optical splitters with large output waveguide number. Because cascade Y-branch splitter has the merit of easy to fabricate, wavelength insensitive, polarization insensitive, and fine uniformity of output powers, most of planar splitter products employ the Y-branch to form the splitters[1,2]. But the length of 1×N branching splitter is proportional to the output waveguide number N and the output waveguide spaces, when the N becomes quite large, the device will become too long to be applied, and the device will have more transmission loss.

To obtain more compact splitter devices with larger output waveguide number, we proposed a novel design of branching splitter. The input optical power is first branched in branching region, and then a bundle of S-shape bends are used to expend the waveguide space for the convenience of fiber pigtail. After detailed analysis, we designed and fabricated a 1×16 splitter in K+/Na+ ion-exchanged BK7 glass.

Ordinary 1×16 cascade Y-branch splitters usually have the structure of Fig. 1. It is composed of Y-branches with bends height h, $2h$, $4h$, and $8h$, respectively. The upper-grade bends are twice the height of the lower-grade bends. The smallest bends height h is equal to the fiber radius, and is usually 125 or 62.5 μm for fiber pigtail. The proposed splitter is shown in Fig. 2, which is composed of a 1×16 branching region and a fan-out region. The configuration of the branching region is the same with conventional splitters, except for a much smaller bends height h' than ordinary spaces h. The fan-out region is composed of a bundle of S-shape bends to extend the space h'.

A conventional symmetric Y-branch is usually composed of three kinds of S-bends: sine, cosine, and double-circle[3−5].

When Y-branch employs sine-shape bends, the functional form of the S-bend is

$$y = \frac{h}{l}x - \frac{h}{2\pi}\sin\left(\frac{2\pi x}{l}\right), \tag{1}$$

where l is the length of Y-branch and h is the height of the bend. From Eq. (1), we can get the curvature radius of the bend

$$R = \frac{l^2}{2\pi h}\frac{1}{\sin(2\pi x/l)}. \tag{2}$$

The curvature radius reaches its minimum while $x = l/4$ or $3l/4$,

$$R_{\min} = \frac{l^2}{2\pi h}. \tag{3}$$

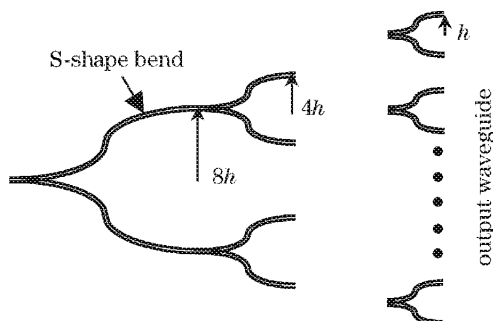Thus, the Y-branch length l is

$$l = \sqrt{2\pi h R_{\min}}. \tag{4}$$
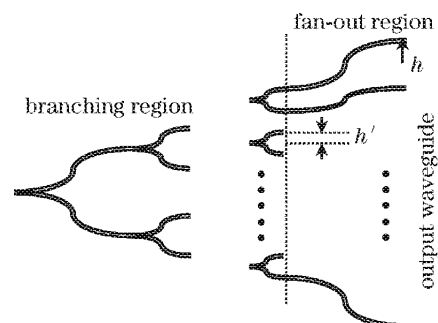

Fig. 1. Geometry of ordinary cascade Y-branch splitters.

Fig. 2. Geometry of a one-step fan-out splitter.

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When Y-branch employs cosine-shape bends, the functional form of the S-bend is

$$y = \frac{h}{2} - \frac{h}{2}\cos\left(\frac{\pi x}{l}\right). \tag{5}$$

The curvature radius of the cosine-shape bend can be expressed as

$$R = \frac{2l^2}{\pi^2 h}\frac{1}{\cos(\pi x/l)}. \tag{6}$$

When $x = 0$ and l, the curvature radius reaches its minimum

$$R_{\min} = \frac{2l^2}{\pi^2 h}. \tag{7}$$

The length of cosine Y-branch l is

$$l = \sqrt{\frac{\pi^2}{2}hR_{\min}}. \tag{8}$$

When Y-branch employs double-circle bends, and the radii of two circles are equal to each other, the radius can be expressed as

$$R = R_{\min} = \sqrt{\frac{l^2 + h^2}{4h}}. \tag{9}$$

So the length of Y-branch l can be expressed as

$$l = \sqrt{4hR_{\min} + h^2}. \tag{10}$$

Because $R_{\min}$ is excessively larger than h, Eq. (10) can be approximated to

$$l \approx \sqrt{4hR_{\min}}. \tag{11}$$

From Eqs. (4), (8), and (11), the bend lengths of the three kinds of Y-branch can by described by the same formula with a different constant a

$$l \approx \sqrt{ahR_{\min}}. \tag{12}$$

For sine, cosine, and double-circle bend, a equals to 2π, $\pi^2/2$, and 4, respectively. Thus, when they have the same minimal radius, the length ratio of three kinds of Y-branch is 1.25:1.11:1.

Because the bending loss mainly lies on the bending radius and the length of bending waveguide[6], for certain radius and certain S-bending shape, the device will have less bending loss while it has shorter length.

For ordinary cascade Y-branch splitter with N output waveguides, the bends height of each grade Y-branch (h_n) is h, $2h$, $4h$, $\ldots$,$\frac{N}{2}h$ respectively, and the length of each grade Y-branch is

$$l_n = \sqrt{ah_nR_{\min}}. \tag{13}$$

Suppose all the S-bends of cascade Y-branch splitter have the same minimal radius $R_{\min}$, and all the Y-branches take the same S-bend type, the total length of the ordinary $1\times N$ splitter is given by

$$L = \sum_{k=1}^{n}\sqrt{ah_nR_{\min}} = \sqrt{ahR_{\min}}\sum_{k=1}^{n}\sqrt{2^k}$$

$$= \sqrt{ahR_{\min}}\frac{\sqrt{2}^n - 1}{\sqrt{2} - 1}, \tag{14}$$
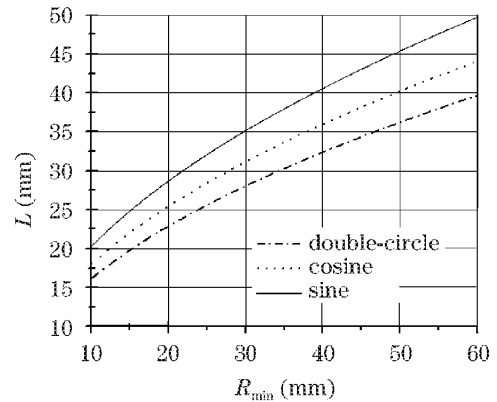

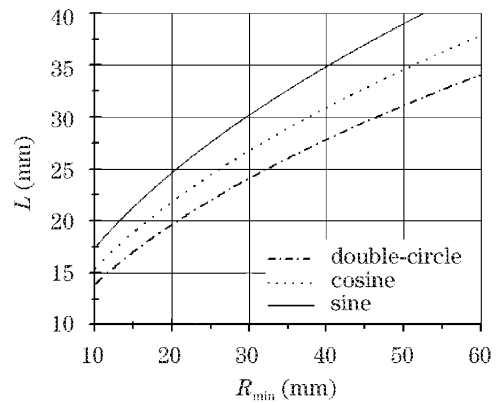Fig. 3. The length of an ordinary cascade 1×16 splitter.

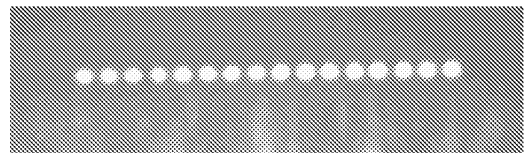Fig. 4. The length of the new 1×16 splitter.

Fig. 5. Near field of the output of branching region.

where n is the grade number of splitter, and $N = 2^n$. Figure 3 shows the length of an ordinary 1×16 splitter, where $h = 125$ μm.

In Fig. 2, we suppose the minimal radius of fan-out S-bend is equal to the minimal radius of Y-branch, the total length of the new splitter is

$$L_1 = \sqrt{ah'R_{\min}}\frac{\sqrt{2}^n - 1}{\sqrt{2} - 1} + \sqrt{a(2^n - 1)(h - h')R_{\min}}. \tag{15}$$

Figure 4 shows the length of this new cascade splitter, where $h = 125$ μm and $h' = 30$ μm.

The final design data of the 1×16 power splitter are as following: wavelength $\lambda = 1.55$ μm, width of waveguide $W = 6$ μm, minimal bends radius $R_{\min} = 30$ mm, output waveguide space $2h = 250$ μm, and branching region space $2h' = 30$ μm. We choose the sine-shape bends to form the Y-branches. The length of ordinary 1×16 splitter is 35 mm, and that of the newly designed splitter
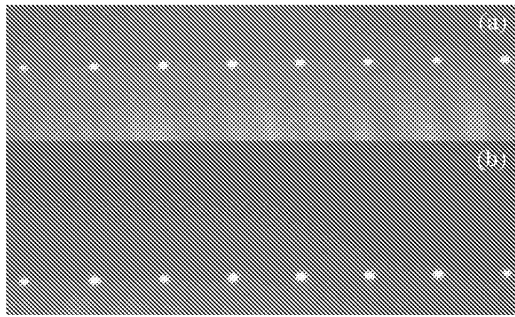
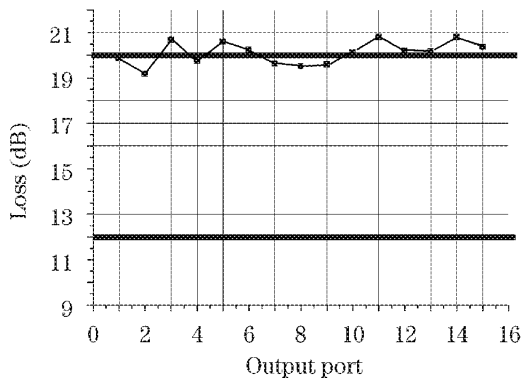Fig. 6. Near field of the output of the splitter. (a): Left 8 output ports; (b): right 8 output ports.

Fig. 7. Insertion loss of each output waveguide.

is 30 mm. Comparing the length of the splitters, the device length of the new splitter is sharply cut.

The 1×16 splitter designed in this paper is formed by

K^+/Na^+ ion-exchanged on BK7 glass, the ion-exchange is carried out in KNO_3 melt in 350−390 °C for about 8−18 hours. Figure 5 shows the near field of the output of branching region, and Fig. 6 shows the near field of the splitter.

Primary test of the device is carried out, the insertion loss of each output path is shown in Fig. 7. The maximal deviation of insertion loss is about 1.6 dB, the deviation of insertion loss is mainly caused by the defections of the waveguides. The mean insertion loss of the splitter is about 8.01 dB, fiber-waveguide coupling loss of the input and output waveguides is about 3 dB according to the simulation, and it is the main reason of quitting big insertion loss. Further improvement of the mean insertion loss is carried out.

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