Design and the fabrication of the small v-bend optical waveguide using an elliptic mirror

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The small v-bend optical waveguide using an elliptic mirror using polyimide is designed and fabricated. Total loss, the wavelength and the polarization dependent loss were 10 dB, 0.7 dB and 0.1 dB, respectively.

Keywords: optical waveguide, small bend, elliptic mirror, polyimide, misalignment

Introduction

Small sized planar lightwave circuits [1] are necessary for large capacity communication systems. Generally, the curved waveguide is used to bend the light in the optical waveguide. The size of the curved waveguide is limited by the minimum radius of the curvature. We proposed the small v-bend optical waveguide using an elliptic mirror, as shown in Fig.1. The v-bend waveguide has a large tolerance on the mirror position misalignment. On the other hand, the total reflection mirror could not bend at a sharp angle and had high loss against mirror position misalignment. Furthermore, total reflection mirror had high wavelength dependent loss [2].

In this paper, the structure of the v-bend optical waveguide was optimized and it was fabricated with fluorinated polyimide [3]. The loss characteristics were also described. Other optical waveguide using the mirror, i.e. N:N optical coupler, was proposed.

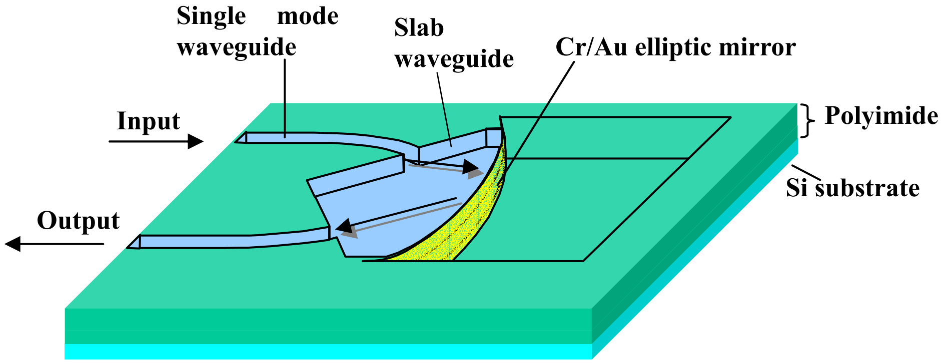

Fig.1 Schematic of small v-bend optical waveguide using an elliptic mirror

Optimized design of the v-bend optical waveguide

The light emitted from one focal point reflects in the elliptic surface and converges on the other focal point. We utilized this property for v-bend waveguide. The Gaussian beam approximation [4] was used for the light propagation in the slab waveguide. High coupling efficiency between the reflected beam and the output waveguide might provide low loss bending. Figure 2 shows the structure of the v-bend optical system. The spot size and the position of the waist of the reflected beam depend on those of the incident beam and the geometrical focal length of the lens f. When $\omega_1 = \omega_2$ and $d_0 = d_1$ are assumed, at the minimum scale Gaussian beam condition, we obtained

$$d_0 = d_1 = f = \frac{\pi \omega_1^2 n}{\lambda}. \tag{1}$$

where n is the effective index of slab waveguide, d_0(d_1) is the distance from the incident (reflected) beam waist to the vertex of the elliptic mirror and ω_1(ω_2) is the spot size of the incident (reflected) beam. The shortest length of the v-bend (Xmin) and high coupling efficiency between reflected Gaussian beam and the output waveguide are obtained if w2 equals the fundamental mode field radius of the output waveguide which core width is 2a. For example, when 2a = 10 μm, λ = 1.55 μm and n =1.534 were assumed, Xmin was calculated to be only 1 mm for Rmin = 10 mm and L = 50 μm.

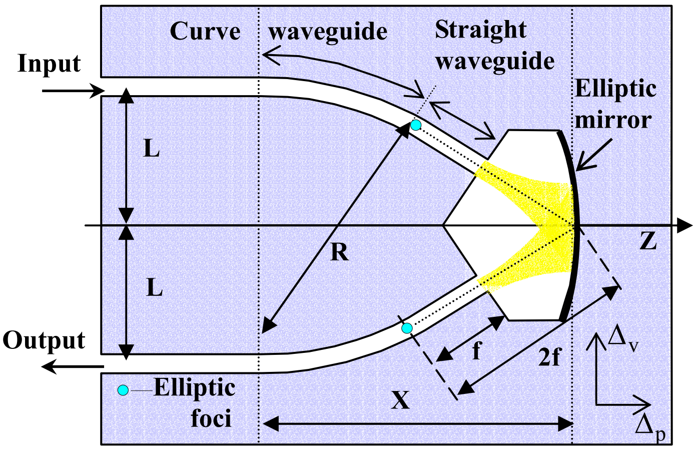

Fig.2 Structure of the optimized v-bend waveguide.

Mirror Loss

The v-bend optical waveguide was fabricated by photolithography and RIE (reactive ion etching). After etching of the waveguide, Cr/Au metal was deposited on the facet. We assumed that origins of the mirror loss could classify into 4 categories [5], (1) the mirror position misalignment, (2) the mirror facet tilt angle, (3) the mirror facet roughness and (4) the mirror absorption.

The excess loss due to the misalignment of the mirror with the parallel direction and the vertical direction against the optical axis (z-direction in Fig.2) were calculated. Figure 3 shows how the excess loss varies with the parallel direction misalignment Δ_p. The excess loss due to the parallel direction misalignment was less than 0.07 dB at $\Delta_p = \pm 2$ μm and that of the vertical direction misalignment Δ_v was 1×10^{-5} dB at $\Delta_v = \pm 2$ μm, it could be almost ignored.

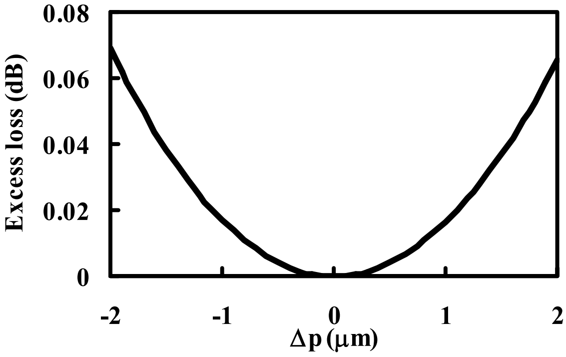

Fig. 3 Excess loss as a function of the parallel direction misalignment(Δp).

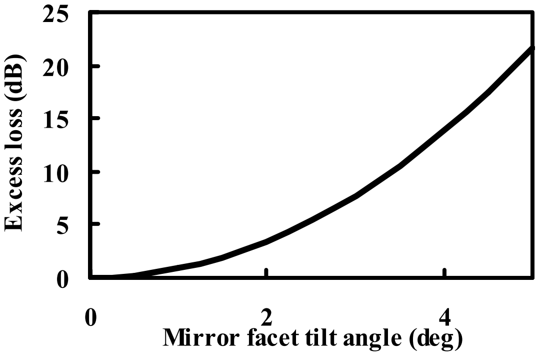

Fig. 4 Excess loss as a function of the mirror facet tilt angle against depth direction.

On the other hand, the excess loss significantly depends on the tilt angle of the mirror facet to the normal direction. Figure 4 shows the excess loss as a function of the mirror facet tilt angle. To keep the loss less than 1 dB, the mirror facet tilt angle has to be less than almost 1 (deg). Mirror roughness is often estimated with the RMS (root mean square) value. The RMS value of the mirror facet roughness etched by the RIE was less than few hundred nanometers. Therefore, it might be also ignored [6].

Fabrication and measurement of the polyimide v-bend waveguide

We have fabricated the v-bend waveguide with fluorinated polyimide which propagation loss is 0.6 dB/cm and 0.9 dB/cm for both TE and TM polarization at the wavelength of 1.55 μm. The minimum size of the v-bend structure was 0.5 mm × 2.22 mm, when the core width of the waveguide (2a), the refractive index difference and the separation length of the input/output waveguides (2L) were 10 μm, 0.46 % and 500 μm, respectively. The measurement setup consists of the tunable optical source, the polarization scrambler and the optical power meter. Figure 5 shows the total loss of the v-bend waveguide as a function of the wavelength. The average total loss was about 10.64 dB. The polarization and wavelength dependent loss were only 0.1 dB and 0.7 dB from 1.525 μm to 1.6 μm, respectively. It seems that the v-bend waveguide did not depend on the wavelength of the optical source.

Figure 6 is the SEM (scanning electron microscope) photograph of the mirror facet. There were the vertical stripes on the facet. As the spacing of these stripes was almost few hundred nanometers and the height of the stripes was less than one hundred nanometers, the scattering loss at the mirror facet might be almost neglected like the loss due to the mirror position misalignment. Since the mirror facet tilt angle was about 2 degree, the excess loss due to the mirror facet tilt was about 3.5 dB. The reflectivity of the Cr/Au mirror seems to be low due to the absorption of the Cr layer. This absorption is one of the reasons of the high total loss.

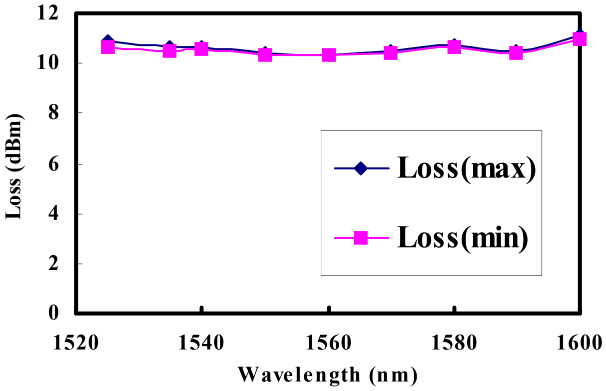

Fig. 5 Total loss of the v-bend waveguide as a function of the wavelength.

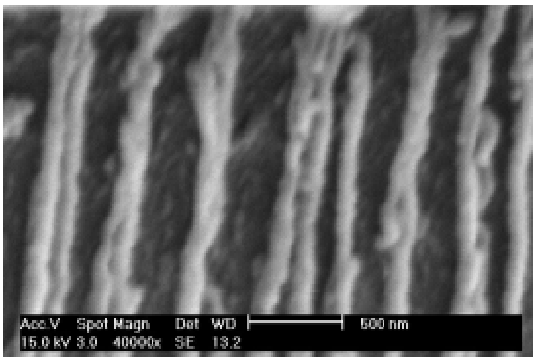

Fig. 6 SEM photograph of the mirror facet.

N:N optical coupler using a mirror

Figure 7 illustrates the N:N optical coupler using a mirror in slab waveguide. The proposed coupler consists of the input waveguides, output waveguide, slab waveguide and the waveguide mirror. The incident light from input waveguides to the slab waveguide will be reflected at the mirror and the light changes to the collimated light and this reflected light will be coupled into output waveguides. The advantages of the proposed coupler are that the length of the device can be almost half compared with that of the conventional one, both input and output fibers can be connected to the same side of the substrate, and the various shapes of mirrors can be designed to reduce aberration. The mirror shape that can collimate the reflected beam was optimized by using numerical calculation. Figure 8 shows the simulated coupling losses of the proposed 8:8 coupler and the conventional one as a function of the distance from the end of the central input waveguide to a mirror (S). The fluctuation was the difference between the maximum and the minimum coupling loss in dB unit. And the maximum loss was the difference between the maximum loss and $-10\times\log_{10}(1/8)$, which was the ideal loss when input signal was divided equally into every waveguide. Figure 9 shows the experimental results of the fabricated 1:4 optical coupler. This graph shows the coupling loss as a function of the wavelength. These results indicate that the loss at 1550nm was about 30dB. The loss dependence on the wavelength was about 2.7dB, the fluctuation of the loss was about 2.9dB and the PDL was about 0.6dB. These values will be reduced by using more refined etching technique.

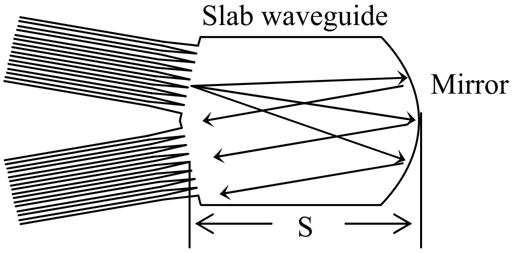

Fig. 7 Schematic of the proposed N:N coupler using a waveguide mirror.

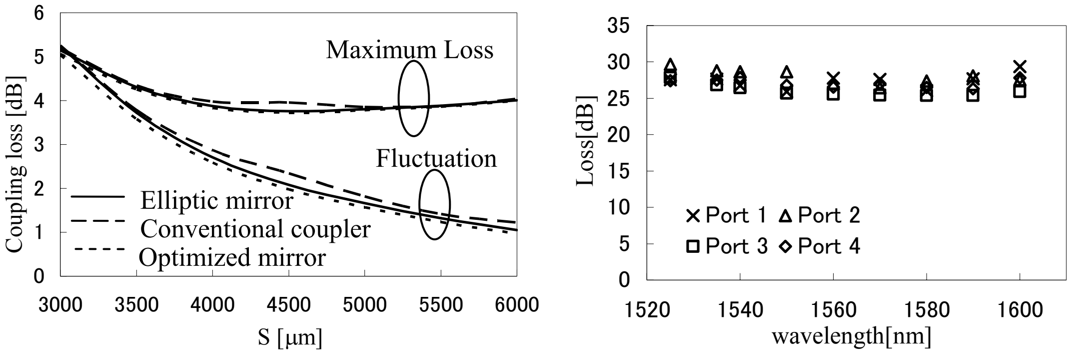

Fig. 8 Calculation results.

Fig. 9 Experimental results of 1:4 coupler.

Summary

We have designed the v-bend optical waveguide using an elliptic mirror, which can perform 180 degree light path bending and has a large tolerance on the mirror position misalignment. The minimum length of the v-bend waveguide became 1-2 mm in which conventional waveguide could not be fabricated. We have fabricated the polyimide v-bend optical waveguide. The total loss was about 10 dB, which mainly attributed to the mirror facet tilt and the absorption of the Cr/Au mirror. The wavelength and polarization dependent loss were only 0.7 dB and 0.1 dB, respectively. The N:N optical coupler using a mirror in slab waveguide was proposed. The performance of this coupler is almost the same compared with the conventional coupler.

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