

WAVEGUIDE END FACE

TECHNICAL FIELD

This invention relates to an end face of an integrated optical waveguide and in particular to the end face of a rib waveguide formed on a silicon-on-insulator (SOI) chip.

BACKGROUND PRIOR ART

The end face of an integrated waveguide, e.g. formed of silica, may be formed by a sawing process or by mechanical polishing to achieve an optical quality facet on the end of the waveguide for coupling light to or from another component, e.g. from a laser diode or to an optical fibre. In other cases, e.g. devices made from III V materials, such as InP or GaAs, the substrate can be cleaved along a crystallographic plane to produce an optical quality facet.

With silicon waveguides, e.g. on a silicon-on-insulator chip, the facets may be fabricated by a dry etching process using well-known lithographic techniques and this enables waveguide facets to be formed at arbitrary positions on a chip. However, with waveguides typically of a width in the range 4 – 10 microns, the resolution limit of standard pattern definition techniques, such as lithography, tends to cause a rounding of the facet which leads to undesirable aberrations in the passage of light therethrough and/or a focusing effect on light emitted or received by the facet.

SUMMARY OF THE INVENTION

According to the present invention, there is provided an integrated optical waveguide having an end face provided on an end portion of the waveguide, the end face having rounded corners at the edges thereof formed during the manufacture of the end face, the end portion being formed so that said end portion and the end face provided thereon have a greater width than the width of the waveguide leading to the end portion so the rounded corners are spaced away from a substantially flat region of the end face formed therebetween, whereby in use, substantially all light passing through the end face passes

through the substantially flat region and focussing effects or aberrations caused by the rounded corners on the light passing through the end face are reduced.

Preferred and optional features of the invention will be apparent from the following description and from the subsidiary claims of the specification.

The invention will now be further described, merely by way of example, with reference to the accompanying drawings, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a plan view of a conventional rib waveguide;

Figure 2 is a schematic plan view of an integrated waveguide according to a first embodiment of the invention; and

Figures 3, 4, 5 and 6 are schematic plan views of further embodiments of integrated waveguides according to the invention.

BEST MODE OF THE INVENTION

Figure 1 shows a plan view of a conventional rib waveguide 1 which typically has a width in the range 4 – 10 microns and shows, somewhat exaggerated, the rounded form of a facet 1A formed at one end of the waveguide. The radius of the rounded corners at the edges of the facet depends on variations in the lithographic etching technique used to form the facet and so leads to variable aberrations in the transmission of light through the facet. The rounded corners may typically have a radius R in the order of 1 to 2 microns. Other waveguide manufacturing processes may also cause similar rounding effects.

Figure 2 shows a plan view of a rib waveguide according to a first embodiment of the invention in which the end face of the waveguide 2 is provided on an end portion in the form of a "T-bar" 2B at the end of the waveguide 2. The result of this is that the end face 2A formed at the end of the waveguide is wider than the

waveguide 2 leading to the end face. With a waveguide having a width W_w in the range 4 – 10 microns, the width of the end portion, ie the length L of the T-bar 2B would typically be in the range 6 to 30 microns, and in some cases up to 60 microns. The same degree of rounding of the corners of the T-bar 2B occurs as in the conventional waveguide shown in Figure 1 but the rounded corners are now spaced away from a central portion of the end face 2A through which light passes on leaving or entering the waveguide 2. This central portion of the end face 2A can thus be formed substantially flat and the aberrations caused by the rounding effect mentioned above can be reduced or minimised depending upon the length L of the T-bar 2B relative to the width W_w of the waveguide 2.

With a waveguide 2 having a width W_w in the range 4 – 10 microns, the width W_T of the arms of the T-bar 2B would also typically be in the range 4 – 10 microns.

The width of the substantially flat central portion of the end face 2A is preferably at least as great as the width W_w of the waveguide 1 so the length L of the T-bar 2B is preferably greater than the width of the waveguide by a length twice the radius R of the rounded corners, ie

$$L \geq W_w + 2R.$$

Figures 3 – 6 illustrate further embodiments employing the same principle, i.e. the use of a facet of greater width than the waveguide leading thereto, to reduce the aberrations caused by the rounding effect discussed above.

Figure 3 shows a waveguide 3 that tapers from a wide portion 3C to a narrow portion 3D and which is provided with a T-bar 3B on the end of the narrow portion 3D. The width of the end face 3A is thus greater than the width of the narrow portion 3D of the waveguide leading thereto.

Figure 4 shows a waveguide 4 that tapers from a narrow portion 4C to a wide portion 4D and which is provided with a T-bar 4B on the end of the wide portion

4D. The width of the end face 4A is thus still greater than the width of the wide portion 4D of the waveguide leading thereto.

It will be appreciated that the degree of rounding, ie the magnitude of the radius R , is defined by the manufacturing process used to fabricate the waveguide and is therefore independent of the width of waveguide. To ensure the central portion of the end face through which the light passes is substantially flat, the arms of the T-bar should each project from the sides of the end face by a distance of at least R .

Figure 5 shows a waveguide 5 with a T-bar 5B provided at the end thereof, the T-bar being inclined to the perpendicular to the waveguide axis. The length of the T-bar 2B shown in Figure 2 is substantially perpendicular to the optical axis of the waveguide 2, whereas in the arrangement shown in Figure 5, the length of the T-bar 5B lies at an angle θ to the perpendicular. The angle θ would typically be up to 10 degrees. The end face 5A is similarly inclined so its normal lies at an angle θ to the optical axis of the waveguide 5. This inclination helps avoid problems caused by back reflection of light from the face 5A interfering with light being transmitted along the waveguide 5.

With a narrow waveguide, e.g. with a width of 4 microns, the arrangement shown in Figure 5 could not be realised without use of a T-bar as the rounding effect of the manufacturing process used to fabricate the end face would obliterate any attempt to incline the end face. Even with a wider waveguide, e.g. having a width of 6 to 8 microns, the rounding effect would significantly reduce the width of the portion of the end face which would be flat and which could thus be formed with its normal inclined to the optical axis of the waveguide.

Figure 6 shows an arrangement in which a plurality of waveguides 6, 7 and 8 lead to a common T-bar 6B. The T-bar 6B is arranged so that the end face 6A

is substantially flat in the regions where light from any of the waveguides 6, 7 or 8 is transmitted therethrough.

The arrangement described above thus ensures that substantially all light passing through the end face 4A passes through the substantially flat central portion thereof. This is achieved by shaping the end of the waveguide so that the physical dimensions of the waveguide widen more rapidly than the optical mode therein so substantially all the light passes through the flat region of the end face and not through the rounded regions at the edges thereof.

CLAIMS

1. An integrated optical waveguide having an end face provided on an end portion of the waveguide, the end face having rounded corners at the edges thereof formed during the manufacture of the end face, the end portion being formed so that said end portion and the end face provided thereon have a greater width than the width of the waveguide leading to the end portion so the rounded corners are spaced away from a substantially flat region of the end face formed therebetween, whereby, in use, substantially all light passing through the end face passes through the substantially flat region and focussing effects or aberrations caused by the rounded corners on the light passing through the end face are reduced.
2. An integrated optical waveguide as claimed in claim 1 in which the end portion has a width of at least $W_w + 2R$, where W_w is the width of the waveguide leading thereto and R is the radius of curvature of corners of the end portion caused as a result of the manufacturing process used to fabricate the end face.
3. An integrated optical waveguide as claimed in Claim 1 or 2 in which the end face is provided on a T-bar provided at the end of the waveguide.
4. An integrated optical waveguide as claimed in any preceding claim in which the end face is inclined so its normal makes an angle θ of up to 10 degrees with the optical axis of the waveguide.
5. An integrated optical waveguide as claimed in any preceding claim in which the waveguide leading to the end face comprises a narrow portion that tapers into a wider portion towards the end portion.



6. An integrated optical waveguide as claimed in any of Claims 1 – 4 in which the waveguide leading to the end face comprises a wide portion which tapers into a narrower portion towards the end portion.
7. An integrated optical waveguide as claimed in any preceding claim in which a plurality of waveguides lead to a common end portion.
8. An integrated optical waveguide as claimed in Claim 7 in which the common end portion is provided by a common T-bar provided at the end of the waveguides.
9. An integrated optical waveguide as claimed in any preceding claim in the form of a rib waveguide.
10. An integrated optical waveguide as claimed in Claim 9 in which the rib waveguide is formed of silicon.
11. An integrated optical waveguide as claimed in Claim 10 in which the rib waveguide is formed on a silicon-on-insulator chip.
12. An integrated optical waveguide as claimed in claim 2 or any claim dependent thereon in which W_w is in the range 4 to 10 microns and R is in the range 1 to 2 microns.
13. An integrated optical waveguide substantially as hereinbefore described with reference to and/or as shown in any of Figures 2 to 6 of the accompanying drawings.