Chapter 22

Y-junctions (Draft)

22.1 Introduction

Y-junctions are important components for distributing power between two waveguides, or combining power from two waveguides. For the latter function it is important that the signals in both input waveguides have the same phase, otherwise part of the input power will be converted to a first-order mode in the output waveguide. Y-junctions have the same functionality as 1x2 MMI-couplers, but in low-contrast waveguide systems they can have lower loss and reflection than MMI-couplers, at the cost of an increased length. In (high-contrast) semiconductor waveguide platforms their loss and reflection is comparable with or worse than MMI-couplers because of the discontinuity at at the position where the gap closes abruptly due to the finite resolution of the lithography. So for semiconductor waveguide platforms MMI-couplers are usually the preferred solution.

Y-junctions are considered as composite building blocks because they are composed of straight waveguides, a taper and waveguide junctions.

22.2 Geometry

Figure 22.1 shows the geometry of a Y-junction. In the most simple design it starts with a linear taper with taper angle θ_Y and taper ratio 2. The taper has a length $L_t = \frac{1}{2} w / \sin\theta_Y$, in which w is the waveguide width, as described in Chapter 21. It is followed by two waveguides at angles $\pm\theta_Y$, with the same width w.

taper

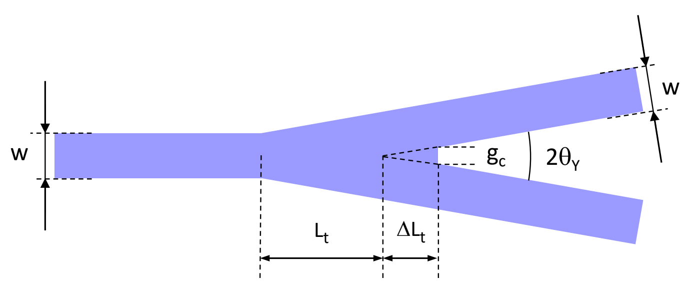

Figure 22.1: Y-junction geometry.

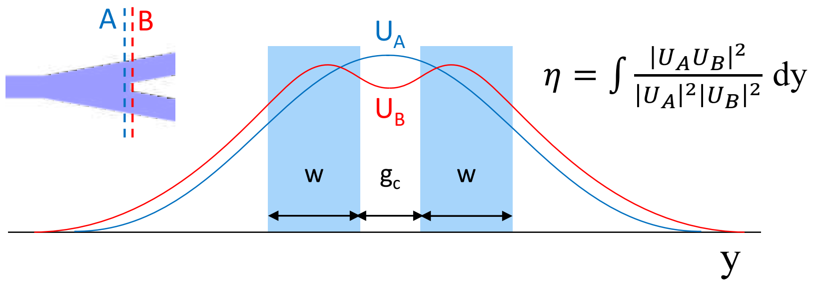

Figure 22.2: Overlap between the modal fields just before and after the junction.

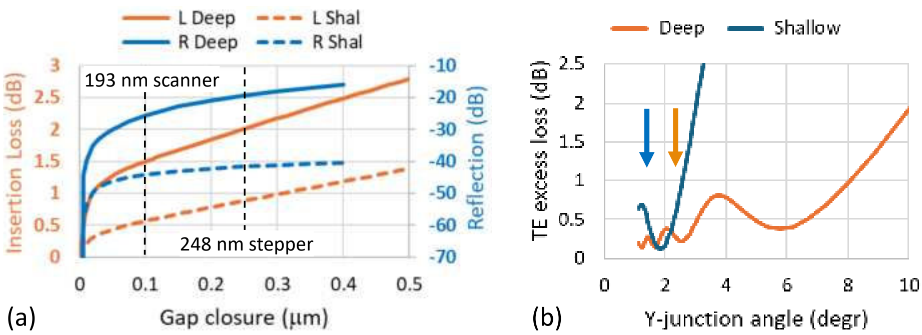

Figure 22.3: a) Excess Loss and Reflection due to abrupt gap closure. b) Excess Loss due to the junction angle θ_Y

excess loss
lithographic resolution

If the taper angle is chosen sufficiently small and the gap between the waveguides is infinitely sharp, the excess loss of the junction, i.e. the loss in excess of the theoretical 3-dB splitting loss, will be very small. However, due to the finite resolution of the lithographic process the gap will close when it becomes smaller than the resolution, which will lead to an extra length $\Delta L_t = \frac{1}{2} g_c / \sin\theta_Y$ of the taper, in which g_c is the width at which the gap closes. This abrupt gap closure introduces excess loss and reflections.

22.3 Excess loss and reflection.

gap closure
coupling loss

The effect of the gap closure is coupling loss and reflection at the discontinuity. The coupling loss can be calculated by taking the overlap integral of the field of the fundamental mode at both sides of the discontinuity, as shown in Fig. 22.2 and described in section 2.115 on page 2-66. The calculations can be done, in principle with the Effective Index Method, as described in Chapter 2, Sec.2.5.1 on page 2-49 The accuracy for shallow waveguides is limited, however. The curves in Fig. 22.3 have been calculated with a 2D-overlap calculation using FIMMWAVE (see Chapter 5, Sec. 5.2.2.2). The brown curves in Figure (a) show the coupling loss for Y-junctions fabricated with standard deep and shallow etched waveguides. As described in Chapter 4, Sec. 4.8 on page 4-30 the resolution attainable with 193 nm scanner lithography is 100 nm, with 248 nm wafer steppers it is approximately 250 nm and with conventional 365 nm (I-line) mask aligners it is about 600 nm. From the figure we see that with 193 nm scanner lithography the predicted excess loss for shallow etched Y-junctions is about 0.5 dB, and for deep etched junctions it is about 1.5 dB. With 248 nm stepper lithography the excess loss for shallow and deep-etched Y-junctions is 0.9 and 2 dB, respectively. For i-line

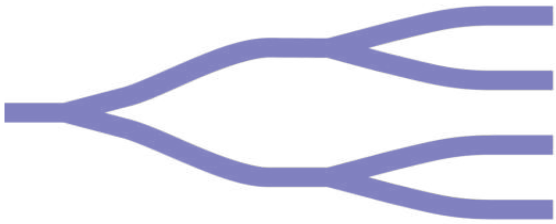

Figure 22.4: Tree Network.

lithography it is about 1.7 and 3 dB, respectively.

In practice the losses may be a bit lower because of the lag effect, described in Section 4.11.2 on page 4-55, which will gradually reduce the etch depth and, as a result, the effective index contrast in the gap, when it becomes narrower. Even with this effect the loss of a Y-junction in standard shallow or deep waveguides is usually larger than the loss of an MMI power splitter. *lag effect*

From the figure we see that the predicted reflection due to abrupt gap closure with 193 nm scanner lithography is < -40 dB and < -25 dB for shallow and deep etched waveguides, respectively, and ~ -40 dB and < -20 dB for 248 nm stepper lithography. For a 365 nm mask aligner the reflection levels are ~ -40 dB and < -12 dB for shallow and deep etched standard waveguides, respectively. We see that from a reflection point-of-view the shallow etched Y-junctions perform slightly better than MMI-couplers. *reflection*

Figure 22.3(b) shows the excess loss as a function of the Y-junction angle. If the taper section is designed according to the design rules described in chapter 21 (1.4° for the shallow-etched taper and 2.3° for the deep-etched one, the additional losses will be low. The predicted losses are well below 0.5 dB. The fringes for small angles are an artefact of the computation, as discussed in Appendix D, Sec. D.2. *design rules*

22.4 Symmetry

The symmetry in the power division over both output waveguides will be very good if the input waveguide carries only one mode. A small fraction of a first order mode can cause significant asysmmetry, however. If, for example, the first order mode in the input waveguide carries 1% of the total power, its amplitude will be approximately $\sqrt{1\%} = 10\%$ of the fundamental mode amplitude. If it adds to the fundamental mode in one branch, it will substract in the other branch. So the amplitude ratio of the total field in both branches will be $(1+0.1)/(1-0.1) \simeq 1.2$ and the power ratio will be $1.2^2 = 1.44$. So 1% first-order mode in the input waveguide leads to an asymmetry of $10\log 1.44 = 1.6\,\mathrm{dB}$. *asysmmetry*

22.5 Tree networks.

Larger splitting ratios $(1:4, 1:8, \ldots)$ can be realized by cascading two or more stages of Y-junctions. The performance of the tree follows directly from the performance of the individual Y-junctions. However, as shown in problem 22.1, the uniformity of the tree is extremely sensitive to small fractions of first-order mode power in the input waveguides of the Y-junctions. Small amounts of mode conversion are almost unavoidable *uniformity* *mode conversion*

Problem: Estimate the maximum acceptable level of first-order mode contamination in the input waveguide of a Y-junction if the maximum acceptable asymmetry in the output power is 0.1 dB.

Solution: An asymmetry of 0.1 dB corresponds to a power ratio of 1.023, and an amplitude ratio $\sqrt{1.023} \simeq 1.01$.This corresponds to $(1+0.005)/(1-0.005)$,so the maximum acceptable amplitude ratio of the first-order and the fundamental mode is 0.005, and the power ratio is $0.005^2 = 25 \cdot 10^{-6}$= -46 dB!

Problem: Estimate the insertion loss of a Y-junction using figure 22.1(right)

Solution:

Problem 22.1: Y-junction design and performance.

in the S-bends connecting the different Y-junctions. Even if the simulation predicts very low mode conversion numbers, first order modes can be generated at every asymmetric irregularity in the waveguide edges.