Aluminium oxide 1x8 splitter tree for blue light

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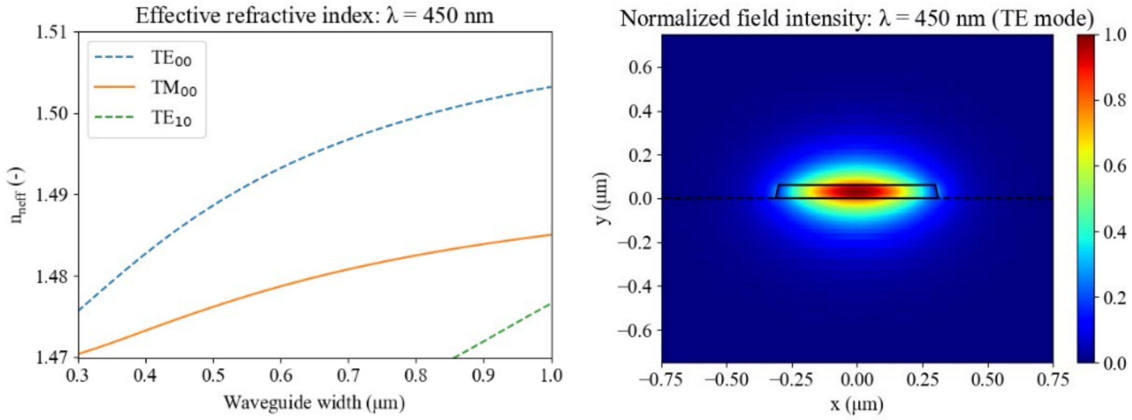
Aluminium oxide (Al_2O_3) has gained interest in the field of integrated photonics. Al_2O_3 shows low propagation losses, and it is known for its high rare-earth ion solubility. Furthermore, the material has a moderately high refractive index, allowing for design of devices with a small footprint. Another important characteristic of $Al_2O_3$is its large band gap (i.e., ~170 nm), compared to materials like InP, SOI and Si_3N_4. The larger band gap results in a transparency window that spans all the way from ultraviolet (UV) wavelengths to the mid-infrared (mid-IR).

In this work, a device is presented that showcases an application of Al_2O_3 at the UV and blue wavelengths. A splitter tree is fabricated from thin Al_2O_3 that supports single mode guiding at these particular wavelengths. Light is evenly split into multiple branches using Y-junctions, to eventually split it into eight output ports. All eight channels are provided with thermal phase shifters. This device can be utilized as an integrated optical phase array (OPA). In this work, the propagation and coupling losses as well as the splitting uniformity of this 1x8 waveguide splitter at 450 nm will be reported.

1. Introduction

Aluminum oxide (Al_2O_3) is a dielectric material that is an excellent candidate for photonic integrated circuits (PICs), especially in the UV and mid-infrared due to its large transparency window expanding from 150 nm to 5500 nm[1–5]. Low-loss sputtered Al_2O_3 thin films for integrated photonic devices have been demonstrated with losses down 0.6 ± 0.3 dB/cm for the fundamental slab mode at 377 nm[6]. W. A. P. M. Hendriks et al. [7]have demonstrated low-loss sputter coated Al_2O_3 waveguides with SiO_2 cladding, with losses down to 2 ± 0.5 dB/cm at 405 nm. This material has a high potential to enter the field of broadband communication applications, high-speed computing and high-resolution sensing applications.

High-density and multifunctional optoelectronic circuits have the potential to play a central role in future communication systems. Splitters are essential building elements for high-density photonic integrated circuits (PIC). They are used to split, combine or attenuate an optical signal. In this work, a device is studied that uses multiple splitters, to evenly split the light into eight different output channels. Each of the splitters in this device is formed by a symmetric Y-junction, which ideally results in a 50:50 splitting ratio without resulting in additional losses. As such, the power uniformity, or splitting ratio, and excess loss are the most important characteristics. This study focusses on the splitting ratio of the Y-junction splitters, employed in a 1x8 splitter tree. First, the design of the device is discussed, followed by an overview of the most important results on the splitting uniformity, and waveguide propagation as well as coupling losses.



(a) (b)

Figure 1 (a) Effective index of an 61 nm high Al2O3 waveguide as a function of its width for light at 450 nm. (b) Waveguide cross-section and simulated signal-mode profile for 600 nm width

2. Simulation and experiment

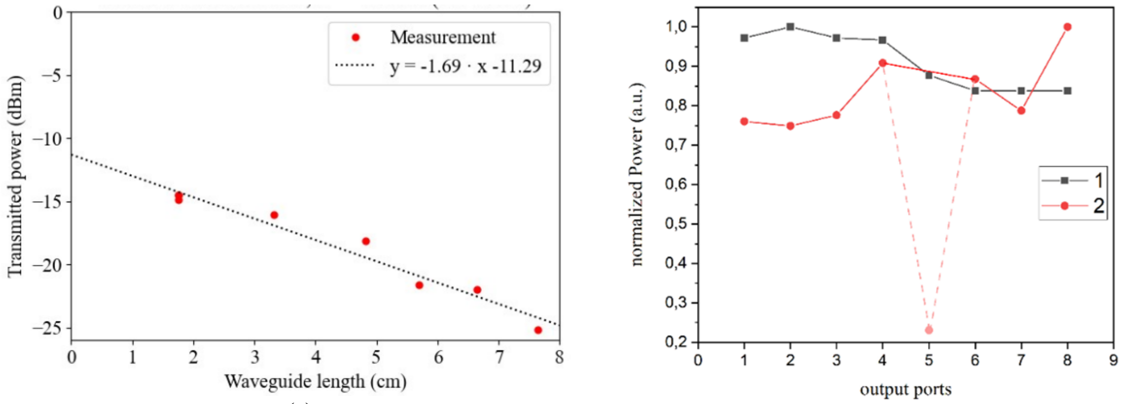
2.1 Design and simulation

Single transverse mode operation is a prerequisite for most PIC components. To select a proper waveguide geometry that supports single mode propagation, the optical modes in 61 nm thick Al_2O_3 ridge waveguide have been simulated with Lumerical MODE. While varying the waveguide width, the number of supported modes and their effective refractive index are determined. Figure 1a shows the supported modes as a function of waveguide width. Whenever the waveguide is wider than approximately 860 nm, higher order modes are supported. For this reason, the waveguide width is set to 600 nm as the higher order TE mode is not supported when even a slight bend is applied. The normalized field intensity of the fundamental TE mode in this waveguide is shown in figure 1b. From this point, this is the waveguide symmetry assumed in the remainder of the study.

2.2 Fabrication and measurement

The 61 nm ridge waveguide mentioned before is fabricated from Al_2O_3 that is RF sputtered on top of a four inch silicon wafer with an 8 µm thick thermal oxide. The Al_2O_3 layer is patterned using electron beam lithography. After development, the waveguide pattern is transferred into the Al_2O_3 using reactive ion etching. Next, an 8 µm SiO2 cladding is deposited and the circuits are diced.

The resulting chip has a size of 1.0 cm by 1.0 cm. At the end facets, the waveguide are tapered, to ease fiber-to-chip coupling through butt coupling. The end facets on both ends of the chip have been polished to further improve the coupling efficiency. After polishing, coupling losses of ~ 6 dB per facet have been measured**.** These coupling losses, as well as the waveguide propagation losses have been extracted from the cutback measurement presented in figure 2a. The cutback measurements is carried out by butt coupling a polarization maintaining (PM) fiber, pm-s350-hp, to the chip. One of the fibers is connected to a 450 nm diode laser, while the other fiber is connected to a power meter.



(a) (b)

Figure 2 (a) Cutback measurements of a 600 nm wide ridge waveguide for the fundamental TE mode at 450 nm. From these measurements, the propagation losses are estimated ~1.7 dB/cm and the coupling losses ~6 dB per facet. *(b) Measured power uniformity for all of the eight output of the 1x8 splitter tree.*

By coupling the light into waveguides of different length, in this case square spirals with different lengths, the transmission as a function of length can be measured which should follow the relation

$$\mathrm{P} = \mathrm{P}_0 \exp(-\alpha L), \tag{1}$$

By expressing the power in dBm, rather than μW, the exponential decay is converted to a linear decaying line, as shown in figure 2a. The slope of the linear fit is an estimate of the waveguide propagation losses, while the intersection point (L = 0) allows you to estimate the coupling losses. Based on the results in figure 2a, waveguide propagation losses for TE mode at 450 nm are ~1.7 dB/cm.

Now that low-loss propagation at 450 nm is ensured, the performance of the 1x8 splitter tree is investigated. In this case, light is coupled into the single input of the 1x8 splitter tree. After coupling, light is distributed over all eight output channels, as shown in figure 3. Since this device is fabricated to potentially function as an OPA, all eight channels are equipped with thermal phase tuners. The heaters and leads allowing for phase tuning are on top of the SiO_2. Since these materials are not transparent, they block the scattered light and cause figure 3 to show some dark areas in which no light is observed. From the visual inspection, it is clear that the excess loss of the individual splitters is low enough to find a substantial amount of light in each of the output ports.

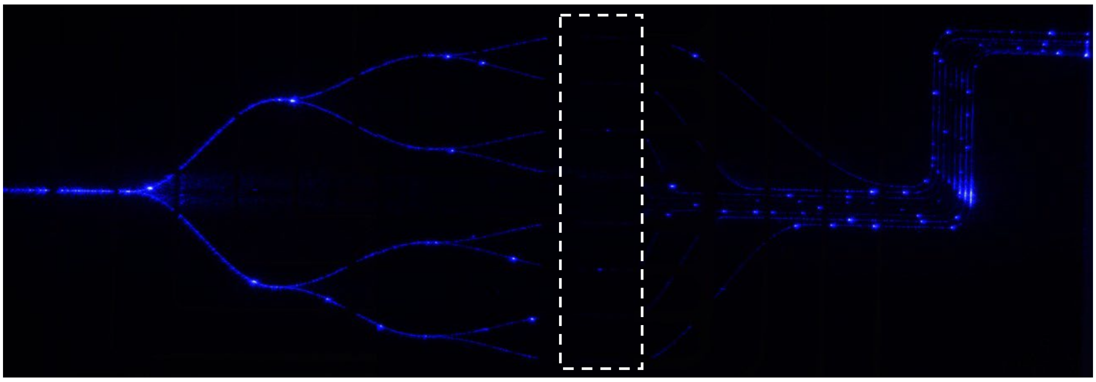


Figure 3. Top view image of the full 1x8 splitter tree, in which a 450 nm (TE mode) signal is split into eight output channels. The phase of each of the eight channels can be tuned separately using the heaters, enclosed by the white dashed region.

The measured output power for each of the eight outputs in the 1x8 splitter tree is shown in figure 2b. It can be seen that the power of the measured outputs are nearly uniform in the first measurement. There is some variability in the measured output power, causing the power to vary from output to output. This variability can be most likely ascribed to having insufficient control over the coupling efficiency. From measurement to measurement, minor temperature fluctuations might have caused misalignments that could be responsible for the variability. It is important to note that these measurements have been performed with a setup in which there is no temperature control. By putting the PIC on a heater, and enclosing it to minimize convective heat flow, these effects might be prevented.

Furthermore, in repeating the measurements, it is observed that the coupling is not fully reproduceable. This lack of reproducibility is most obvious from the measured power at output five. Since we go to shorter wavelengths, the ability of light absorption by dust particles in the environment increases. Therefore, the difference in the measured values for output five could be ascribed to absorption of light by a particle. Therefore, it is important to consider an enclosure for the setup, to prevent these kinds of effects.

3. Conclusion

We have demonstrated low loss sputter coated Al_2O_3 waveguides with SiO_2 cladding, with losses down to 1.7 dB/cm at 450 nm. We then checked the performance of the fabricated splitter on this platform, and the results indicate relative uniformity in output power.

References

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