Ultra-broadband Spectral Beam Combiner

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Abstract: A novel ultra-broadband spectral beam combiner is designed and demonstrated spanning greater than four octaves from ultraviolet to mid-wave infrared bands with low M squared output.
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1. Introduction

High power and broadband sources spanning ultraviolet to mid-infrared wavelengths are highly desirable technologies for integrated solutions to molecular detection and sensors [1-2]. The ultra-broadband spectral beam combiner, compatible with integrated heterogeneous laser sources [3-5], can provide a discrete array of wavelengths covering the UV to Mid-IR wavelength range from a single waveguide output with high beam quality by designing for a low M squared output. Similar beam combining systems with comparable performance and functionality have only been demonstrated with non-integrated, free space optical components.

Previous examples of adiabatic coupler analysis, such as [6-7], treat each waveguide propagation constant, β, as slowly varying such that β is treated as a constant along the coupler length. Previously derived expressions with constant β do not agree with the performance of this coupler so relevant analysis must include propagation constants with a finite derivative with respect to the propagation distance. Beam propagation method (BPM) simulation software was instead used to design this coupler and predict coupling efficiency trends versus coupler length and wavelength.

The goal is to design a coupler that has high coupling efficiency from the input fundamental mode to output fundamental mode across as broad of spectrum as possible such that the limiting factor on the transmission bandwidth is the material absorption bandwidth. By utilizing adiabatic coupling from one of the inputs for a longer wavelength regime and minimal coupling from the other input for a shorter wavelength regime, the fundamental mode transmission can reach above 90% for a four octave span from UV to Mid-IR with a single narrow transition band where incomplete coupling occurs and transmission falls as low as 50%. This is the undesirable region of operation so it is shown here that this region can be engineered to occur at a particular wavelength band.

2. Ultra-broadband combiner

The ultra-broadband coupler has two input waveguides, labeled the “bar” and “cross” inputs, and a single output waveguide, as shown in Fig. 1. The ultra-broadband combiner’s length is minimized while maintaining adiabaticity by simultaneously tapering the coupler gap and each waveguide width along the length of the coupler.

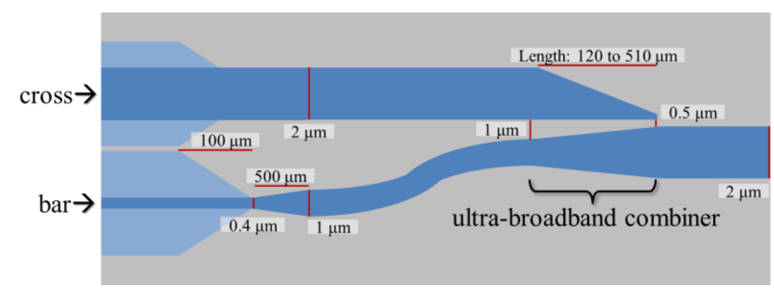

Fig. 1. Ultra-broadband combiner and input tapered waveguide schematic. Light blue color represents 100 nm tall Si_3N_4, blue color represents 200 nm tall Si_3N_4, and the grey color represents the SiO_2 cladding.

The bar input waveguide is initially a partially etched 0.4 µm wide buried rib in order to minimize higher order mode excitation during the measurement. This input waveguide is then adiabatically tapered in two steps to a fully etched 1.0 µm wide buried channel waveguide for the input to the ultra-broadband combiner. Similarly, the cross input waveguide is a 2 µm buried rib and is tapered to a 2 µm buried channel waveguide.

This device was fabricated using 200 nm stoichiometric Si_3N_4 on 2 µm thermal SiO_2 on 4 inch silicon wafers with 2 µm PECVD SiO_2 deposited for the top cladding. The Si_3N_4 was etched with ICP. Microscope images in Fig. 2 show the fabricated devices and the output waveguide facets.

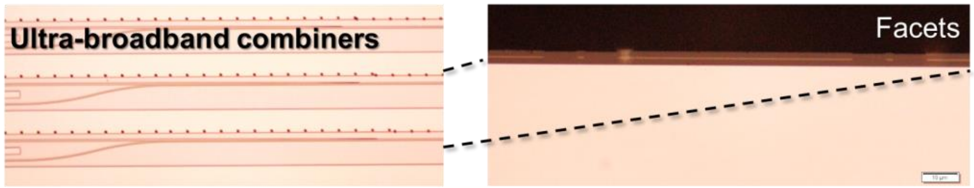

Fig. 2. Fabricated ultra-broadband combiners top view and facet view.

The device yield was 100% for the 90 measured devices out of 1680 devices processed on a 4-inch wafer. Etched channels in the cladding silicon dioxide are visible along the side of the coupler. These are not used here, but are on the mask to allow a substrate undercut to reduce substrate leakage loss of the longest wavelengths.

3. Results and Discussion

The measured transmission above and below the cross-over wavelength corresponds well with the BPM simulation in Fig. 3. The transition band is slightly blue shifted due to several fabrication issues including strain and the PECVD top cladding deposition, affecting the material indices, which were not accounted for in this simulation.

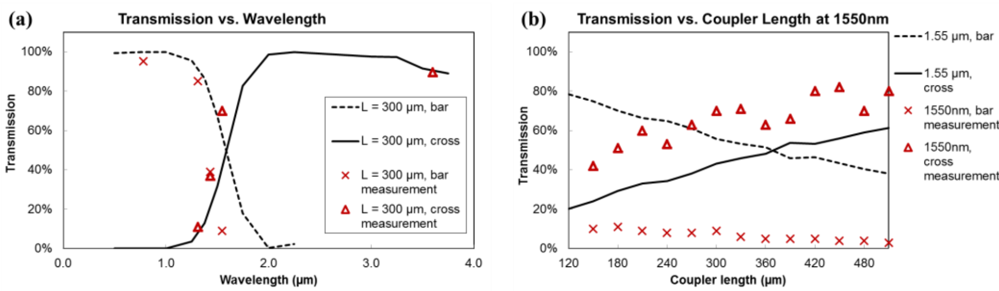

Fig. 3. (a) Transmission vs. wavelength for 300 µm coupler length and (b) transmission vs. coupler length for 1550 nm wavelength in the bar and cross inputs including overlaid BPM simulated transmission.

We have demonstrated ultra-broadband transmission greater than 90% over multiple spectral bands and minimized the band where transmission decreases less than 90%. This technology is demonstrated on an ultra-broadband platform compatible with existing spectral combining technologies and lasers bonded to silicon. We have demonstrated heterogeneously integrated lasers on silicon at wavelengths 1.06, 1.25, 1.65, and 2.0 µm. It is now feasible to envision an integrated array of lasers spanning UV to Mid-IR bands spectrally combined into a single output waveguide for high power and ultra-broadband applications.

4. References

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