Automated Design of Nanophotonic Waveguide-to-Waveguide Couplers

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Abstract: We demonstrate a design algorithm which automatically generates wavelength-scale coupling devices between arbitrary waveguide modes with high efficiency. Our algorithm is fast (∼20 min.), can be extended to multiple dimensions, and requires no trial-and-error.

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1. Motivation

In order to route and process optical information on-chip, it is absolutely critical to be able to efficiently transfer photons from one waveguide mode to another. However, current strategies either 1) require large device areas and tunable material parameters, 2) are only applicable to effectively 1D systems, or 3) operate on brute force parameter search.

We present an algorithm that quickly (∼20 min.) designs high efficiency (∼95% conversion) nanophotonic waveguide couplers in two dimensions. The resulting devices are extremely compact, on the order of only 1-2 vacuum wavelengths per side, and can couple between seemingly arbitrary waveguide modes. Notably, neither trial-and-error nor the modeling of device subcomponents are utilized.

2. Method

The algorithm operates by calculating the boundary electromagnetic fields needed for perfect operation (100% conversion), and then varying the interior fields and permittivities to reproduce the boundary fields. Numerically, we fix $H(border) = H_{\text{perfect}}$, and then minimize the residual in the electromagnetic wave equation, $\|\nabla \times \varepsilon^{-1} \nabla \times H - \mu\omega^2 H\|^2$, by varying both $H(interior)$ (interior magnetic field) and ε (permittivity).

Note that the algorithm actually places much greater emphasis on achieving perfect device performance than even satisfying physics (the wave equation)! Specifically, it is this "objective-first" approach, coupled with the boundary field formulation, that greatly speeds up the design process by eliminating the need to repeatedly solve the wave equation.

Lastly, we validate our designs in simulation (finite-difference frequency-domain) by exciting the input waveguide mode and then calculating the transmitted power in the desired output waveguide mode.

3. Results

Figs. 1, 2 and 3 show the result of our algorithm, as applied to the design of nanophotonic waveguide couplers in two dimensions.

Note that we allow ε to vary continuously between the permittivity of air and silicon, even though discrete values are more amenable to fabrication.

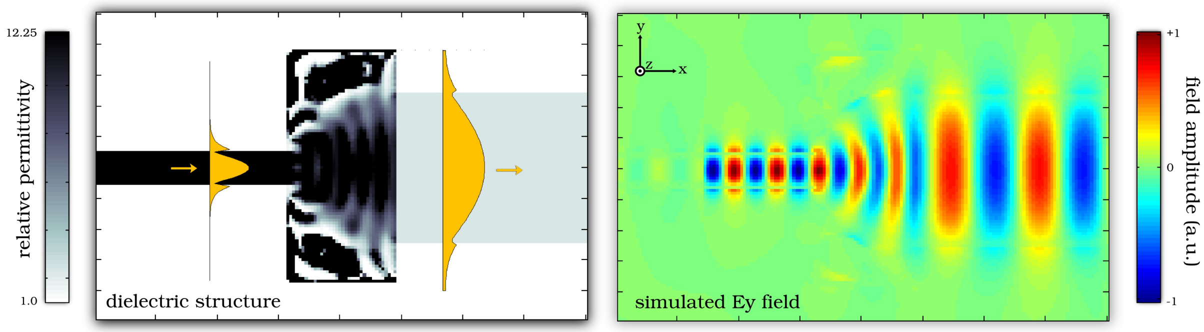

Fig. 1. caption test