Dielectric-plasmonic waveguide couplers: an explorer's map

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Photonic integrated circuits (PICs) rely on the efficient transfer of light between waveguides [1]. One common approach to achieve this is based on directional coupling, wherein two adjacent waveguides with the same propagation constant periodically and efficiently exchange power. Directional couplers can be short ($L \gtrsim \lambda$) and are typically composed of dielectrics with wavelength-scale lateral dimensions. Further miniaturization to deep sub-wavelength scales is possible using plasmonic (metal) waveguides [2], but they are lossy, which complicates design optimization procedures. Full-wave finite element method (FEM) design approaches are flexible, but slow and resource-intensive. A simpler method relies on calculating the Eigenmodes (EM) of each waveguide, accounting for excitation/propagation of each EM [1, 2]. The simplest model uses coupled mode theory (CMT), where only two parameters are required: the propagation constant $\beta = k_0 n_{\text{eff}}$ and the coupling parameter κ [1]. CMT is less used in plasmonic PIC designs, because calculating κ rigorously requires complicated overlap integrals [3]. Here we present a simplified CMT model where lossy dielectric-plasmonic coupling is a perturbation of the lossless case [1]. Fig. 1(a) shows the power distribution in a phase-matched plasmonic directional coupler: in evaluating the power in the dielectric- and plasmonic- regions, we find that all methods agree. We construct a map of the coupling efficiency η_{max} and its associated coupling length L_c as a function of modal parameters $\Im m(n_{\text{eff}})$ and $\Delta n_{\text{eff}} = 2\kappa/k_0$. The results, in regions where CMT is valid ($\Delta n_{\text{eff}}/n_{\text{eff}} < 0.1$), is shown in Fig. 1(c). This "explorer's map" will be useful in designing any dielectric-plasmonic PIC.
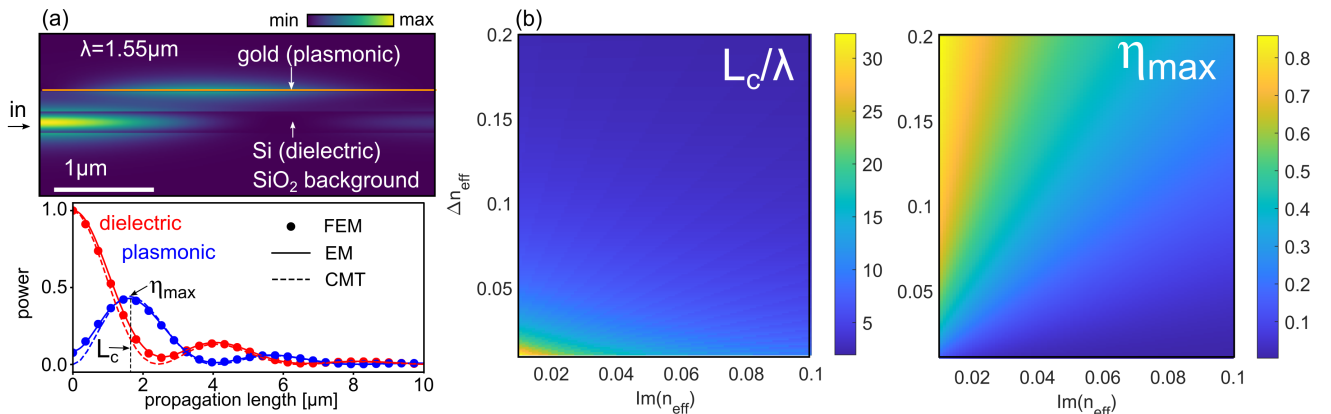

Figure 1: (a) Example plasmonic directional coupler calculations. (c) η_{max} and L_c/λ maps.

[1] A. K. Taras *et al.*, *Advances in Physics: X* 6, 1894978 (2021).

[2] A. Tuniz and M. A. Schmidt, *Optics Express* **24**, 7507-7524 (2016).

[3] S.-L. Chuang, *Journal of Lightwave Technology*, **5** 5 (1987).