Compact couplers between dielectric and metal-dielectric-metal plasmonic waveguides

Georgios Veronis, Wonseok Shin, and Shanhui Fan
Department of Electrical Engineering, Stanford University, Stanford, California 94305
gveronis@stanford.edu

Abstract: We theoretically investigate the properties of compact couplers between high-index-contrast dielectric waveguides and metal-dielectric-metal subwavelength plasmonic waveguides. We show that they can be designed to have high transmission efficiency over a broad range of wavelengths.

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1. Introduction

It has been shown that a metal-dielectric-metal (MDM) structure with a dielectric region thickness of ~100 nm supports a propagating mode with a nanoscale modal size at a wavelength range extending from DC to visible [1]. Thus, such a waveguide could be potentially important in providing an interface between conventional optics and subwavelength electronic and optoelectronic devices. In such waveguides the propagation length of the fundamental mode is limited by material loss in the metal and is on the order of tens of micrometers at frequencies around the optical communication wavelength (λ_0=1.55 μm) [2]. Thus for longer distances it is expected that conventional dielectric waveguides with diffraction limited optical mode confinement will be used to carry the optical signal. The propagation length in dielectric waveguides is primarily limited by fabrication related disorders and is orders of magnitude larger than the propagation length of MDM plasmonic waveguides [3]. Couplers between MDM and dielectric waveguides will therefore be essential components for most applications involving the use of MDM waveguides.

2. Couplers without transition region

In this paper we theoretically investigate the coupling of high-index contrast dielectric waveguides to MDM plasmonic waveguides. We use the finite-difference frequency-domain (FDFD) method [4].

We first consider a coupler created by simply placing an air-silicon-air dielectric slab waveguide terminated flat at the exit end of a two-dimensional silver-air-silver MDM plasmonic waveguide (inset of Fig. 1a). In Fig. 1a we show the coupler transmission as a function of the width of the plasmonic waveguide w_p at λ_0=1.55 μm. The width of the dielectric waveguide is w_d = 300 nm, which approximately corresponds to the optimal width of a silicon slab waveguide surrounded by air that achieves the minimum TM modal size. We observe that the transmission efficiency in this coupler is high and the maximum transmission of 68% is obtained for w_p=40 nm. The transmission is also weakly dependent on w_p for w_p >20 nm. In Fig. 1b we show the profile of the magnetic field for a coupler with w_d=300 nm, w_p=50 nm. The power is incident from the left, so that the incident and reflected waves result in an interference pattern in the dielectric waveguide.

In general we found that for a given width of the subwavelength MDM waveguide w_p, there is an optimum width of the dielectric waveguide w_d which maximizes the transmission efficiency and vice versa. We also found that for a given w_d the optimum w_p is significantly smaller than w_d. This is due to the fact that a subwavelength MDM waveguide collects light from an area significantly larger than its cross-sectional area. More precisely, we found that the transmission cross section of a MDM waveguide, defined as the transmitted power into the waveguide normalized by the incident plane wave power flux, is significantly larger than its geometric cross-sectional area. On the other hand, we found that the transmission cross section of dielectric waveguides is approximately equal to their geometrical area.

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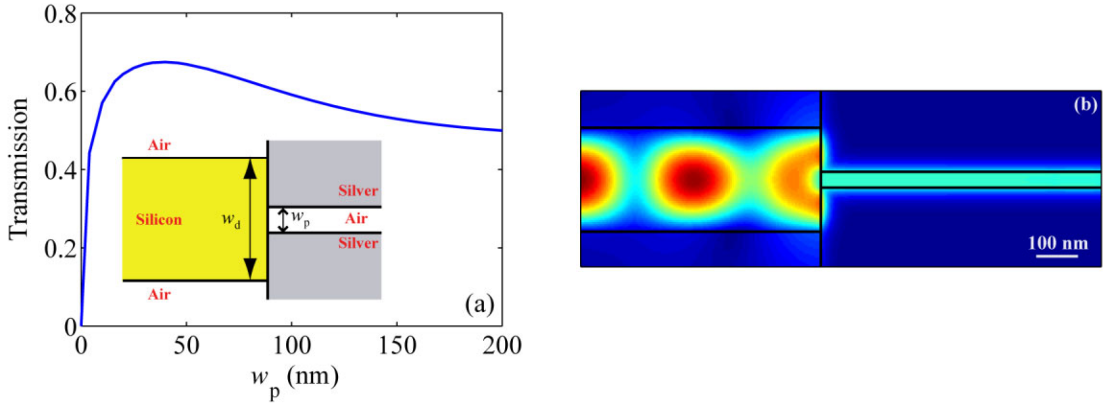

Fig. 1. (a) Power transmission efficiency of a coupler between a dielectric and a MDM waveguide as a function of the width of the plasmonic waveguide w_p at λ_0 =1.55μm, calculated using FDFD. The coupler, created by placing the dielectric waveguide terminated flat at the exit end of the MDM waveguide, is shown in the inset. Results are shown for w_d = 300 nm. (b) Profile of the magnetic field amplitude for w_d =300 nm, w_p =50 nm.

3. Couplers consisting of multisection tapers

To further increase the transmission, we design a coupler consisting of a multisection taper shown in Fig. 2a. The coupler design used here consists of a number of dielectric waveguide and MDM waveguide sections. The widths of these sections are optimized using a genetic global optimization algorithm [5] in combination with FDFD. Using this approach we designed a coupler with 93% transmission efficiency for w_d=300 nm, w_p=50 nm at λ_0=1.55 μm. In this design we use 4 dielectric waveguide sections and 4 MDM waveguide sections. The lengths of all waveguide sections are 50 nm. The designed coupler is therefore extremely compact with a total length of 400 nm. The magnetic field profile for this optimized coupler design is shown in Fig. 2b.

Both the simple coupler of Fig. 1a and the multisection taper of Fig. 2a were optimized at a single wavelength of λ_0=1.55 μm. We also calculated the transmission efficiency of these couplers as a function of wavelength. We found that in both cases the transmission efficiency is close to its maximum value in a broad range of wavelengths. This is due to the fact that in both cases the high transmission efficiency is not associated with any strong resonances. We also investigated couplers between three-dimensional dielectric waveguides and MDM plasmonic waveguides and showed that they can be designed to have high transmission efficiencies similarly to the corresponding two-dimensional devices.

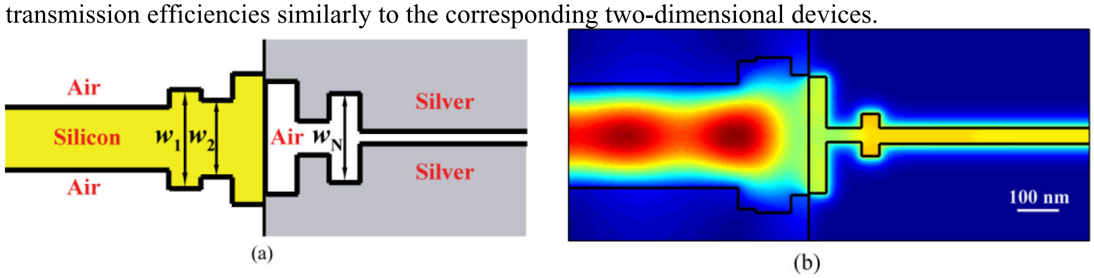

Fig. 2. (a) Schematic of a coupler consisting of a multisection taper. (b) Profile of the magnetic field amplitude of the optimized coupler design for w_d =300 nm, w_p =50 nm and 8 waveguide sections. The optimized widths of the dielectric waveguide sections are w_1 =420 nm, w_2 =440 nm, w_3 =440 nm, w_4 =340 nm, while the widths of the MDM waveguide sections are w_5 =330 nm, w_6 =40 nm, w_7 =40 nm, w_8 =120 nm.

4. References

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