Crosstalk between three-dimensional plasmonic slot waveguides

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Abstract: We investigate in detail the crosstalk between three-dimensional plasmonic slot waveguides. We show that, with appropriate design, the crosstalk between such waveguides can be greatly reduced, without significantly affecting their modal size and attenuation length.

OCIS codes: 130.2790, 240.6680.

1. Introduction

The capability of guiding light at deep subwavelength scales is of great interest in optoelectronics, in part because such capability may enable ultradense integration of optoelectronic circuits. This prospect for integration has motivated significant recent activities in exploring plasmonic waveguide structures. Among these, two-conductor waveguide geometries, which are the optical analogue of microwave transmission lines, are of particular interest because they support modes at deep subwavelength scale with high group velocity over very wide range of frequencies. As a prominent example of two-conductor waveguide geometries, 3-D plasmonic slot waveguides, consisting of a deep subwavelength slot introduced in a thin metallic film, were recently investigated [1-4]. To enable ultradense integration, however, a key consideration is the packing density of optical waveguides and devices. When two waveguides are brought in close proximity, their modes overlap resulting in coupling and crosstalk between the waveguides [5]. The crosstalk, in general, becomes stronger as the distance between the waveguides is reduced. Thus, the coupling strength between two waveguides sets a limit on their maximum packing density.

2. Coupling between plasmonic slot waveguides

In this paper we investigate in detail the crosstalk between subwavelength plasmonic slot waveguides. We consider the coupler formed between two identical waveguides such that phase-matching is automatically satisfied. This corresponds to the strongest coupling [5], and therefore the worst-case scenario for crosstalk. Thus, we start from a single-mode waveguide structure, and consider a coupler structure consisting of two such waveguides, which satisfies the mirror symmetry relation $\varepsilon_r(x,y)=\varepsilon_r(-x,y)$, where ε_r is the dielectric function. Such a coupler supports two eigenmodes with either symmetric or antisymmetric electric field distribution with respect to the y axis. We use a full-vectorial finite-difference frequency-domain method [6] to calculate these eigenmodes, and the corresponding modal propagation constants γ_s and γ_a at a given wavelength λ_0. We found that for coupled lossy waveguides in general there is a maximum in the power transfer efficiency from one waveguide to the other. We also found that the properties of the eigenmodes of the coupler completely determine the transfer behavior between the two waveguides, and thus the maximum transfer power p_{max} from one waveguide to the other is only a function of γ_s and γ_a.

We observe that for coupled 3-D plasmonic slot waveguides, the calculated maximum transfer power p_{max} is orders of magnitude larger than p_{max} for the corresponding 2-D metal-dielectric-metal (MDM) plasmonic waveguides (Fig. 1). We emphasize that, while in the 2-D case the coupling occurs only through the metal, in the 3-D case the coupling occurs primarily through the dielectric, in which the evanescent tail is much larger compared to the one in the metal.

3. Reducing crosstalk between plasmonic slot waveguides

Here we show that, with appropriate design, the crosstalk between 3-D plasmonic slot waveguides can be reduced even *below* the crosstalk levels of 2-D MDM plasmonic waveguides, without significantly affecting their modal size and attenuation length.

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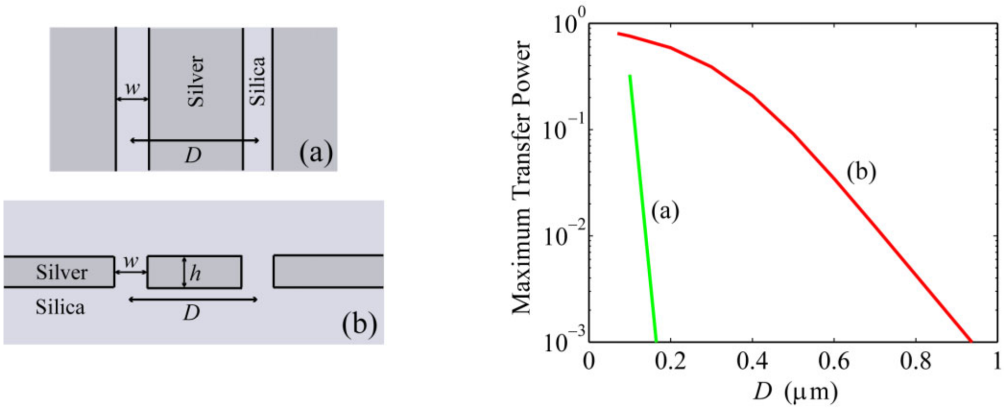

Fig. 1. Maximum transfer power p_{max} as a function of the distance D between two coupled 2-D MDM plasmonic waveguides (green line), and between two coupled 3-D plasmonic slot waveguides (red line). In all cases, the slot widths are w=50 nm, the metal film thicknesses are h=50 nm, and the operating wavelength is λ_0=1.55 μm.

As a starting point, to reduce the coupling through the dielectric, we increase the thickness h_i of the metal film separating the two slots (Fig. 2(a)). We observe that as h_i increases, the coupling strength between the slots decreases, so that p_{max} decreases (Fig. 2(a)). In addition, for h_i>0.9 μm, the crosstalk between 3-D plasmonic slot waveguides is reduced below the crosstalk levels of the corresponding 2-D MDM plasmonic waveguides (Fig. 2(a)).

The crosstalk between the waveguides can be further reduced by using an *I*-shaped central metal region (Fig. 2(b)), which further reduces the coupling through the dielectric. We observe that, for a given thickness h_i, as w_i increases, the coupling strength between the slots decreases, so that p_{max} decreases (Fig. 2(b)). In addition, we found that the additional metal films do not significantly modify the modal power density profile, and that the attenuation length of the supported modes is modified by only ~1%.

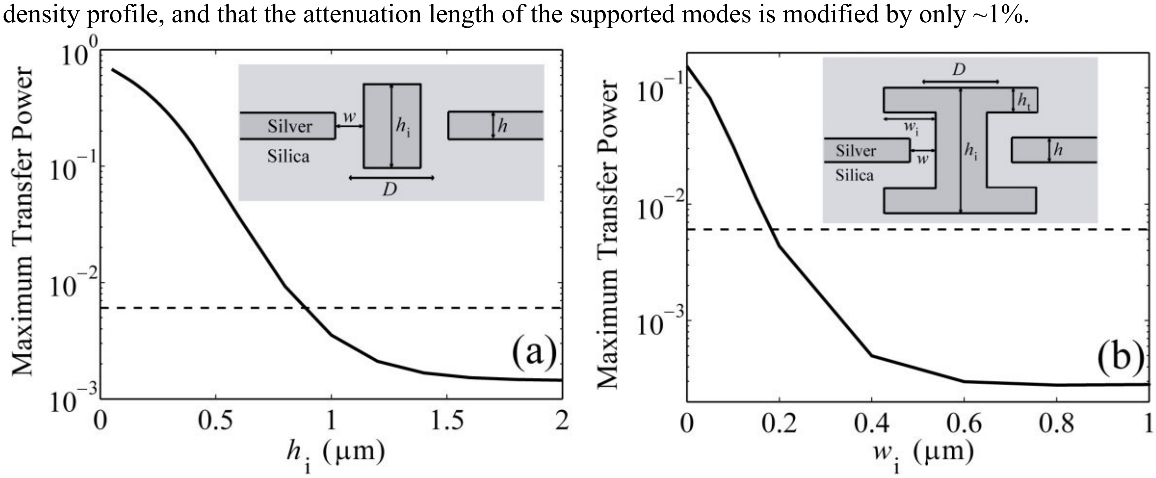

Fig. 2. (a) Maximum transfer power p_{max} as a function of h_i for a structure (inset), in which the metal film separating the two slots has an increased thickness (solid line). Also shown is p_{max} for two coupled 2-D MDM plasmonic waveguides with the same w and D (dashed line). The distance between the two plasmonic slot waveguides is D=150 nm. All other parameters are as in Fig. 1. (b) Maximum transfer power p_{max} as a function of w_i for a structure (inset), in which the metal region separating the two slots is *I*-shaped (solid line). The metal film thicknesses are h_i=400 nm, h_t=50 nm. All other parameters are as in (a).

4. References

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