ENHANCING PROPAGATION LENGTHS OF SURFACE PLASMON POLARITONS IN NANOSCALE WAVEGUIDE DEVICE

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INTRODUCTION

Surface plasmon polaritons (SPPs) are propagating electromagnetic surface waves that are evanescently confined to a metallic surface (1). When efficiently excited, SPPs can be intense relative to the incident light, making them attractive for use in a range of applications, such as chemical and biological sensing, spectroscopy, telecommunication, imaging and device physics. For many of these applications, the SPP propagation length, L_x, on the surface should be as long as possible. We investigate the enhancement in L_x achieved using asymmetric waveguides (see Figure 1) with a variety of glass core thicknesses, d (2, 3).

THEORY

We use the FDTD method (4) with auxiliary differential equations and the total-field scattered-field approach to solve Maxwell's curl equations,

$$\frac{\partial \mathbf{E}}{\partial t} = \frac{1}{\varepsilon_r}\nabla\times\mathbf{H}, \quad \frac{\partial \mathbf{H}}{\partial t} = -\frac{1}{\mu_r}\nabla\times\mathbf{E}, \qquad [1]$$

for the structure in Figure 1. The minimum incident angle for light to efficiently couple into SPPs via momentum matching for the attenuated total reflection method shown in Figure 1 is given by

$$\theta_{SPP} = \sin^{-1}\left\{\left(\varepsilon'_m(\omega)\varepsilon_1/\varepsilon_2(\varepsilon'_m(\omega)+\varepsilon_1)\right)\right\}, \qquad [2]$$

where a Drude model is used to describe the dispersive dielectric constant of the metal: $\varepsilon_m(\omega) = \varepsilon_m'(\omega) + i\,\varepsilon_m''(\omega)$. The calculations we present correspond to an incident wavelength λ_0 = 532 nm, dielectric constants $\varepsilon_1 = \varepsilon_3 = 1.0$ (air), $\varepsilon_2 = 2.25$ (glass), and $\varepsilon_m = -10.1 + i\,0.84$ (silver), an incident angle $\theta_{SPP} = 44.6$, metal thickness t_m = 30 nm, and varying values of core thickness d.

We compare FDTD results with frequency domain modal calculations (5) for the corresponding transverse magnetic (TM) waveguide modes of the propagation region in Figure 1. For a given optical frequency ω, waveguide modes are defined as solutions of Maxwell's equations satisfying the appropriate continuity boundary conditions at each interface as well as asymptotic boundary conditions. We calculate the propagation constants, $k_x = \beta + i\alpha$, where the imaginary component, α, is related to the propagation distance L_x.

RESULTS

Electric field intensities are given in Figure 2 for two representative cases: $d = \infty$ (top) and d = 15 nm (middle). The FDTD results show an oscillatory dependence of the SPP propagation length, L_x, as a function of d, with maxima corresponding to thirty-fold enhancements (Figure 2, bottom). Modal analysis (to be presented) shows that maximum values of L_x correspond to the tuning of d through the opening of new TM waveguide modes.

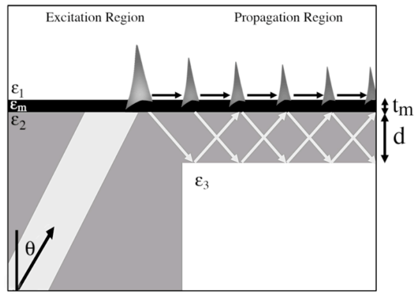

Figure 1. Asymmetric waveguide device showing proposed mechanism for increased SPP propagation lengths.

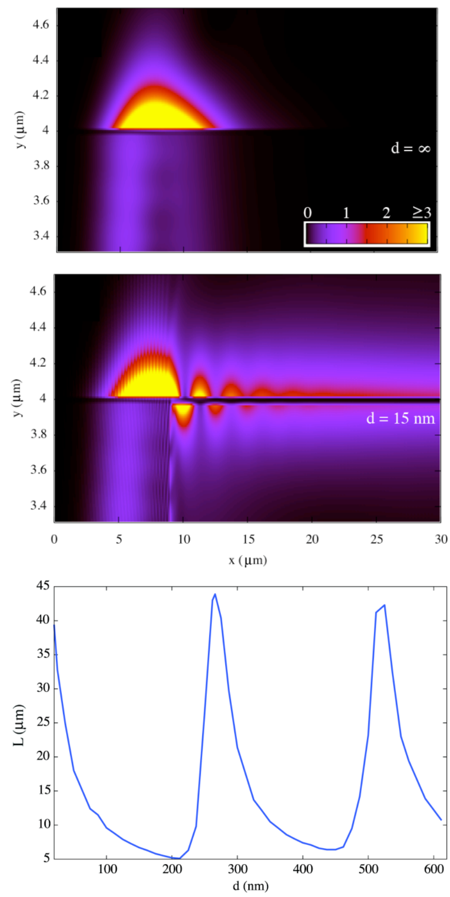

Figure 2: FDTD results showing time averaged electric field intensities for $d = \infty$ (top) and d = 15 nm (middle). Bottom plot shows dependence of SPP propagation lengths, L_x, as a function of core glass thickness, d.

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