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Study of Optical Coupling at Junction of Plasmonic Waveguides

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***Abstract* – To investigate of optical coupling at a junction of plasmonic waveguides is indispensable for designing highly efficient optical devices, such as photodetectors for low incident light. We perform electromagnetic simulation of plasmonic waveguides to study optical coupling and design efficient optical devices. In our proposed devices using plasmonic waveguides, the optical energy can be concentrated as surface plasmon and efficiently transmitted.**

***Index Terms* — optical coupling, plasmonic waveguide, surface plasmon.**

1. Introduction

Recently, plasmonic waveguides have attracted attention for realizing highly sensitive and integrated optical devices; optical energy can be concentrated as surface plasmon and transmitted along plasmonic waveguides.

In this presentation, we will investigate efficiency of optical coupling at a junction of plasmonic waveguides performing electromagnetic simulation. Characteristics of the coupling efficiency and the field distribution will be discussed for a few models of junctions to design highly sensitive devices for weak light sources and efficient energy splitter.

2. Computational Method

Electromagnetic simulation is performed by employing the finite-difference-time-domain (FDTD) method. To apply the finite difference formula for the Maxwell equations, electromagnetic fields can be computed [1, 2].

A plasmonic waveguide consists of a dispersive metal stripe whose characteristic is assumed to be the Drude model. The polarization current density is evaluated by the motion equation of an electron using the auxiliary differential equation (ADE) method [3, 4]. The electromagnetic field and the polarization current density are computed by the following finite difference formulas:

$$\mathbf{H}^{n+\frac{1}{2}} = \mathbf{H}^{n+\frac{1}{2}} - \frac{\Delta t}{\mu_0}\left(\nabla \times \mathbf{E}^n\right), \qquad (1)$$

$$\mathbf{E}^{n+1} = C_1\mathbf{E}^n + C_2\left\{\nabla \times \mathbf{H}^{n+\frac{1}{2}} - \frac{1}{2}(1+\alpha)\mathbf{J}^n\right\}, \qquad (2)$$

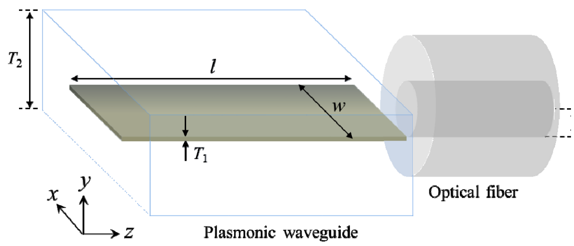

Fig.1 Computational model of a junction between a plasmonic waveguide and an optical fiber.

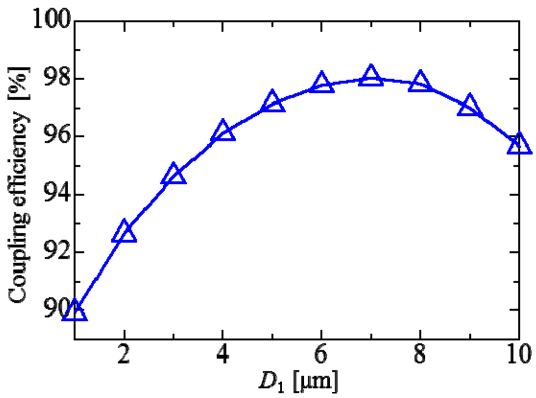

Fig.2 Coupling efficiency of a plasmonic waveguide and an optical fiber.

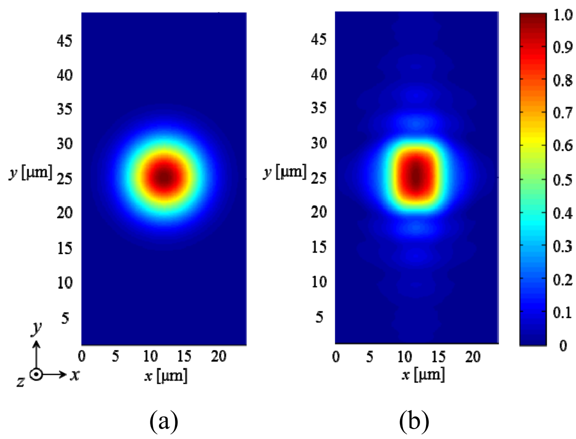

Fig.3 Field distribution of the electric field for (a) optical fiber and (b) plasmonic waveguide.

$$\mathbf{J}^{n+1} = \alpha \mathbf{J}^{n} + \beta\left(\mathbf{E}^{n+1} + \mathbf{E}^{n}\right). \tag{3}$$

where

$$\begin{cases} C_1 = \dfrac{2\varepsilon_0 - \Delta t\beta}{2\varepsilon_0 + \Delta t\beta}, \quad C_2 = \dfrac{\Delta t}{2\varepsilon_0 + \Delta t\beta}, \\ \alpha = \dfrac{1}{\xi}\left\{1 - \dfrac{\Delta t\,\nu}{2}\right\}, \\ \beta = \dfrac{\varepsilon_0 \omega_p^2 \Delta t}{2\xi}, \\ \xi = 1 + \dfrac{\Delta t\,\nu}{2}. \end{cases} \tag{4}$$

3. Computational Results

Figure 1 illustrates the computational model to study the optical coupling between a plasmonic waveguide and an optical fiber. The waveguide is made of a Au stripe. The thickness T_1 is 20 nm, the width w is 8 μm, and it is surrounded by the SiO_2 clad whose thickness T_2 is 44 μm. The optical fiber is assumed to be a single mode fiber and the core radius is 4.1 μm. The incident wave is a Gaussian beam propagating in the z direction with the wavelength of 1550 nm.

We investigate efficiency of the coupling for varying the distance D_1 from 1 μm to 10 μm as shown in Fig. 2. When D_1 is 7 μm, the coupling efficiency becomes the highest and it is about 98%. The field distribution is plotted in Fig. 3. The distribution for the plasmonic waveguide becomes similar to the Gaussian shape when the coupling efficiency becomes the highest.

Figure 4 shows another example to study the optical coupling. The computational model consists of multiple Au stripes in SiO_2 for designing energy splitter. The incident light comes to the junction from the S1 side as surface plasmon.

The electromagnetic simulation is performed to investigate the coupling efficiency and energy splitting ratio. Figure 5 shows the distribution of the electric fields. The fields concentrate around S2 and S3 as surface plasmon and they are equally split. Table 1 gives the energy splitting ratio of plasmonic waveguides S2 and S3. To change the placement, the energy splitting ratio can be controlled.

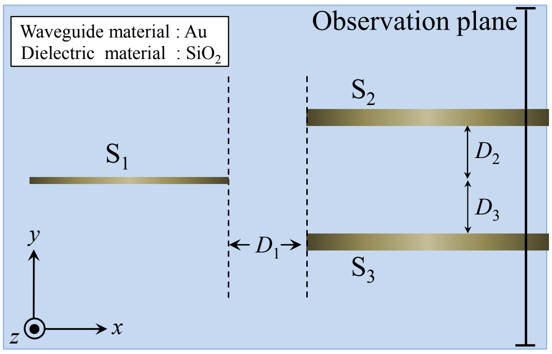

Fig.4 Computational model of a junction between plamonic waveguides.

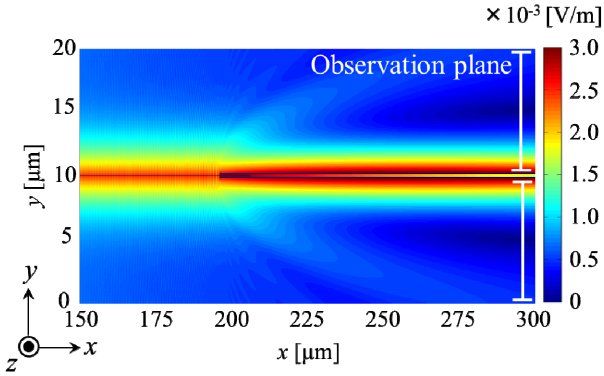

Fig.5 Electric field distribution in the case of three pieces of metal stripe (D_2 and D_3 = 100 nm)

Tab.1 Energy splitting ratio

	S_2 [%]	S_3 [%]
D_1 = 100 nm D_2 = 100 nm	50.0	50.0
D_1 = 500 nm D_2 = 100 nm	47.3	52.7
D_1 = 1000 nm D_2 = 100 nm	44.3	55.7
D_1 = 1500 nm D_2 = 100 nm	41.5	58.5

4. Conclusions

In this presentation, we investigated optical coupling at junctions for a few computational models consisted of plasmonic waveguides. To perform electromagnetic simulation, characteristics of optical coupling at junctions and energy splitting ratio have been clarified.

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