Band-Pass Property of a Three-Dimensional Slit-Type Plasmonic Filter

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***Abstract*—A band-pass property of a three-dimensional (3D) slit-type plasmonic filter based on a metal-insulator-metal waveguide is investigated using the frequency-dependent FDTD method. It is revealed that the 3D filter with a typical metal thickness of 0.05 μm results in a broad transmission bandwidth of 94%, while a two-dimensional filter shows a narrow one of 2%. To obtain a narrow transmission bandwidth for the practical 3D filter, we insert a dielectric material into the slit section and increase the metal thickness to 0.2 μm. It is found that the bandwidth is significantly reduced to 9% for the 3D filter.**

I. Introduction

A metal-insulator-metal (MIM) structure has received considerable attention, since a surface plasmon polariton (SPP) wave can be confined and guided in a subwavelength region. Using MIM structures, several plasmonic filters have been investigated, e.g., the characteristics of stub-type filters have been studied theoretically [1], [2]. However, most of these investigations have been performed using two-dimensional (2D) structures. Very recently, three-dimensional (3D) structures have also been studied for several filters and resonators [3]-[5]. We have shown that the transmission characteristics of a 3D stub-type filter can be improved with a dielectric material being inserted into the stub section [4].

In this article, we investigate the band-pass property of a 3D slit-type filter having a gap partially filled with metal in the MIM waveguide. Since the slit-type filter has been examined only for a 2D structure [6], we first compare the transmission characteristics of the 2D and 3D filters. It is revealed that the 3D filter with a typical metal thickness of 0.05 μm [7] gives rise to a broad transmission bandwidth in which an undesirable transmission occurs at longer wavelengths, while the 2D filter shows a narrow one. To obtain a narrow transmission bandwidth for the practical 3D filter, we insert a dielectric material (SiC) into the slit section and increase the metal thickness to 0.2 μm. It is found that the bandwidth is significantly reduced to 9%, when compared with 94% for the initial 3D filter.

II. Discussion

The slit-type filter to be analyzed is shown in Fig. 1. The metal gap width of the input/output sections is fixed to be $w = 0.05$ μm. The metal thickness is initially chosen to be $h = 0.05$ μm that is typical for the 3D plasmonic gap waveguide [7]. The slit length and width are initially set to be $L_S = 0.3$ μm and $W_S = 0.05$ μm, respectively. The thicknesses of the metal walls are $W_m = 0.02$ μm and $L_m = 0.05$ μm. The midpoints of L_S and L_m match in the z direction. The refractive index in the slit section is denoted by n_S. The metal is chosen to be Ag, the dispersion of which is expressed by the Drude model [3]. The Drude model is incorporated into the FDTD method using the trapezoidal recursive convolution technique [8]. The wavelength response at the output port is calculated using the Fourier transform together with the pulse excitation technique.

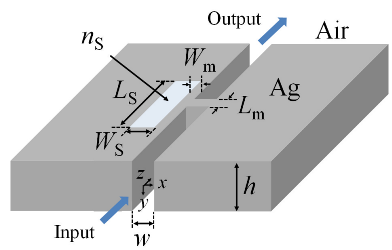

Fig. 1. Slit-type filter.

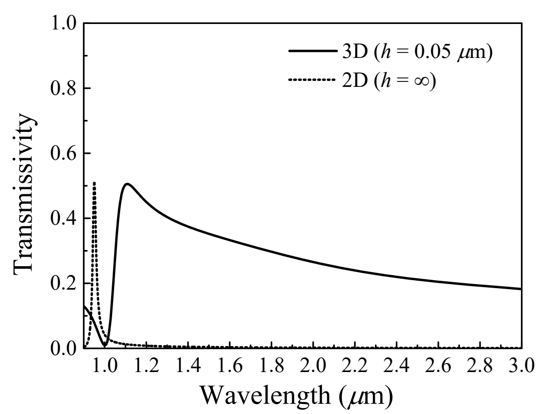

Fig. 2. Transmission spectra.

Figure 2 shows the transmission spectrum of the 3D filter. For comparison, also included is the result of the 2D filter ($h = \infty$). It is seen that the 2D filter shows a narrow transmission peak with a bandwidth of 2%. Unfortunately, a sufficient band-pass property cannot be obtained for the 3D filter, due to an undesirable transmission at longer wavelengths (94% bandwidth). This undesirable transmission is caused by the fact that the radiation fields occurring at the discontinuity of the waveguide are coupled to the following output waveguide.

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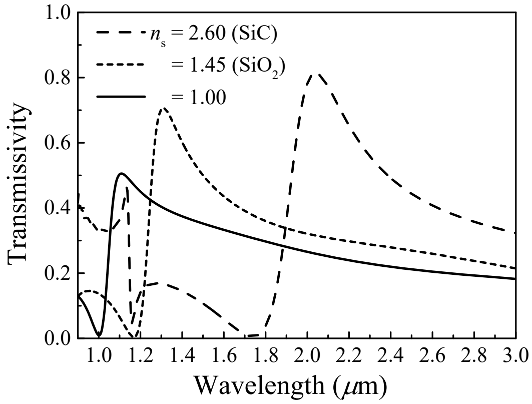

Fig. 3. Transmission spectra for several n_S values.

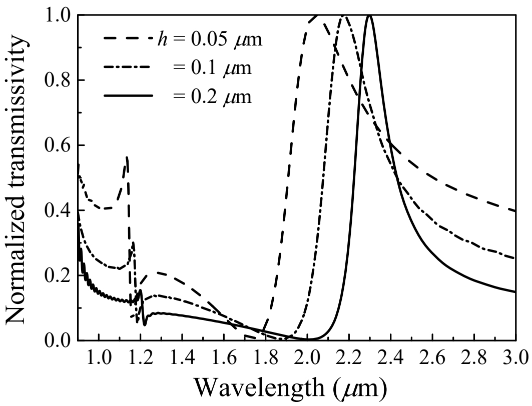

Fig. 4. Transmission spectra for several metal thicknesses.

To obtain a band-pass property for the 3D filter, we first increase the output power at the transmission peak. To do so, we insert a dielectric material into the slit section. The transmission spectra are shown in Fig. 3 for several n_S values, in which $n_S = 1.45$ (SiO_2) and 2.60 (SiC) are chosen. It is found that the transmission peak increases as n_S is increased, i.e., the maximum transmissivity becomes 81% for $n_S = 2.60$, while it is 51% for $n_S = 1.00$. This is because the insertion of a dielectric material enhances field confinement to the slit, leading to reduced radiation fields.

We next reduce the undesirable transmission at longer wavelengths. For this, we need to further reduce the radiation power coupled to the following output waveguide. For the 2D filter ($h = \infty$), there exists no radiation field occurring at the discontinuity, since the field is completely confined to the waveguide and slit. Therefore, it is expected that the use of a thick metal layer can reduce the radiation field even for the 3D structure. Figure 4 depicts the transmission spectra for the filter with an increased metal thickness ($n_S = 2.60$), in which the transmissivity is normalized to its maximum value. Although not shown, the radiation fields are reduced as expected, with a subsequent reduction of the transmissivity at longer wavelengths. In Fig. 4, the bandwidth is reduced to 9% for $h = 0.2$ μm. Note that a thicker metal layer of more than $h = 0.2$ μm results in an increased propagation loss.

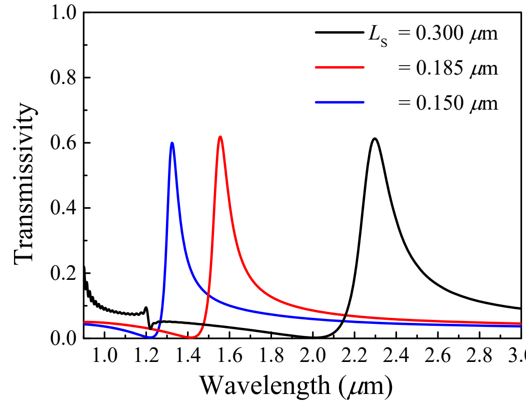

Fig. 5. Transmission spectra for several slit lengths.

We finally adjust the slit length L_S to obtain a maximum transmissivity at 1.31 and 1.55 μm. Figure 5 shows the transmission spectra for several slit lengths ($h = 0.2$ μm). The transmission peak is seen to be obtained at 1.31 and 1.55 μm for $L_S = 0.15$ and 0.185 μm, respectively. A wavelength splitter can be designed using these filters, which will be shown at the presentation.

III. Conclusion

We have investigated a slit-type plasmonic filter with a gap partially filled with metal in the MIM waveguide. It is shown that the 2D filter shows a narrow transmission bandwidth of 2%, while the 3D filter gives rise to a broad one of 94%. To obtain a narrow transmission bandwidth, we insert a dielectric material into the slit section and increase the thickness of the metal layer. As a result, we achieve a reduced bandwidth of 9% for the practical 3D filter.

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