Hybrid Wedge-integrated Plasmonic-photonic Waveguide

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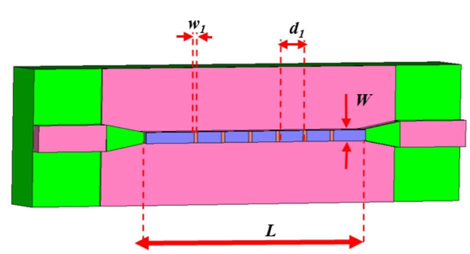
***Abstract*— In this work, a novel design of hybrid integrated plasmonic-photonic waveguide is proposed to work at 1550 nm wavelength and have low loss specification of photonic waveguides and high optical mode confinement of plasmonic waveguides. Unlike other designs, metallic nanoparticles are deposed inside the mask layer to have less radiation from the waveguide and increase transmitting light. Moreover, by using wedge shape for the mask layer of the waveguide, higher order modes suppress.**

I. Introduction

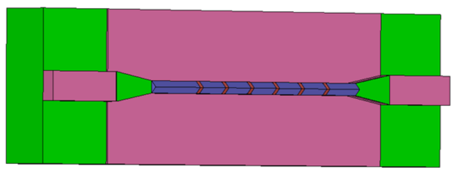
Subwavelength plasmonic waveguides cause revolution in photonic-integrated-circuits (PICs) due to their metallic nature that gives the ability to confine the optical mode in the nanometer scale as explained in [1]. However, the metallic nature of plasmonic waveguides has large propagation loss drawback that limit the utilization of these waveguides in complicated PICs as discussed in [2]. On the other hand, low-loss photonic wave guides such as ones in [3], are suitable for transmitting optical signal over long distances. However, as discussed in [4], due to small refractive index contrast between clad and core in photonic waveguides, optical mode is less confined compare with plasmonic waveguides. Hence, to benefit of high optical mode confinement of plasmonic waveguides and low propagation loss of photonic waveguides, these two different waveguides are co-integrated with each other similar to the structure proposed in [5]. To this end, plasmonic waveguides with maximum efficiency and structure's compatibility with photonic waveguides should be chosen for integrating with photonic waveguides. Among different types of plasmonic waveguides, hybrid plasmonic waveguides attract more attention due to their higher confinement as well as low propagation loss as discussed in [2]. In [1-2], silicon-on-isolator (SOI) compatible hybrid plasmonic waveguide is proposed due to its silicon-based nature. Moreover, in this waveguide, single mode is excited by designing a thin layer of silicon oxide with low refractive index material (SiO_2 with 1.45 refractive index), which is stacked between silicon with high refractive index (Si with refractive index around 4) and metal strip. On the other hand, as discussed in [3], in photonic waveguides, silicon nitride (Si_3N_4) with refractive index around 2 can be used as the mask layer on SOI platform instead of Si due to its 0.1 dB/cm propagation loss in infrared range. As proved in [6], the mask layer should have more than 100 nm thickness to have less sensitivity to deformation during fabrication process. Hence, in this work, similar to [5], to have high efficient hybrid integrated plasmonic-photonic waveguide, photonic waveguide with Si_3N_4 mask layer and hybrid plasmonic waveguide are integrated with each other on SOI platform. However, unlike [5], SiO_2 thickness is thin to support hybrid plasmonic dominant mode and metal nanoparticles are not deposed on the top of the mask layer (Si_3N_4). Here, metallic nanoparticles are placed inside Si_3N_4 layer to have more ability to transmit light instead of radiating it by nanoparticles as nano-antennas (similar [7]). Moreover, effect of mask layer's shape (strip of Si_3N_4 with 100 nm thickness and metallic nanoparticles) on suppressing higher order modes of transmitted light inside the proposed waveguide is studied. The proposed waveguide is designed to work at 1550 nm wavelength (standard telecommunications as discussed in [1]) and simulation is prepared in CST Studio Suite® from 190 THz to 195 THz (infrared range).

II. Waveguide Design

The proposed structure of the hybrid integrated plasmonic-photonic waveguide is shown in Fig. 1 (a) on SOI platform, which is merged to silicon waveguide (used in communications) by linear taper similar to [2]. As discussed in [8], higher order modes are excited around edges of the waveguide. Hence, to suppress higher order modes excited at edges, the proposed waveguide in Fig. 1 (b), has wedge shape mask layer. Both proposed waveguides in Fig. 1, have same dimensions (L = 4450 nm, W = 200 nm, w_1 = 70 nm, d_1 = 480 nm) and work in standard telecommunication range (around 193.5 THz). In these designs, 10 nm SiO_2 layer is stacked between 100 nm mask layer (include Si_3N_4 and silver nanoparticles) and thick Si layer (same dimension as [1]).



(a)



(b)

Fig. 1. (a) Proposed hybrid integrated plasmonic-photonic waveguide and (b) hybride wedge-integrated plasmonic-photonic waveguide.

III. SIMULATION RESULTS

To support that the proposed waveguides in Fig. 1 have more advantage compare with conventional hybrid plasmonic and photonic waveguides, transmission loss and matching of these waveguides should be compared with each other. To this end, magnitude of first mode simulated transmission ($|S_{21}|$) and reflection ($|S_{11}|$) coefficients of waveguides in Fig. 1, hybrid plasmonic waveguide and photonic waveguide with Si_3N_4 mask layer are shown in Fig. 2 (a) and (b) respectively. All of the simulated waveguides have same dimensions and only their mask layer are different as discussed before. As seen in Fig. 2 (a), the simulated $|S_{21}|$ of the hybrid wedge-integrated plasmonic-photonic waveguide is more than others from 190 THz to 195 THz (less transmission loss). Moreover, as seen in Fig. 2 (b), both waveguides of Fig. 1 have acceptable matching in simulated frequency band ($|S_{11}|$ < -10 dB) like photonic waveguide.

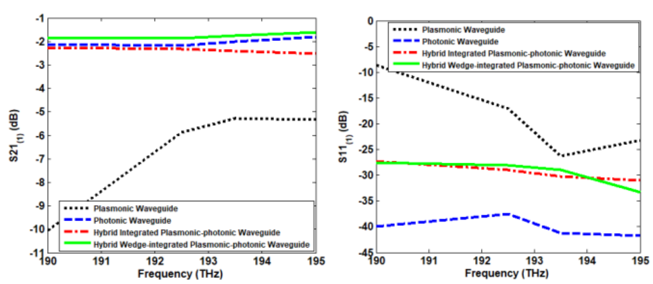


Fig. 2. (a) $|S_{21}|$ and (b) $|S_{11}|$ of simulated waveguides.

Next, to study the ability of the proposed designs in Fig. 1 to suppress higher order modes of light more than hybrid plasmonic and photonic waveguides, ratio of $|S_{21}|$ of second order mode to first mode is depicted in Fig. 3 for these four waveguides. As shown in Fig. 3, only the hybrid wedge-integrated plasmonic-photonic waveguide has the ratio less than 1 meaning second order mode's transmission coefficient is less than first mode. Similarly, in Fig. 4, ratio of $|S_{21}|$ of third order mode to first mode is illustrated for proposed waveguides in Fig. 1, hybrid plasmonic and photonic waveguides. Both proposed designs in Fig. 1, have the ratio less than 1. Hence, based on simulation results, hybrid wedge-integrated plasmonic-photonic is more efficient than other simulated waveguides to transmit light with less loss and more higher order mode suppression.

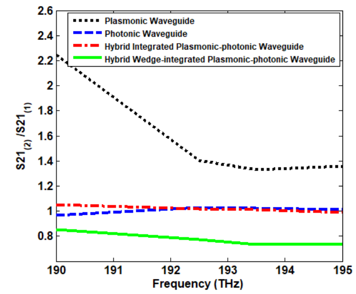


Fig. 3. Ratio of $|S_{21}|$ of second order mode to first mode of simulated waveguides.

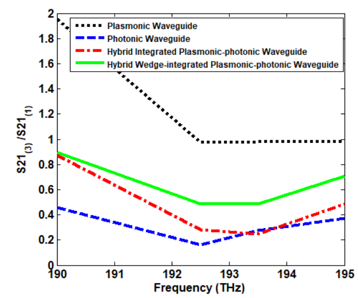


Fig. 4. Ratio of $|S_{21}|$ of third order mode to first mode of simulated waveguides.

IV. CONCLUSION

In this work, the novel hybrid wedge-integrated plasmonic-photonic waveguide is proposed with less insertion loss compare with conventional plasmonic and photonic waveguides and more higher order mode suppression.

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