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Concurrent Dual Band Nanoplasmonic MIM Slot Waveguide Based Directional Coupler

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Abstract: **This article reports the design and numerical analysis of a metal-insulator-metal plasmonic directional coupler. The directional coupler design can be used in the concept of the Step impedance resonators (SIRs); thus only one design is needed for dual-band action in both of the optical bands. Therefore, the structure development in the improved architectures pertaining to filtering as well as multiplexing devices are necessary for end of these kind of specifications without reducing the dimensions of the subsystems. The proposed coupler can be used in both optical bands 1299-nm (O) & 1629-nm (L). The directional coupler design works very well in the improvement of photonic integrated circuits (PICs) and also it can be mixed with existing silicon based photonic circuits.**

Keywords: **Plasmonics, MIM, Directional coupler, Step impedance resonators, PICs.**

I. INTRODUCTION

The future generation systems are designed for dealing with large data transfer in rapid succession, it can effectively runs the wireless communication system in the sub-wavelength range [1-2]. To fulfil this requirement, simultaneous operation and controlling several frequency bands of communication systems might be helpful. Due to this, plasmonic slot waveguide based devices can easily handle or regulate the light within the subwavelength regime and obtain the potential in making of miniaturized PICs. Hence, the advanced designed systems for multiplexing filters are essential for concluding the next generation communication systems (limiting the dimensions of structure, control the utilization of power and expense of complex systems).

Several nanoplasmonic MIM waveguide based devices have been designed such as MIM waveguide [1], dielectric-metal-dielectric (DMD) waveguide [2], MIM-slot waveguides [3], nano-particles and nano-wires [4-5] to implement the optical devices. Out of all these reported structures, MIM waveguide is most suitable due to its subwavelength character along with maximum scale of light detention. Many passive optical structures have been designed and reported based on MIM waveguide, such as filters [6-9], combiner/splitter [10-11], couplers [12-13] and multiplexers /de-multiplexer [14-17].

Since, most of these devices posses subwavelength features; numerical methods pertaining to demanding electromagnetic (EM) analysis are hard to be applied. Consequently, variety of approximate methods in EM analysis for these kind devices is really desired. Particularly, by using transmission line models several plasmonic devices have been designed [18]. Researchers deliver the ideas and regular design methodologies connected from microwave engineering to plasmonics to improve the design capability. It is lucky that the transmission line model directly confirms to the MIM slot waveguide arrangement is quite popular. MIM slot waveguide with stubs [19] and resonators are already designed using transmission lines and have single frequency optical band. No attempt is made to apply for designing a dual-band directional coupler. This is the fact that, we have designed a step impedance resonator (SIR) based dual-band directional coupler using MIM slot waveguide.

This letter is arranged as follows; The transmission line characteristics and edge coupled MIM slot waveguide is introduced in section II. The proposed edge coupled MIM slot waveguide model is applied for analyzing the MIMSIR. The proposed model is justified by a widely recognized full wave simulation method in section III. Finally, the conclusions are discussed in section IV.

II. TRANSMISSION LINE CHARACTERISTICS EDGE COUPLED PLASMONIC MIM WAVEGUIDE

To explain the behavior of plasmonic MIM waveguide based directional couplers in sub wavelength range, the coupled mode theory (CMT) has been proposed by Andrey et.al. [20]. In another way Rezaei et al. have been reported a distributed circuit model for side-coupled MIM waveguide [21]. Till now, the directional coupler designs for a single band operational frequency were reported [22]. There is no report in the literature for the edge coupled MIM waveguide the geometry of which is shown in Fig. 1.

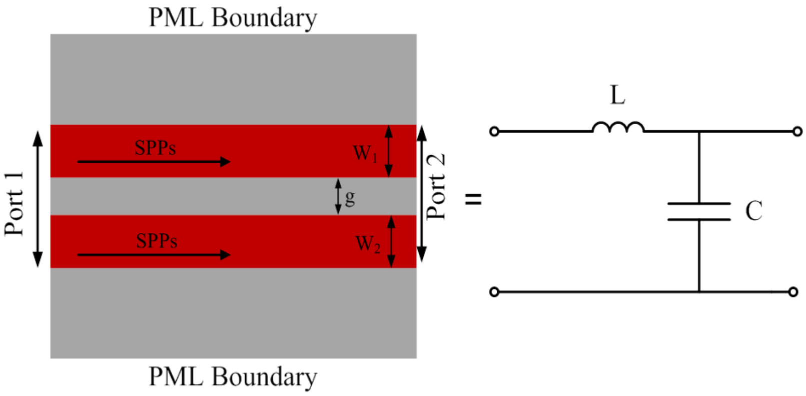


Fig.1 Schematic of Edge Coupled Plasmonic MIM Waveguide

The guiding structures of the coupled waveguide works for both even/odd modes which can be similar to the coupled mode of quasi-TEM transmission lines used at microwave frequencies. To analyze the distribution of the field in couple modes, the full wave simulation software tool (CST Microwave studio) has been used.

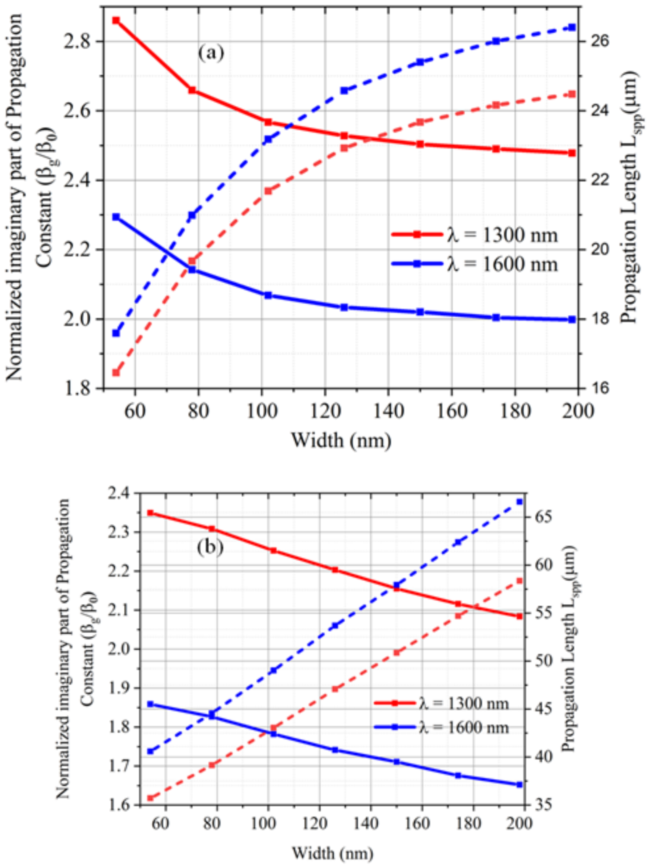


Fig.2 Variation in Normalized imaginary part of Propagation Constant and Propagation Length with Width (W_1) of MIM Waveguide for Wavelength λ=1300-nm and 1600-nm for (a) even mode (b) odd mode.

This section describes the characteristics of the modes supported by the SPPs based edge coupled MIM waveguide. The simulations are carried out by Drude model for silver as a metal [23] and the relative permittivity of the silver is given by

$$\varepsilon_m = \varepsilon_\infty + \frac{\omega_p^2}{j\omega(\Gamma + j\omega)},$$

where $\varepsilon_\infty = 1.38 \times 10^{16}$ radian/ second, and T = 2.73×10^{13} radian/sec. SiO_2 (Silica) has been used as a dielectric material (εd = 2.5). The variations in simulation process in effective index (neff) and propagation length (LSPP) for both the modes (even/odd) as a function of gap-widths (W1 and W2) for optical frequency bands O(1300 nm) and L(1600 nm) are shown in Fig. 2 (a, b) and 3 (a, b) respectively.

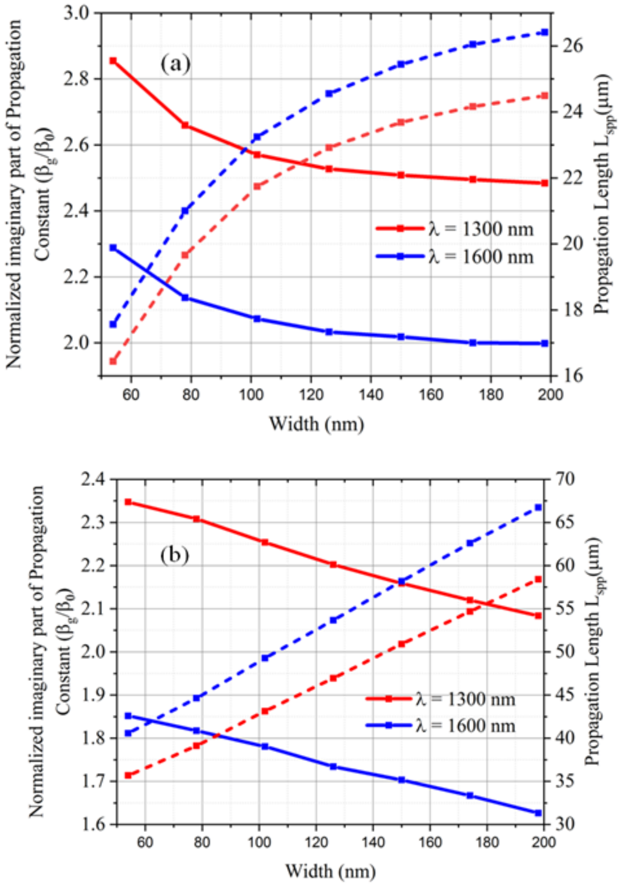
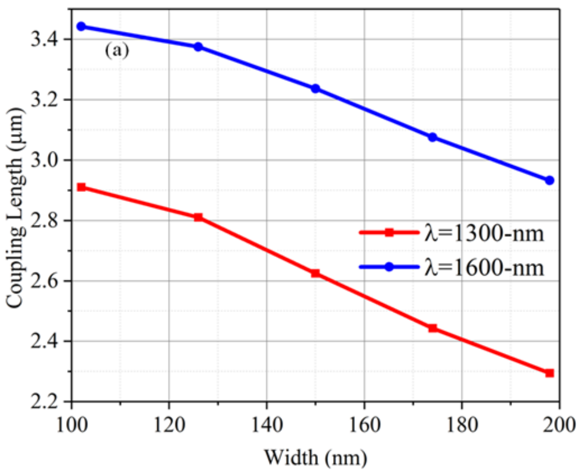


Fig.3 Variation in Normalised imaginary part of Propagation Constant and Propagation Length with Width (W_2) of MIM Waveguide for Wavelength λ=1300-nm and 1600-nm for (a) even mode (b) odd mode.



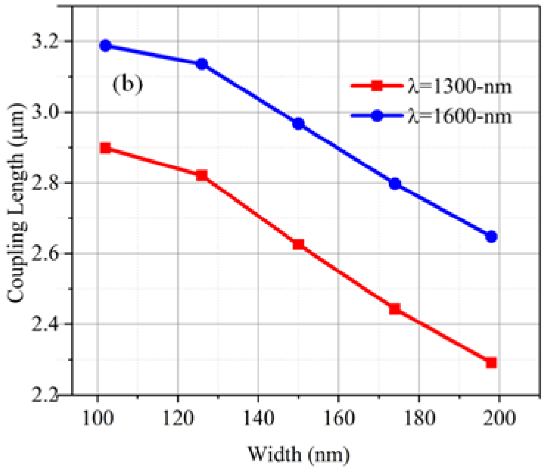


Fig.4 Coupling Length(µm) verses (a)Width (W_2) (b)Width (W_1) of MIM Waveguide for Wavelength λ=1300-nm and 1600-nm

It is well known that the coupling length (LC) of the edge-coupled MIM gap waveguides given by Eq. (1) [24-25]. The variation in coupling length with wavelength as a function of gap width W1 and W2 is shown in Fig. 4 (a, b)

$$L_C = \frac{\pi}{\beta_{odd-\text{mode}} - \beta_{even-\text{mode}}} \quad (1)$$

Where

$$\beta = n_{eff} k_0$$

III. GEOMETRY, RESULTS, AND DISCUSSION

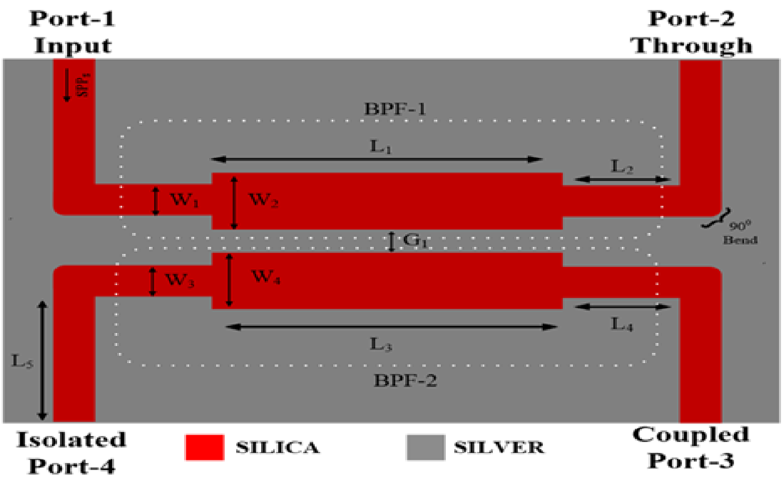
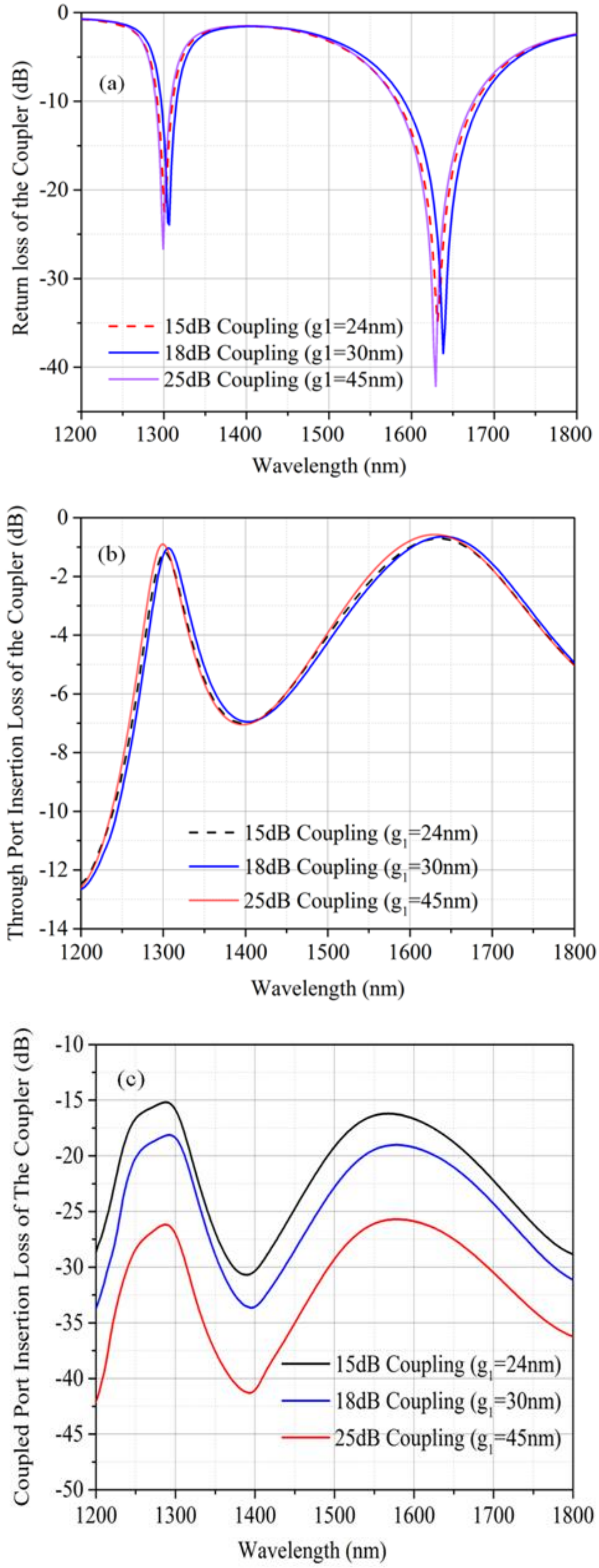


Fig.5 Geometry of the dual band MIMSIR based plasmonic Directional Coupler for fixed widths W_1 =100nm, W_2=360nm, W_3=100nm, W_4=360nm , lengths L_1=2000 nm,L_2=500 nm, L_3=1900 nm, L_4=475nm, L_5=630 nm, G_1=60 nm.

For these structures, the edge-coupled MIM waveguide, the directional coupler has been designed. The uniform side-coupled slot waveguide section has been replaced by a SIR coupled-line section for obtaining the dual-band characteristics, as shown in Fig. 5. The grid sizes (5nm X 5nm) have been used throughout the simulation process using CST Microwave studio. The improved dimensions of the plasmonic MIM waveguide based dual-band directional coupler are: W_1=100nm, W_2=360nm, W_3=100 nm, W_4= 360nm, Lengths L_1 = 2000nm, L_2 = 500nm, L_3 = 1900nm, L_4 = 475nm, L_5 = 630nm and G_1 = 40 nm. The simulation analysis of the transmission and reflection coefficients (direct-port and coupled-port) and isolation of 15-dB, 18-dB and the coupling loss 25-dB is shown in Fig. 6. In both bands, the isolation is more than 36-dB have been achieved. The electric and magnetic field of edge coupled plasmonic MIM waveguide based directional coupler is shown in Fig. 7 for even and odd modes. One can possibly recognize the existence of magnetic-wall (for even-mode) and electric-wall (for odd-mode) at the symmetry of plane.



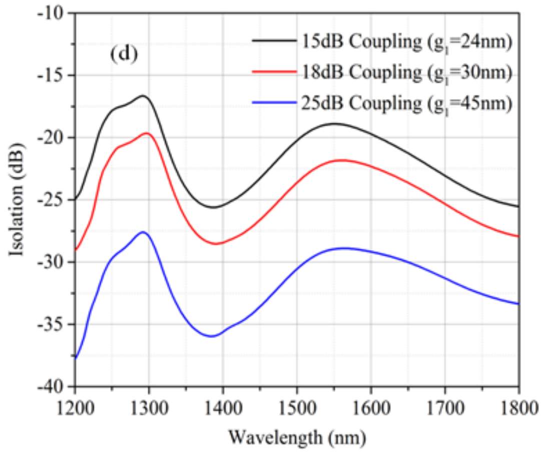


Fig.6 Simulated (a) Return Loss (b) Through port Insertion Loss (c) Coupled port Insertion Loss (d) Isolation (dB) of the Coupler

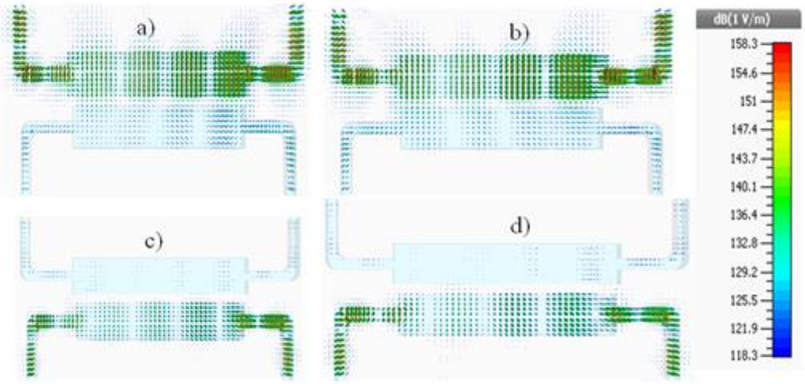


Fig.7 Field distribution at Wavelength 1630-nm

IV. CONCLUSION

Plasmonic edge-coupled MIM waveguide based dual-band directional coupler are designed and presented. The directional coupler design can be used in the concept of the Step impedance resonators (SIRs); thus only one design is needed for dual-band action in both of the optical bands. Therefore, the structure improvement in the enhanced architectures pertaining to filtering as well as multiplexing devices are necessary for conclusion of these kind of specifications without reducing the dimensions of the subsystems. The directional coupler design can be used in the concept of the Step impedance resonators (SIRs); thus only one design is needed for dual-band operation in both of the optical bands (O & L). The present design directional coupler works extremely well in the improvement of photonic integrated circuits (PICs). These designs will be useful for existing silicon PICs.

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