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Design of a Band-Stop Filter Based on Metal–Insulator–Metal (MIM) Plasmonic Structures

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Abstract: n this paper, **a** controllable stop-band filter based on **an** MIM waveguide-coupled resonator cavity is proposed for ultra-wideband (UWB) applications. The designed filter is simulated and analyzed in the mid-infrared region. The transmittance spectrum of this filter was generated using R-Soft CAD software **employing** the 2D Finite-Difference Time-Domain (FDTD) method. To enhance the performance of the proposed filter, the wavelength filtering range was broadened by incorporating a second resonator on the opposite side, **separated by** an optimized distance D between the two cavities. To further improve the filter characteristics, a third and fourth cavity were added, resulting in a wider bandgap width. This topology finds frequent applications in highly integrated photonic circuits.

Keywords: Surface plasmons polaritons, FDTD method, Metal–insulator–metal waveguide, stopband filter .

1. Introduction

Surface plasmon polaritons (SPPs) are hybrid electromagnetic waves that arise from the strong coupling between incident photons and the collective oscillations of free conduction electrons at the interface of a metal and a dielectric material. These surface-bound waves have attracted intense research interest because they possess the unique ability to confine and manipulate light at dimensions significantly smaller than the wavelength of light in free space, thereby bypassing the conventional diffraction limit [1]. This unprecedented waveguiding capability makes SPPs arguably the most viable and promising approach for the miniaturization of optical components and their integration into densely packed plasmonic integrated circuits (PICs), which could potentially revolutionize future information processing systems by combining the speed of photonics with the compactness of electronics.

Within the diverse landscape of plasmonic guiding architectures, metal-insulator-metal (MIM) waveguides have garnered substantial attention from the nanophotonics community. This prominence is primarily attributed to their exceptional capacity for extreme optical confinement within the nanoscale insulator layer, coupled with a relative simplicity in their fabrication process compared to other complex three-dimensional nanostructures [2]. These attributes have positioned MIM waveguides as a robust and promising fundamental architecture for the practical realization of functional chip-scale photonic devices. Leveraging these advantageous dispersion

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properties, a plethora of functional components based on the MIM configuration have been proposed and rigorously investigated, encompassing vital building blocks for optical circuits, including efficient optical filters [3, 4], ultrasensitive refractive index sensors [5, 6], and compact directional couplers [7, 8].

Band-stop filter (BSF) devices based on SPPs phenomenon are attracting more attention because of their importance in optical networks and spectrum select techniques, [9]. In this study, a novel SPPs stop-band filter has been developed and numerically investigated with R-Soft CAD software and the Finite-Difference Time-Domain (FDTD) method, the optical filter structure is based on the MIM waveguide coupled with cavities. This topology finds frequent applications in highly integrated photonic circuits

2. Structure design and simulation results

Our proposed structure is shown in Fig. 1, it consists of a waveguide connected to a resonator cavity. The filter parameters L1 and W are fixed at 200nm and 50nm respectively. This filter's metal area is silver, and its dielectric region is air. The dispersive relative permittivity of Ag is described by the Drude Model [10] :

$$\varepsilon_m = \varepsilon_\infty - \frac{\omega_p^2}{\omega^2 - i\omega\gamma}$$

Here, $\varepsilon\infty=3.7$ represents the dielectric constant at the infinite frequency. $\omega p=1.38 \times 10^{16}$ Hz is the bulk plasma and γ is electron collision frequencies with value, 2.73×10^{13} Hz, .ω is the angular frequency of incident light.

R-Soft CAD software with FDTD method is used to simulate the transmission spectrum of the suggested structure; Outgoing waves are absorbed using the perfectly matched layer (PML), without reflections. We perform 2D simulations due to the significant computational time savings that may be achieved without sacrificing calculation accuracy[11]

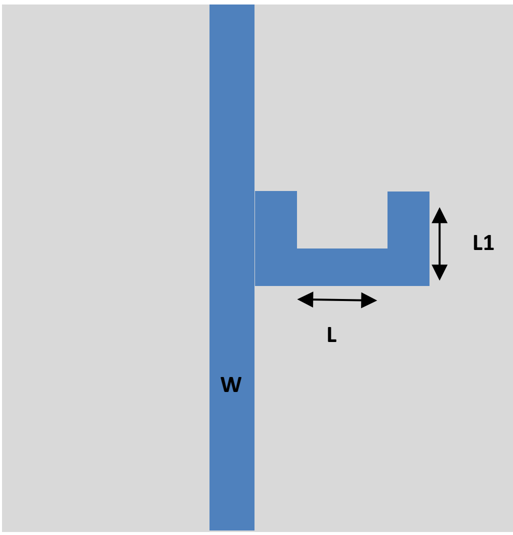

Figure.1 Schematic diagram of proposed filter.

Transverse magnetic (TM0) is the only mode that can be excited by MIM waveguides since the waveguide's width is so narrow in comparison to the incident wavelength. The cavity's resonance wavelength for the TM0 mode can be characterized as follows. [12]:

$$\lambda_m = \frac{2R_e(n_{eff})l_{eff}}{m}, m = 1,2,3 \ldots$$

where $R_e(n_{eff})$ signifies the real part of the SPP's effective refractive index, l_{eff} is the resonator's effective resonance length.

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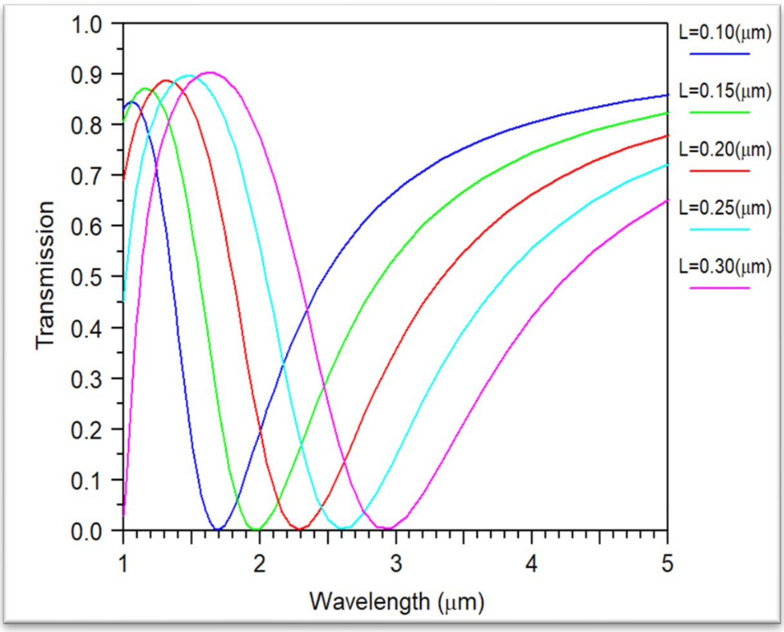
Figure 2(a) illustrates the simulated transmission spectra of the proposed structure under varying geometric conditions, specifically focusing on the influence of the structural parameter L. A detailed analysis of the spectral response reveals a distinct correlation between the physical dimensions of the filter and its resonance characteristics. Notably, as the dimension H1 is progressively augmented from 100 nm to 300 nm, a pronounced redshift is observed, wherein the primary resonance peak consistently shifts toward longer wavelengths. Based on this parametric analysis, it becomes evident that the geometric configuration profoundly impacts the filter's overall efficiency. Consequently, the optimal value for the parameter L1 is established at 100 nm, a configuration that ensures a highly robust transmission spectrum characterized by an ideal resonance profile and maximized transmittance.

(a)



(b)

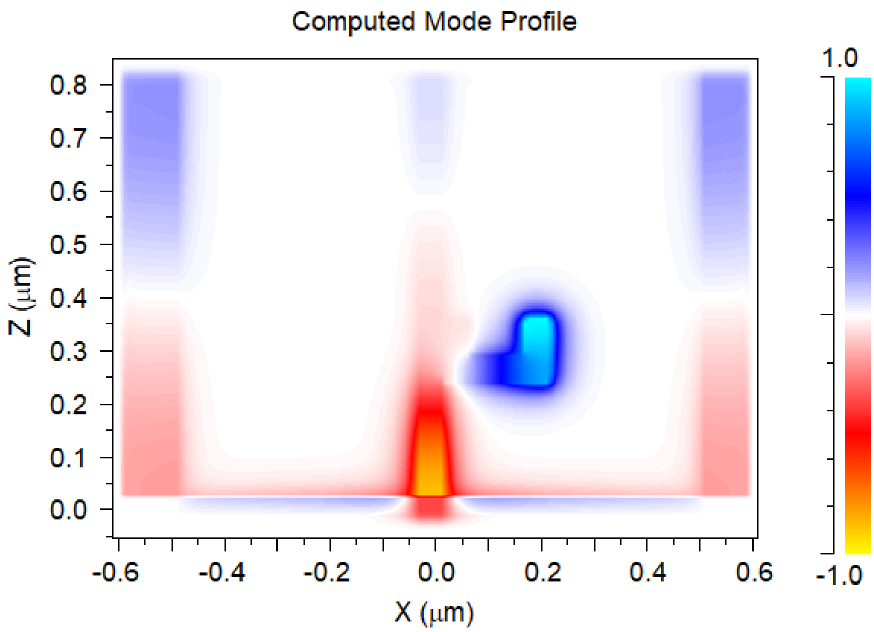


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Figure.2 (a) Reponses spectrum of the designed filter for various H1. (b) The proposed structure's magnetic field distribution at the resonance wavelengths.

Furthermore, the magnetic field distribution at the resonance wavelength 1.65 µm is depicted in Fig. 2. (b). According to this result, the incident light is confined to the resonator cavity.

To improve filter performance, we add a second resonator on the other side of the waveguide that has the same size as the first.(see fig.3) ..

The effect of the distance D between the resonators cavities is studied and illustrated in fig.4. (a) . As a result, with increasing the value D from 70 nm to 320 nm the pass band transmittance at the left side of band gap width is improve and the transmission spectrum forms a U-shaped .

Moreover fig.4. (b) demonstrated that the band gap width of the SPPs filter with two resonators (Green line) is greater than the bandwidth of the SPPs filter with only one resonator (blue line). As a result, the optimal length D is 320nm

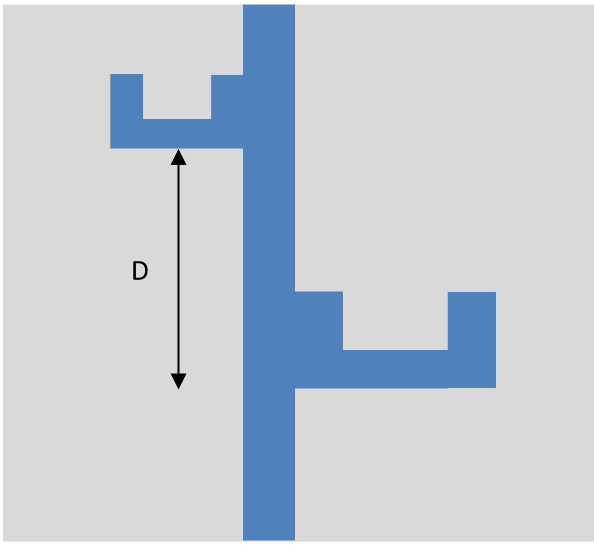

Figure.2 2D Schematic illustration of proposed device with double cavities

(a)

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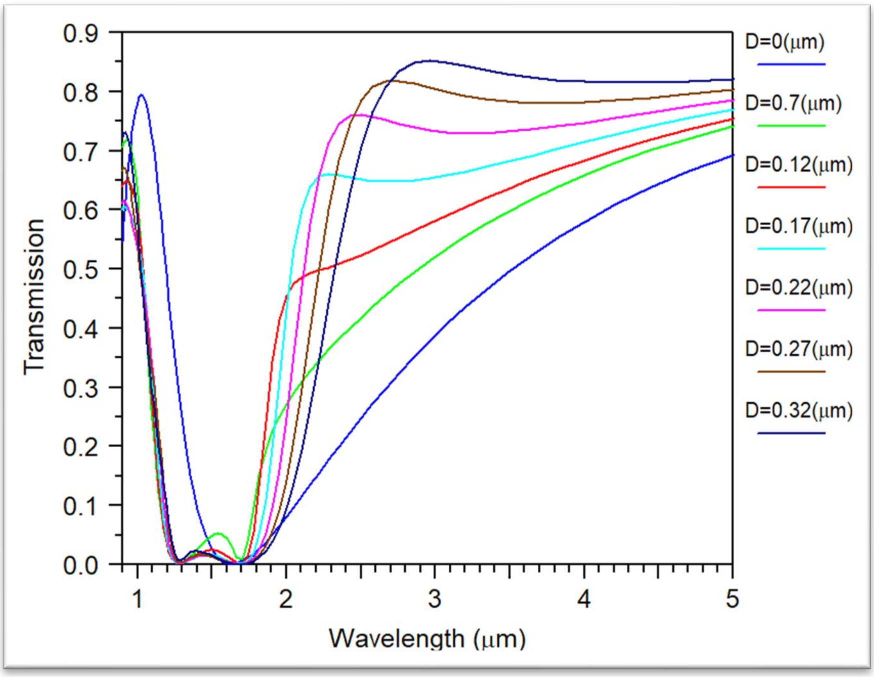

(b)

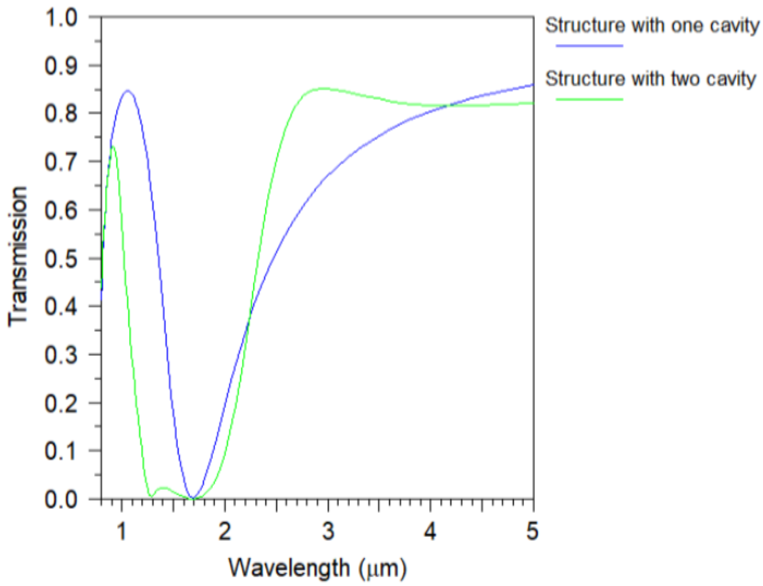

Figure.4.(a) Reponse spectrum of a stop-band filter with double cavities for various D. (b) Reponse spectrum of a filter with one and two cavities at D = 300 nm.

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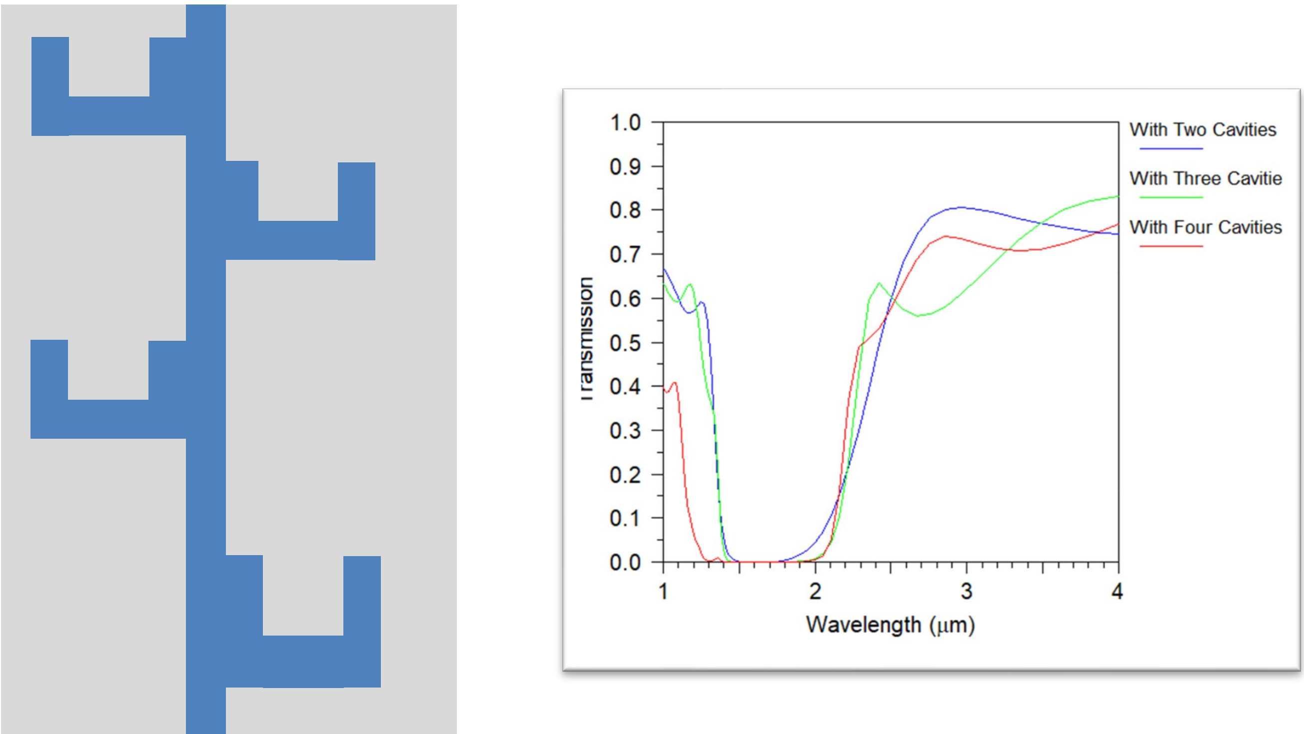

Figure.4.(a) Astop-band filter with four cavities . (b) Reponse spectrum of a filter with two ,three and four cavities at D = 320 nm.

To further improve the filter characteristics, a third and fourth cavity were introduced into the structure. The addition of these cavities enhances the coupling between resonators and strengthens the plasmonic resonance effect, leading to a broader stopband. As a result, the bandgap width is significantly increased, which improves the filtering performance and wavelength selectivity of the proposed filte.

3. Conclusion

In this work, we propose and rigorously investigate the design of a highly controllable plasmonic stop-band filter. The fundamental architecture of this device relies on a metal–insulator–metal (MIM) waveguide system that is strategically side-coupled with a series of resonant cavities. This configuration is specifically engineered to cater to the growing demand for ultra-wideband (UWB) applications operating within the mid-infrared spectral regime. To accurately evaluate the electromagnetic behavior and the underlying physical mechanisms of the proposed design, extensive numerical simulations were conducted. The transmission spectra and the steady-state field distributions were systematically analyzed utilizing the two-dimensional Finite-Difference Time-Domain (2D-FDTD) method, executed via the robust computational framework of R-Soft CAD software.

The computational findings reveal a profound correlation between the geometrical complexity of the structure and its spectral response, demonstrating that the filtering capabilities can be significantly optimized by cascading multiple coupled resonators. Specifically, the integration of a second resonant cavity into the waveguide system facilitates a pronounced broadening of the operational filtering wavelength range. Furthermore, the sequential addition of third and fourth cavities introduces stronger localized resonance coupling effects. This multi-cavity interaction not only expands the bandgap width considerably but also enhances the signal attenuation within the stop-band, thereby drastically improving the comprehensive filtering characteristics of the device. Ultimately, the proposed multi-resonator MIM structure demonstrates exceptional dynamic tunability and superior stop-band performance. Given its nanoscale footprint and high efficiency, this novel architecture emerges as a highly promising candidate for next-generation, on-chip optical communication systems, particularly in the development of highly integrated nanoplasmonic and photonic integrated circuits (PICs).

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References

[1] M. Zavvari, M. Taleb Hesami Azar, and A. Arashmehr, “Tunable Band-Stop plasmonic filter based on square ring resonators in a metal- insulator-metal structure,” *J. Mod. Opt.*, vol. 64, no. 20, pp. 2221–2227, 2017, doi: 10.1080/09500340.2017.1349195.

[2] I. Zegaar, A. Hocini, and H. Ben Salah, “Modeling and analysis of the RI sensitivity of plasmonic sensor based on MIM waveguide-coupled structure,” *J. Phys. Conf. Ser.*, vol. 1859, no. 1, 2021, doi: 10.1088/1742-6596/1859/1/012024.

[3] H. Salimzadeh Khatooni, K. Abbasian, and T. Nurmohammadi, “A tunable band-stop plasmonic waveguide filter and switch designing with triangular resonator based on Kerr non-linearity,” *Optik (Stuttg).*, vol. 224, no. October, p. 165708, 2020, doi: 10.1016/j.ijleo.2020.165708.

[4] I. Zegaar, A. Hocini, A. Harhouz, D. Khedrouche, and H. Ben Salah, “Design of a Double-Mode Plasmonic Wavelength Filter Using a Defective Circular Nano-Disk Resonator Coupled to Two MIM Waveguides,” *Prog. Electromagn. Res. Lett.*, vol. 104, pp. 67–75, 2022, doi: 10.2528/PIERL22012905.

[5] S. Ghorbani, M. Sadeghi, and Z. Adelpour, “A highly sensitive and compact plasmonic ring nano-biosensor for monitoring glucose concentration,” *Laser Phys.*, vol. 30, no. 2, 2020, doi: 10.1088/1555-6611/ab5797.

[6] A. Harhouz and A. Hocini, “Highly sensitive plasmonic temperature sensor based on Fano resonances in MIM waveguide coupled with defective oval resonator,” *Opt. Quantum Electron.*, vol. 53, no. 8, 2021, doi: 10.1007/s11082-021-03088-3.

[7] A. O. Zaki, K. Kirah, and M. A. Swillam, “Hybrid plasmonic electro-optical modulator,” *Appl. Phys. A Mater. Sci. Process.*, vol. 122, no. 4, pp. 1–7, 2016, doi: 10.1007/s00339-016-9843-y.

[8] S. Das, A. Salandrino, J. Z. Wu, and R. Hui, “Near-infrared electro-optic modulator based on plasmonic graphene,” *Opt. Lett.*, vol. 40, no. 7, p. 1516, 2015, doi: 10.1364/ol.40.001516.

[9] I. Zegaar, A. Hocini, D. Khedrouche, H. Ben Salah, and H. Bahri, “Plasmonic stop-band filter based on an MIM waveguide coupled with cavity resonators,” *J. Phys. Conf. Ser.*, vol. 2240, no. 1, 2022, doi: 10.1088/1742-6596/2240/1/012025.

[10] H. Ben Salah, H. Bahri, A. Hocini, I. Zegaar, S. Ingebrandt, and V. Pachauri, “Design of a plasmonic sensor based on a nanosized structure for biochemical application,” *J. Phys. Conf. Ser.*, vol. 2240, no. 1, 2022, doi: 10.1088/1742-6596/2240/1/012024.

[11] H. Ben salah, A. Hocini, M. N. Temmar, and D. Khedrouche, “Design of mid infrared high sensitive metal-insulator-metal plasmonic sensor,” *Chinese J. Phys.*, vol. 61, no. August, pp. 86–97, 2019, doi: 10.1016/j.cjph.2019.07.006.

[12] A. Hocini, H. Ben salah, D. Khedrouche, and N. Melouki, “A high-sensitive sensor and band-stop filter based on intersected double ring resonators in metal–insulator–metal structure,” *Opt. Quantum Electron.*, vol. 52, no. 7, pp. 1–10, 2020, doi: 10.1007/s11082-020-02446-x.