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مقایسه و شبیه‌سازی نور آهسته در درگاه‌های خروجی یک نانوسامانه موجبری ۲×۲ کاناله بر مبنای شفافیت القایی پلاسمونیک ناشی از تغییرات در شعاع ساختار تشدیدگر حلقوی

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چکیده – روش شبیه‌سازی بر اساس تفاضلات محدود در حوزه زمان، ناشی از تحلیل آنالوگ شفافیت القایی الکترومغناطیسی در یک موجبر پلاسمونیکی فلز-دی‌الکتریک-فلز که شامل یک حفره بیضوی متقارن هست، پیشنهاد شده است. این مقاله به مقایسه و بررسی یک ساختار جدید جهت به‌وجود آوردن نور آهسته بر مبنای شفافیت القایی پلاسمونیک در یک تشدیدگر بیضوی شکل، مبتنی بر فلز-دی‌الکتریک-فلز می‌پردازد. در این ساختار پیشنهاد شده، یک سامانه موجبری به شکل رینگ رزوناتور بیضوی با دو کانال ورودی و دو کانال خروجی به‌جهت بررسی مودهای پلاسمون تشکیل شده در درون این ساختار مورد بررسی و تحلیل قرار گرفته شده است. جنس فلز مورد استفاده در این ساختار، طلا بوده و از پلی متیل متا آکریلیت به‌عنوان دی‌الکتریک بهره برده‌ایم. طول موج پمپ به‌جهت شفاف‌سازی محیط را ۱۵۵۰ نانومتر و طول موج سیگنال به‌کار رفته را ۸۲۰ نانومتر در نظر گرفتیم. طول این سامانه پلاسمونیک نیز ۵۰۰ نانومتر است. در این ساختار پیشنهادی، قسمت حقیقی و موهومی ضریب شکست و ضریب آهستگی نور آهسته شده را به‌دست آوردیم که سرعت گروه در یکی مسیرهای خروجی ساختار پیشنهادی ۳۳ و در مسیر دیگر ۳۵ به‌دست آورده شده است. از این نتایج، می‌توان در طراحی آنتن‌های سهموی و مخابراتی، خطوط تاخیردهنده نوری کنترل‌شده استفاده نمود.

کلید واژه- تشدیدگر حلقوی، فلز-دی‌الکتریک-فلز، شفافیت القایی پلاسمونیک، ضریب شکست، نور آهسته.

Comparison and Simulation of Slow Light on Output Ports in a Nano-Waveguide Systems of 2×2 Channels based on Plasmonic Induced Transparency Resulting from Change in the Radius of the Ring Resonator Structure

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Abstract- Method of the analog of electromagnetically induced transparency (EIT) in plasmonic metal–dielectric–metal (MIM) waveguide is proposed by using symmetric side-coupled elliptic cavities and simulated by Finite-difference time-domain (FDTD). In this paper comparison and investigation in novel structure creating a slow light device based on plasmonic induced transparency (PIT), in ring resonator of elliptic shape with metal-dielectric-metal is examined. In this proposed structure, a ring resonator with two input ports and two output ports for occurrence and investigate of plasmon's mode in a waveguide system is examined. Poly metyle meta acrylate is used for dielectric that is sandwiched between gold metal layers. Wavelength of the pump for transparency of media is 1550 nm and wavelength of small signal in this structure is 820 nm. The length of this proposed device is 500 nm. In the proposed structure, we will get the real and imaginary of refractive index and slow down factor. The large group index get 33 in the cross way and 35 can be obtained at another PIT window. The results of this study can be used to design parabolic antennas and telecommunications, optical delay lines controlled.

Keywords: Ring Resonator, Metal-Dielectric-Metal, Plasmonic Induced Transparency (PIT), Refractive Index, Slow Light.

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1 Introduction

When it comes to gathering together the unique property of two old trusted chip-scale technologies, indeed Electronics and Photonics owing to its ultra-high speed and superior intelligence respectively, metallic structures can have been once again emerged to bridge them as a new field of technology well-called as "*Plasmonics*" [1-2]. As known, confining Electromagnetic (EM) waves on a metal surface -where they are coherently coupled to the collective oscillation of surface free electrons as Surface Plasmons (SPs) - provides us with a flexible technology to control and manipulate light waves even at nano-scale dimensions [3-4]. While plasmonics researchers have been interested to work with various aspects of that [5], the issue of squeezing and guiding Surface Plasmon Polaritons (SPPs) into plasmonic waveguide structures are one of the promising opportunities to bring photonic and electronic devices joined near each other [6].
This makes them so promising in many fields such as optical switch [2], biosensing, spectroscopy [3], microscopy [4], solar cells [5], imaging [6], metamaterials [7], all optical modulators and variable true delays.
The article is configured as follows: next section (Sec. II) introduces the proposed 2x2 MDM waveguide system design. Then, we will proceed with more information about the constructing waveguide structure and device principle in section (III). After that, section (IV) will be devoted to the 2x2 ring resonator provision of configuration and simulation results. Finally, conclusion remarks will be summarized in section (V).

2 Proposed 2x2 Metal/Dielectric/Metal Ring Resonator Configuration

An induction plasmonic mode creates transparency in structures to reduce speed of light (signal). For induction creation, secondary powerful light (pump) is used for stimulation of plasmonics modes formation and deceleration of signal light in waveguide. Dielectric material in this study is called PMMA with a refractive index close to (n=1.4) [2, 4]. The thickness of metal layer made from gold is G. In conventional photonic ring resonators, basically, two waveguides exists [3, 4]. One for straight waveguide at a side of circular (loop) waveguide. The cross sectional dimensions of waveguides are proportional to light wavelength. We've used this concept for designing a plasmonic waveguide ellipse shape ring resonator in the field of integrated slow light plasmonic device. In figure 1, the configuration of a plasmonic MDM ellipse shape ring resonator is shown.

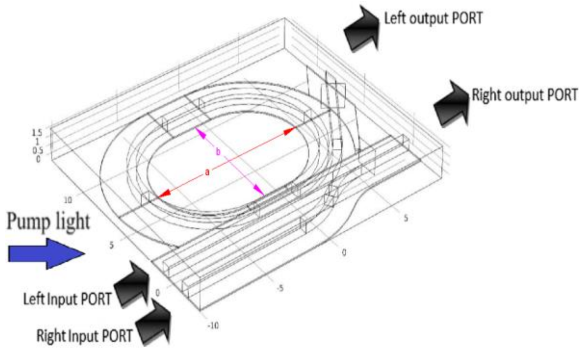

Figure 1: The proposed 2x2 plasmonic Metal/Dielectric/Metal (MDM)-structure wave guide configuration which can ellipse shape delay line two input SPP waves of different free-space wavelength (around λp=1550 nm) to the two output ports.

3 The 2×2 Channel Elliptic Ring Resonator Provision

After a summery about the constructing plasmonic structure, we want to proceed with the main issue of article: how the proposed design will present a 2x2 channel ellipse shape ring resonator operation. Relying on the MDM structure which renders a uniform plasmonic mode being propagated through the device in the z-direction, we can see this configuration as a plasmonic channel slow light.
As mentioned, optical behavior of device is numerically investigated by using 3D Finite Element Method (3D-FEM) based Electromagnetic -Wave simulation. However, these simulations are exposed to all-optical carrier-transport-steered changes in the optical properties of structure.

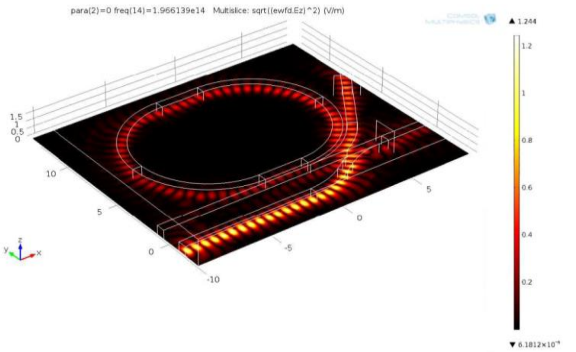

Figure 2: Numerical simulation of the ellipse shape proposed 2x2 plasmonic Metal/Dielectric/Metal (MDM)-structure wave guide ring oscillator-based slow light to show through the wave plasmonic cross from the waveguide coupling with oscillating wave. Dimension of this design is the micrometer scale.

4 Supplementary Simulation and Discussion

To get an overall view of how the proposed all-optical plasmonic MDM 2x2 wave guide configuration works, and also investigate its systematic characteristics, we attempt to launch supplementary EM simulations, and try to discuss on results.

4.1 Extracting Optical Characteristics of the proposed Device in the Right Output Port

As a primary value-wise outcome of the device simulation, the proposed wave guide's plotted with respect to variation of large and small diameters of ellipse shape ring resonator. These simulations results of right output port of the proposed slow light device that shown in fig. 2. You can see that the simulations are steered for three MDM structures – the red-marked curve for thickness of metal [G=100 nm] -two diameter of elliptical [a=5000 nm and b=3500 nm] case and the black-marked curve for thickness of metal [G=100 nm] -two diameter of elliptical [a=4500 nm and b=4000 nm] case and the ones blue-marked curve for thickness of metal [G=100 nm] -two diameter of elliptical [a=4000 nm and b=4500 nm]. Furthermore, in fig. 3, as can be seen, subplots of (a), (b) and (c) represent of absorbance, real part of refractive index and SDF of the slow light device. These curves are plotted for specific values of length of device. The effective length of this device is constant and is 500 nm. The large and small diameters of elliptical alteration in ellipse shape ring resonator are able to change the optical properties of the slow light device.

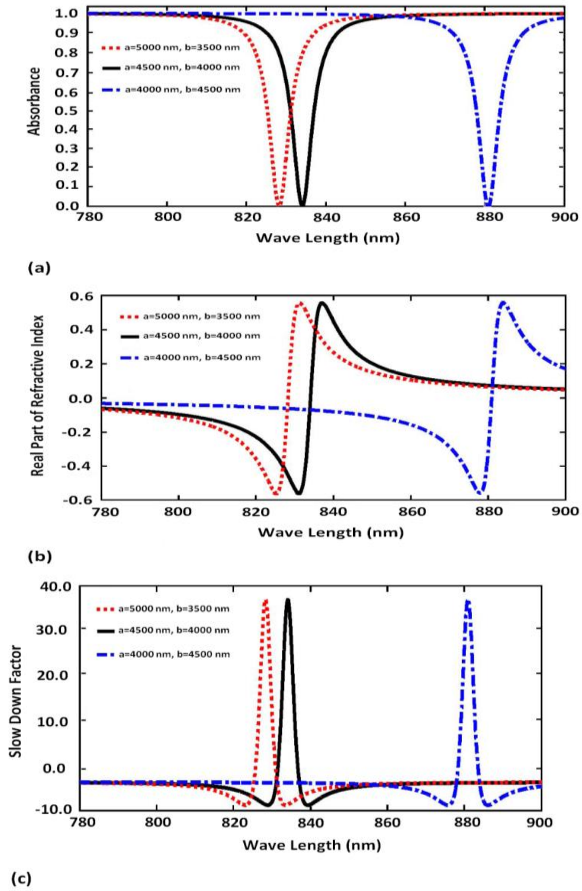

Fig 3. The absorption coefficient (imaginary part of the refractive index) in various large and small diameters elliptical of ring resonator in right output port shown in the (a) on metal-dielectric-metal waveguide structure is proposed. The real part of the refractive index on metal-dielectric-metal waveguide structure in various large and small diameters elliptical of ring resonator in right output port shown in the (b). The slow down factor (SDF) in various large and small diameters elliptical of ring resonator in right output port shown in the (c) on metal-dielectric-metal waveguide structure is proposed. The whole thickness of gold metal in the presented structure of MDM is 100 nm (G).

4.2 Equations and References Extracting Optical Characteristics of the proposed Device in the Left Output Port

As a primary value-wise outcome of the device simulation, the proposed waveguide's plotted with respect to variation of large and small diameters of ellipse shape ring resonator. These simulations results of left output port of the proposed slow light device that shown in fig. 2. You can see that the simulations are steered for three MDM structures – the red-marked curve for thickness of metal [G=100 nm] -two diameter of elliptical [a=5000 nm and b=3500 nm] case and the black-marked curve for thickness of metal [G=100 nm] -two diameter of elliptical [a=4500 nm and b=4000 nm] case and the ones blue-marked curve for thickness of metal [G=100 nm] -two diameter of elliptical [a=4000 nm and b=4500 nm].

Furthermore, in fig. 4, as can be seen, subplots of (a), (b) and (c) represent of absorbance, real part of refractive index and SDF of the slow light device. These curves are plotted for specific values of length of device. The effective length of this device is constant and is 500 nm. The large and small diameters of elliptical alteration in ellipse shape ring resonator are able to change the optical properties of the slow light device.

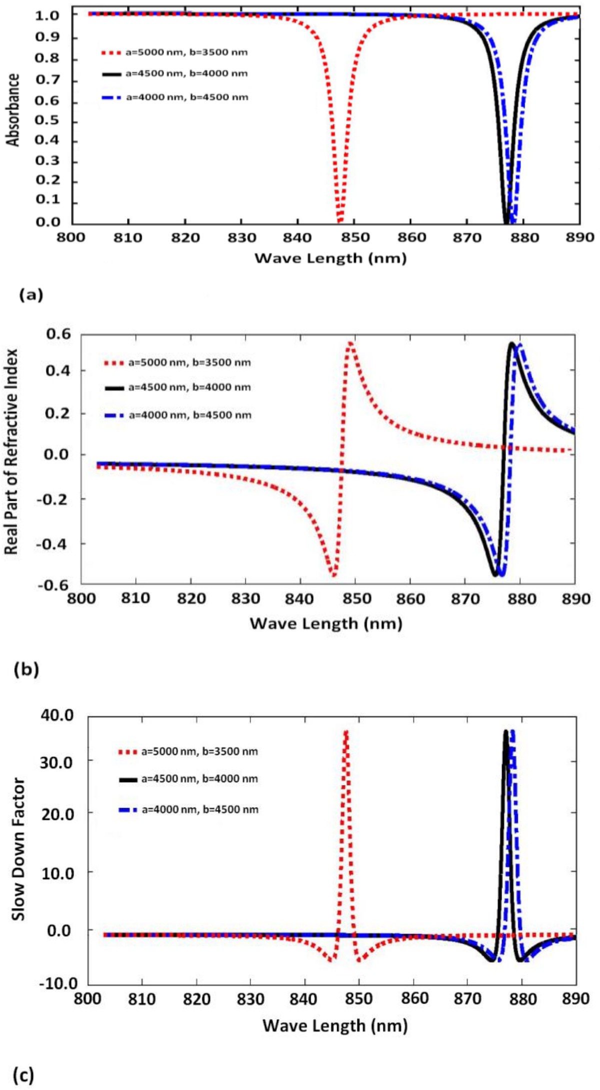

Fig 4. The absorption coefficient (imaginary part of the refractive index) in various large and small diameters elliptical of ring resonator in left output port shown in the (a) on metal-dielectric-metal waveguide structure is proposed. The real part of the refractive index on metal-dielectric-metal waveguide structure in various large and small diameters elliptical of ring resonator in left output port shown in the (b). The slow down factor (SDF) in various large and small diameters elliptical of ring resonator in left output port shown in the (c) on metal-dielectric-metal waveguide structure is proposed. The whole thickness of gold metal in the presented structure of MDM is 100 nm (G).

5 Conclusion

In general, using plasmonic waveguides as alternatives for photonics devices that have been designed and built based on conventional dielectric waveguides have the advantage of obtaining much smaller sizes (up to several thousand times smaller). The wavelength of the incoming light wave as a signal in this investigation is considered to be equal to 820 nm and also transparent to pump wavelength of 1550 nm affecting the proposed structure is calculated. Plasmonic devices, propose higher speeds with lower density and power consumption than their photonic or electronic counterparts. As a result of investigations, the effects of Plasmonic Induced Transparency (PIT) in the ring resonator design of the waveguide system with MDM, showed good agreement between transport phenomena and dispersion in the window transparency. Group velocity obtained at two proposed design are estimated to be more than 33.

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References

[1] H. Kaatuzian, *Photonics*, 2nd Edition (AUT, 2009), Vol. 2, in Persian.

[2] M. Keshavarz Moazzam, H. Kaatuzian, "Electro-Plasmonic 2x2 Channel-Routing Switch Arranged on thin-Si-doped Metal/Insulator/Semiconductor/ Metal structure," *Applied Optics*. Vol. **54**, No. 20, 6199-6207, 2015.

[3] Ahmad Naseri Taheri, Hassan Kaatuzian "Numerical investigation of a nano-scale electro-plasmonic switch based on metal-insulator-metal stub filter," *Opt Quant Electron*, Springer, Vol. **20**, No. 11, 198-207, 2014.

[4] Hassani Keleshtery M. , Kaatuzian H., Mir A., "Analysis and Investigation of Slow Light Based on Plasmonic Induced Transparency in Metal-Dielectric-Metal Ring Resonator in a Waveguide System with Different Geometrical Designs", *Optics and Photonics Journal*, Vol. **6**, No. 8B, pp. 177-184, Aug. 2016.

[5] S. Zhan, H. Li, G. Cao, Z. He, B. Li, and H. Yang, "Slow light based on plasmonic-induced transparency in dual-ring resonator-coupled MDM waveguide system," J. Phys. D, *Appl. Phys.*, vol. **47**, no. 20, p. 205101, Apr. 2014.

[6] X. Han, T. Wang, X. Li, B. Liu, Y. He and J. Tang, "Dynamically Tunable Slow Light based on Plasmon Induced Transparency in Disk Resonators Coupled MDM Waveguide System," *J. Phys. D: Appl. Phys*. **48** 235102 (10pp), 2015.

[7] A. Eftekharian, H. Atikian and A. H. Majedi, "Plasmonic superconducting nanowire single photon detector," *Opt. Exp.*, vol. **21**, no. 3, pp. 3043-3054, Feb. 2013.