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شبیه‌سازی و مقایسه مشخصات رخ‌داد نور آهسته به‌روش شفافیت القایی پلاسمونیک ناشی از به کارگیری فلزات طلا و نقره در یک نانوساختار فلز-دی‌الکتریک-فلز

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چکیده – با استفاده از ادوات پلاسمونیک، با تبدیل نور ورودی به شبه‌ذرات سطحی پلاسمون، در مرز بین فلز و دی‌الکتریک، در فرکانس یکسان، و با ابعاد کوچکتر، امکان هدایت سیگنال نوری و پردازش سریعتر آن در فضای بسیار فشرده‌تر فراهم می‌آید. در این مقاله ساختار جدیدی برای تولید نور آهسته بر مبنای شفافیت القایی پلاسمونیک در یک تشدیدگر حلقوی مبتنی بر فلز-دی‌الکتریک-فلز ارایه داده‌ایم. طول سامانه پلاسمونیک ۶۰۰ نانومتر و شعاع حلقه ۵/۵ میکرومتر است. در ساختار پیشنهادی، ابتدا جنس فلز به کار رفته را طلا و در مرحله بعد نقره در نظر گرفته‌ایم. در هر دو حالت، جنس دی‌الکتریک به کار رفته، پلی متیل متا آکریلیت، طول موج پمپ مورد استفاده ۱۵۵۰ نانومتر و طول موج سیگنال ۸۶۰ نانومتر بوده است. نتایج شبیه‌سازی نشان می‌دهد زمانی که جنس فلز در ساختار پیشنهادی طلا بوده، ویژگی‌های نور آهسته، از لحاظ میزان ضریب آهستگی نسبت به حالتی که جنس فلز نقره بوده، به مراتب بهتر است.

کلید واژه- شفافیت القایی پلاسمونیک، شبه‌ذرات سطحی پلاسمون، سرعت گروه، نور آهسته، فلز-دی‌الکتریک-فلز.

Simulation and Characteristics Comparison of Slow Light Occurrence Using Plasmonic Induced Transparency Resulting from Utilization of Gold and Silver in the Nano-Structure of Metal/Dielectric/Metal

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Abstract- **Using plasmonic devices, by converting incoming light into surface plasmon polaritons on the border between metal and dielectric at the same frequency, faster signal processing and light transmission is possible in the very compact space. In this paper we tried to design a new structure for slow light creation based on plasmonic induced transparency in a circular metal-dielectric-metal resonator. Length of the proposed plasmonic system is about 600 nm and the radius of the ring is equal to 5.5 micrometers. First we used gold as the metal of the structure then changed it to silver. In both cases, the dielectric material is poly-methyl meta-acrylic, the pump wavelength is 1550 nm and the signal wavelength is 860 nm. Simulation results show that in the first case, where the metal is gold, slow light features are much better in comparison with the second case, where the metal is silver.**

Keywords: Plasmonic Induced Transparency (PIT), Surface Plasmon Polaritons (SPPs), Groups Velocity, Slow Light, Metal-Dielectric-Metal.

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1 Introduction

Research on surface plasmon polaritons (SPPs) is growing rapidly due to their special properties. This makes them so promising in many fields such as meta-materials [1, 2], imaging [3], spectroscopy [4], microscopy [5], solar cells [6, 7], nanolithography [8] and highly integrated photonic circuits [4-6]. Plasmonic waveguides can confine the electromagnetic field below the dispersion limit. So, highly integrated photonic circuits are possible.

Great sensitivity of SPP waveguides to their environmental conditions potentially leads to realizing ultrasensitive photonic sensors. There is a trade-off in all SPP waveguide (SPPW) structures between mode confinement and propagation loss. This is because of metal in the structure which reduces the effective mode area while imposing Ohmic loss to SPPs [5]. In order to reduce the effective mode area for highly integration purposes, most of the mode area should be placed in the metal side since this imposes more loss and consequently propagation length will be decreased. Conversely, in order to increase the propagation length, most of the mode area should be placed out of the metal and this will increase the effective mode area [2].

The article is configured as follows: next section (Sec. II) introduces the proposed metal/dielectric/metal (MDM) waveguide system design. Then, we will propagate the SPPs at a single metal-dielectric interface and device principle in section III. After that, section IV will be devoted to the ring resonator provision of configuration and simulation results. Finally, conclusion remarks will be summarized in section V.

2 PROPOSED 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 poly-methyl meta-acrylic (PMMA) with a refractive index close to n=1.41 [2, 4]. The thickness of metal layer made from gold or silver is G. In conventional photonic ring resonators, basically, two waveguides exists [3-4]. One of them is straight waveguide and the other is circular (loop) waveguide. The straight sectional dimensions of waveguides are proportional to the light wavelength. We've used this concept for designing a plasmonic waveguide circle shape ring resonator in the field of integrated slow light plasmonic device. In figure 1, the proposed configuration of a plasmonic MDM circle shape ring resonator is shown.

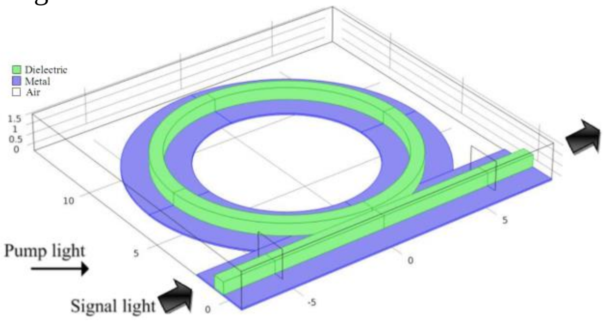

Figure 1: Schematic configuration of the proposed circular plasmonic MDM resonator structure.

SPPs are surface electromagnetic modes that propagate at the interface of a dielectric with real electric permittivity ε_1 and a metal with permittivity $\varepsilon_2(\omega) < 0$ as shown in figure 2.

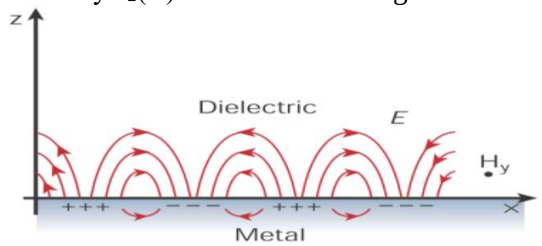

Figure 2: Electric and magnetic field distribution and charge oscillations at the metal/dielectric interface. SPPs propagate along the x-direction.

The complex permittivity or complex dielectric function can be expressed as:

$$\varepsilon = \varepsilon' + i\varepsilon'' \qquad (1)$$

where ε' is the real part and ε'' is the imaginary part of the permittivity. In addition, the response of the material to the incoming optical field is expressed as the complex refractive index as:

$$N = n + ik \qquad (2)$$

where n and k are the real and imaginary part of the refractive index. The equations (1) and (2) are related to each other by:

$$\varepsilon' = n^{۲} - k^{۲} \qquad (3)$$

$$\varepsilon'' = ۲nk \qquad (4)$$

These parameters are known as optical constants of the material however, in many of the materials they change with the frequency of the incident optical field. Especially in metals, the dielectric parameters are strongly dependent to the optical frequency. In order to use the permittivity of metals in the calculations of the spectrometry some mathematical models are introduced, such as Lorentz model, Lorentz-Drude model and Extended Drude model.

2.1 Propagating the SPPs at a single metal-dielectric interface

Surface plasmon polaritons are electromagnetic waves propagating at the interface between a dielectric and a metal evanescently bounded in the perpendicular direction. These electromagnetic surface waves are created from the coupling of the optical fields to oscillations of the metal's electron plasma. Based on the dispersion relation and the spatial field distribution, the surface plasmons are described quantitatively.

By solving the Maxwell's equation at a single metal-insulator interface, the wave equation is produced, in which for the transverse magnetic (TM) modes is

$$\frac{\partial^2 H_y}{\partial z^2} + \left(k_0^2 \varepsilon - \beta^2\right) H_y = 0 \qquad (5)$$

where $k_0 = \omega / c_0$ is the wave vector of the propagating wave in vacuum. Now, we should consider a simple flat boundary between an dielectric ($z>0$) with a real positive permittivity ε_2 and a metal ($z<0$) with a complex permittivity $\varepsilon_1(\omega)$ (for metals $\mathrm{Re}\{\varepsilon_1(\omega)\} < 0$). Supposing the condition of propagating wave bounded to the interface with evanescent falloff in z-direction, the solutions for TM waves in $z > 0$ is:

$$H_y(z) = A_2 e^{i\beta x} e^{-k_2 z} \qquad (6)$$

$$E_x(z) = iA_2 \frac{1}{\omega \varepsilon_0 \varepsilon_2} k_2 e^{i\beta x} e^{-k_2 z} \qquad (7)$$

$$E_z(z) = -A_1 \frac{\beta}{\omega \varepsilon_0 \varepsilon_2} k_2 e^{i\beta x} e^{-k_2 z} \qquad (8)$$

The dispersion relation of the SPPs propagating at the metal-dielectric yields:

$$\beta = k_0 \sqrt{\frac{\varepsilon_1 \varepsilon_2}{\varepsilon_1 + \varepsilon_2}} \qquad (9)$$

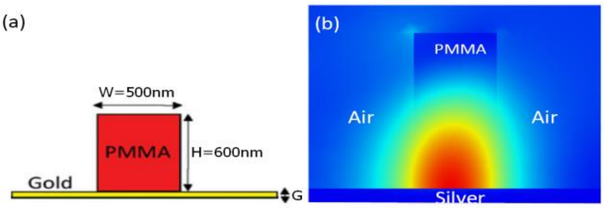

Figure 3: (a) Schematic representation of the SPPs from proposed waveguide (b) Mode distribution of optimal configuration.

3 The Circular 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 circle 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.

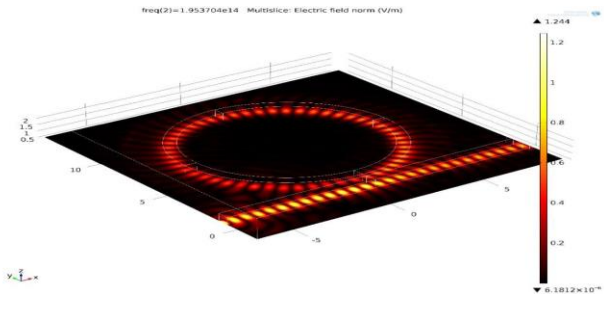

Figure 4: Numerical simulation of the proposed circular plasmonic MDM-structure waveguide based on ring oscillator slow light to show the plasmonic waves from the waveguide coupling with oscillating wave. The lengths are in micrometer scale.

4 Result of Simulations and Discussion

As a primary value-wise outcome of the device simulation, the proposed wave guide's plotted with respect to variation of the thickness of the metal of the circle shape ring resonator. These simulations results of output port of the proposed slow light device that shown in Fig. 4. You can see that the simulations are steered for four MDM structures –

the red-marked curve for thickness of gold metal [G=100 nm] case and the blue –marked curve for thickness of gold metal [G=120 nm] case and the pink-marked curve for thickness of silver metal [G=100 nm] case and the ones black-marked curve for thickness of silver metal [G=120 nm]. Furthermore, in fig. 5, 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 600 nm. The radius of circle alteration in circular shape ring resonator is able to change the optical properties of the slow light device.

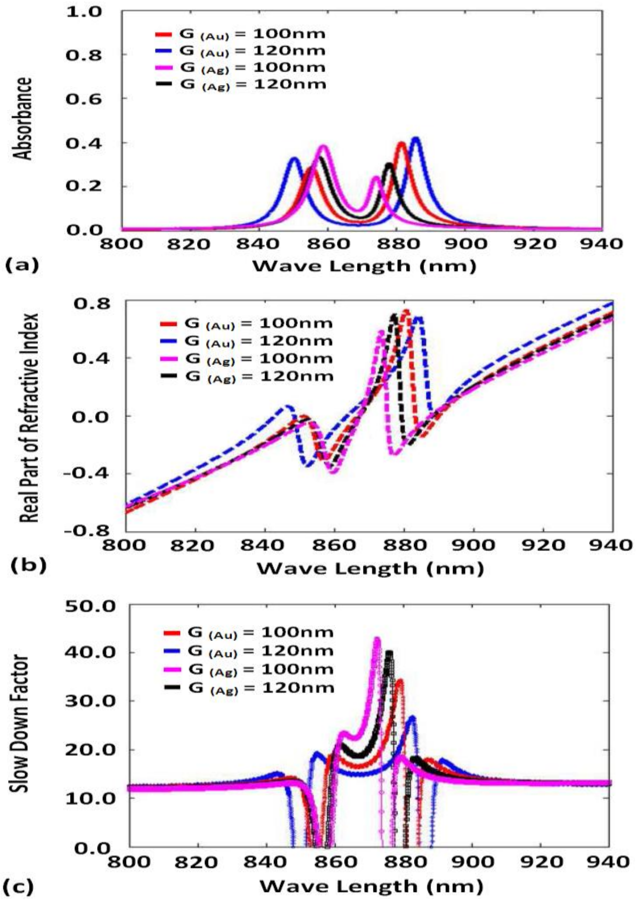

Fig 5. The absorption coefficient (imaginary part of the refractive index) in various thickness of metal (Au and Ag) with constant of the radius circular ring resonator shown in the (a) on MDM waveguide structure is proposed. The real part of the refractive index on metal-dielectric-metal waveguide structure in different thickness of metal (Au and Ag) with constant of the radius circular ring resonator in the (b). The slow down factor (SDF) in several thickness of metal (Au and Ag) with constant of the radius circular ring resonator in the (c) on MDM waveguide structure is proposed. The whole radius of circular ring resonator is R=5500nm in the presented structure of MDM.

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 860 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. Group velocity obtained at two proposed design are estimated to be more than 27.

Acknowledgments

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