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بررسی یک حسگر تشدیدگر میکرو حلقویِ ترکیبیِ مد پلاسمونی- فوتونی

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چکیده- در این مقاله یک حسگر تشدید کننده میکرو حلقوی فشرده دوتایی و تکی را بر اساس موجبرهای پلاسمونیک و فوتونیک هیبریدی بر روی بستر سیلیکون روی عایق بررسی می شود . موجبر هیبریدی شامل یک ساختار فلز-شکاف-سیلیکون است که در آن انرژی نوری به شدت در شکاف باریک (فاصله بین تشدید کننده میکرو حلقوی و دیسک طلا) افزایش می‌یابد. از روش تفاضل-محدود در حوزه زمان برای شبیه سازی مشخصه‌های نوری افزاره به عنوان یک حسگر نوری استفاده می شود. حساسیت حسگر پیشنهاد شده ترکیبی با استفاده از دو میکرو رزوناتور به دلیل هم‌پوشانی مدهای قوی با محیط بالایی پیرامون حسگر زیاد است. حساسیت دستگاه بستگی به وجود یا عدم وجود دیسک فلزی دارد و می‌توان آن را بر اساس کاربرد حسگر طراحی کرد. بهترین ضریب کیفیت برابر ۴۸۷۴/۶۵ برای نوسانگر حلقوی دوتایی به شعاع‌های ۴/۲ و ۳/۸ میکرومتر در حضور دیسک طلا به دست آمده است. مزیت اصلی حسگرهای تشدید کننده حلقوی هیبریدی پیشنهادی، حساسیت بالا آن ها می‌باشد و می‌تواند به طور بالقوه به صورت آرایه‌ای مجتمع شود تا افزاره حسگر بیوشیمیایی آزمایشگاه روی تراشه را ایجاد کند.

کلید واژه- تشدید کننده تک حلقوی، تشدید کننده دو حلقوی، حساسیت، ضریب کیفیت ، منحنی عبور

An Investigation of a Hybrid Plasmonic-photonic Mode Micro-Ring Resonator Sensor

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Abstract- In this paper a compact double and single micro-ring resonator sensor based on a hybrid plasmonic and photonic waveguides on a silicon-on-insulator substrate is investigated. The hybrid waveguide is consisting of a metal-gap-silicon structure, where the optical energy is greatly enhanced in a narrow gap. The finite-difference time-domain (FDTD) method is used to numerically simulate the device optical characteristics as an optical sensor. The sensitivity of the proposed hybrid double micro-ring resonator is large due to the large overlap with the upper-environment sensing medium. The sensitivity of the device depends on the presence or absence of a metal disk and can be designed based on the application of the sensor. The best quality factor of ٤۸۷٤,٦٥ is obtained for double ring resonator with ٤,۲ µm and ۳,۸ [illegible]
high sensitivity. This sensor can be potentially integrated in an array to form lab-on-chip biochemical sensing devices.

Keywords: double ring resonator, quality factor, single ring resonator, sensitivity, transmission curve.

١. Introduction

Developing photonic devices which use silicon as an optical medium (silicon photonics) on silicon-on-insulator (SOI) wafers attract more attention due to the well-developed silicon technology and compatibility with other electronic devices [١, ٢]. However, different types of plasmonic waveguides have been proposed in recent years, but few are compatible with the waveguides used in silicon photonics [٢]. Plasmonic waveguides benefit from the high field enhancement and confinement at low frequencies (due to the interaction of electrons and electromagnetic waves) that realize high resonance quality factor Q and sensitivity in sensing applications [٢, ٣]. In ٢٠٠٨ [٤], using a ring resonator and a gold disk (on a SOI substrate) a plasmonic waveguide has been proposed to create a coupled dielectric silicon photonic mode and the surface plasmonic mode. In the transmission and curvature loss of the hybrid plasmonic-dielectric structure have been investigated but the sensibility of the structure on variation of the refractive index *n* of the environment has not been discussed [٥,٦].

In this paper is investigated the effect of the presence of gold discs, as an plasmonic medium, on the resonance condition and sensibility of both single- and double-ring resonators. It shows that the presence of gold disk has significant effect on resonance spectrum and increases the sensitivity of the structure by coupling the dielectric mode with plasmonic modes [٦]. Also, it shows that the double ring resonators improve the Q, sensitivity, and the rate of excitation. Optical WGs of ring resonators are designed in such a way that the part of the optical energy known as an evanescent field be above the surface of the WG that reacts with the analyte in the vicinity of the WG [٦]. As the refractive index (n) of the environment changes, the resonant wavelength (λ_{res}) of ring resonator changes [٦].

We should mention, using gold discs in addition of enhancing the quality of the resonance of electromagnetic modes, is also biocompatible and does not oxidize easily (for example in comparison with silver) [٥,٦].

Simulations are performed numerically using the FDTD method that directly solves the Maxwell time-related equations. In this paper, by optimizing the structure parameters, the Q parameter has been increased. The structure of this paper can be used in optical sensors and also another prominent feature of the designed structure is the reduction of full width at half maximum (FWHM) in the presence of gold disc. Innovation in the designed sensor, the presence of a gold disc and the presence of dual micro circular amplifiers with optimized structural dimensions, which has been able to increase the quality and sensitivity parameters compared to other sensors.

٢. Device Structure and Working Principle:

Figure ١ shows the schematic of the proposed hybrid plasmonic single (Fig. ١(a) and (b), respectively top and lateral view) and double (Fig.١ (c)) micro-ring resonator sensor. The micro-ring resonator is composed of one or two silicon circular strip encompassing two metal disk in the center. The silicon ring radius is R (from the outer edge). The metal gold disk has the same height h as the silicon layer, and its separation from the silicon strip is W_{slot}. The micro ring resonator is associated with two typical silicon bus waveguides in width W to stimulate the resonance. The distance between the bus WGs and the rings and the distance between the two rings is denoted by W_g and $W_{g'}$, respectively. The single ring resonator (SRR) and double ring resonator (DRR) is designed over a buffer layer of silicon dioxide ($SiO_٢$) and the top of ring resonator is covered by water. In this structure the mode of silicon dielectric and the mode of surface plasmons of gold disk are strongly interconnected and form a combined mode. The coupling strength is affected by both the slot and the silicon strip widths and also the n of medium. Due to the excitation of surface plasmon wave and the discontinuity of electric-field between the silicon strip sidewall, the electric-field is greatly enhanced in the narrow slot (distance between the micro-ring resonator and the gold disk)

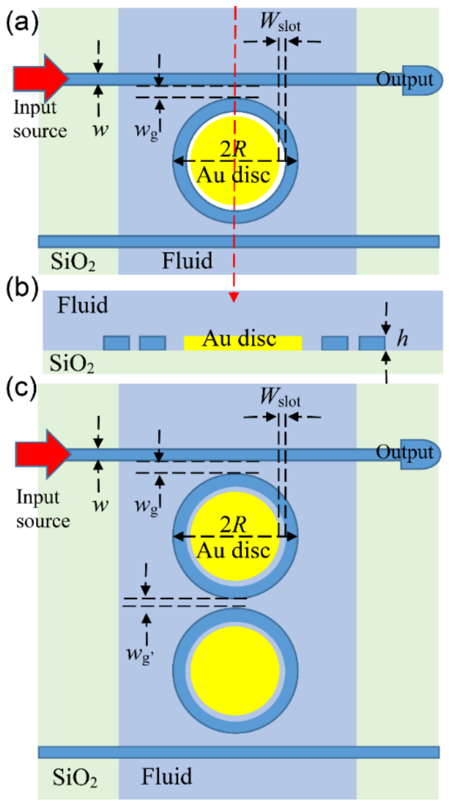

Fig.۱: Schematic diagram of a ring resonator based on, (a) single ring resonator top view, (b) single ring resonator lateral view, and (c) double ring resonator in hybrid plasmonic WGs.

(W_{slot}) [٦]. Because there is a large overlap between the waveguide mode and the peripheral environment, a small variation in the n of environment, lead to a large resonance wavelength shift. The values of geometrical dimensions used in this paper is presented in Table ۱, which specifies the values for SRR and DRR structures. The hybrid waveguide consists of a metal-slot-silicon structure in which the optical energy in a narrow slot is greatly increased, and the role of this type of structure is to increase the overlap of strong modes with the upper sensor environment, which is important in detection.

Table۱. Geometrical parameters of SRR and DRR

Parameter (µm)	SRR	DRR
R	۴,۲	۴,۲
W	۰,۴	۰,۴
W_g	۰,۰۵	۰,۰۵
$W_{g'}$	---	۰,۱۵
W_{slot}	۰,۱۵	۰,۱۵
h	۰,۴	۰,۴

۳. Simulation Method

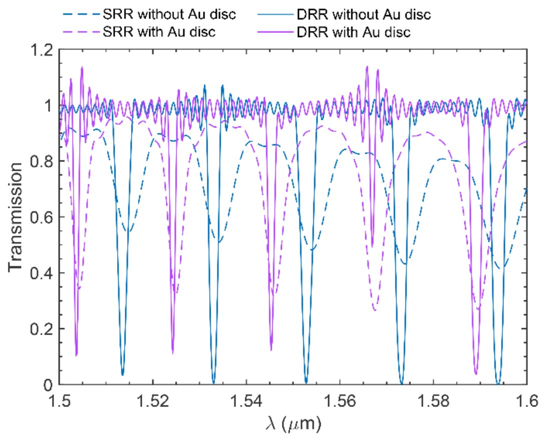

Fig.۲: Transmission curves in SRR and DRR in presence and absence of gold disc.

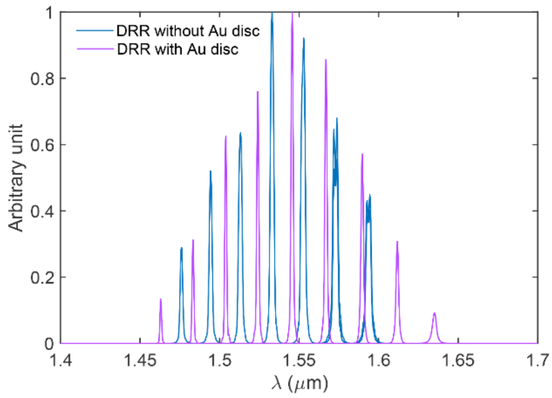

Fig.۳: Resonance spectra in DRR. Curve in terms of the maximum amount of electric field on the resonance wavelength

The input source of the structure is calculated for fundamental TE mode, in a wavelength range of ۱۵۰۰ □□ □□ ۱۶۰۰ □□. □□ □□□□□□□ □□□□□□□ □□ □□□□ structure TM mode show much lower Q than TE mode. In this simulation, perfectly matched layer boundary conditions (PMLs) are used. Also, the simulations have been performed by collapsing a ۳□ □□□□□□□□ □□ ۲□ □□□□□ □□□ □□□□□□□□□□ □□□□□ method, and simulating a two dimensional (۲D) FDTD which is much faster and uses less memory compared to a ۳D FDTD simulation but with the same results. Also is excited ring resonator by impinging calculated TE mode to the input waveguide.

۴. Results and discussions

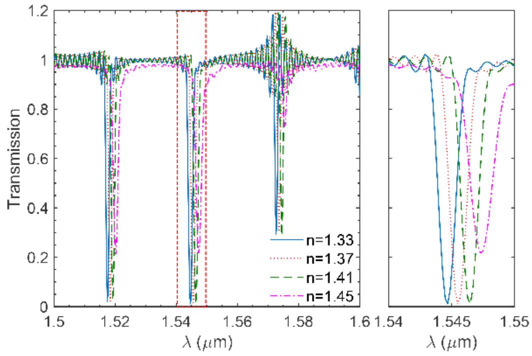

Fig.٤: Spectral response of DRR for different refractive index of environment.

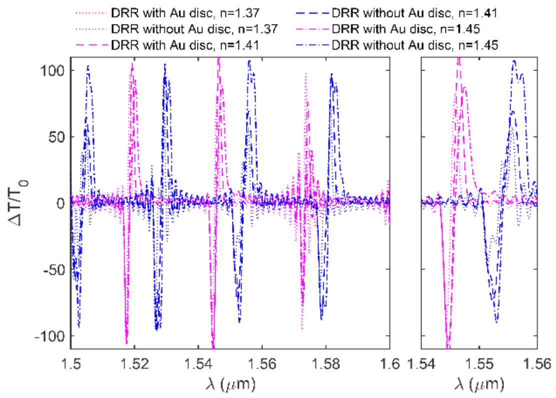

Fig.٥: Normalized transmission variation for different refractive index for DRR.

In this section, is compared the quality coefficient, transmission curve and sensitivity parameters in SRR and DRR structures. The electric field in the narrow slot is considerably enhanced by the

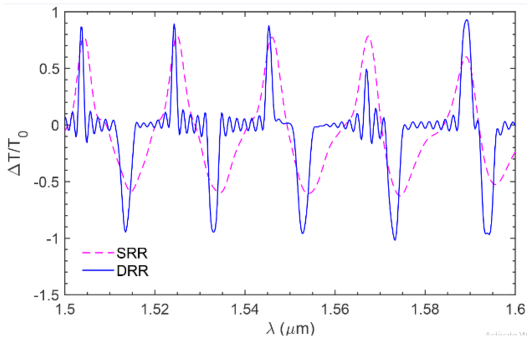

Fig.٦: Normalized transmission variation for different DRR and SRR.

excitation of the surface plasmon wave and the discontinuity of the electric field across the Si strip wall. Optical resonance in the μ ring is obtained by the following structural formula:

$$ƛ=۲\pi Rn_{eff}/m \quad (۱)$$

Where R and neff is the radius and effective refractive index of the μ ring, respectively. and m is the mode number which is an integer.

Figure ۲ shows the transmission curves in single-ring and double-ring resonator that shows that double ring resonators with gold disc have a stronger resonance. Figure ۳ shows that the gold disc in the double ring resonator structure decreases the FWHM of resonance spectra that leads to enhancement of Q. Figure ٤ shows that a small change in *n* leads to a strong change in the resonance wavelength and consequently the normalized transmission variation ($\Delta T/T_۰=T-T_{n=۱,۳۳}/T_{n=۱,۳۳}$) as illustrated in Fig. ٥ and Fig. ٦.

۵. Conclusion

In this paper, was presented two types of ring resonator designs based on ordinary silicone WG and plasmonic hybrid WG. The combined state in the structure is obtained with the photonic state in the silicon waveguide and the plasmonic state in the metal surface. The width of the silicon ring and the width of the gap are carefully adjusted to achieve the maximum coupling of photonic and plasmonic states that lead to a high electric field in the gap. In this paper, the transmission curve and resonance spectrum as well as the Q parameter in DRR and SRR structures based on plasmonic and conventional waveguides were simulated. The sensor designed in this paper has the best quality coefficients of ٤٨٧٤,٦٥ and ١٢٢٨,١٥, which are used in trapping and detection of nanoparticles, which is a new innovation in detection applications

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