ارائه راهکاری برای افزایش میزان جذب در آشکار ساز نوری پلاسمونیک

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چکیده – در این مقاله یک ساختار جدید جهت افزایش میزان جذب در آشکار سازهای نوری پلاسمونیک ارائه شده است. در این ساختار یک لایه شیشه بین طلا و نیمه هادی قرار داده شده است. این لایه باعث به وجود آمدن مسیرمناسب تری برای نفوذ نور به زیر طلا، انتقال موج به طرفین قطعه، درگیر کردن بخش بیشتری از نیمه هادی در فرایند تولید زوج الکترون- حفره و افزایش تزویج نور به درون نیمه هادی شده است. این ساختار با نرم افزار *Lumerical* و به روش *FDTD* شبیه سازی شده است. افزایش جذب در این مقاله به چهار برابر آشکار ساز های مشابه رسیده است.

کلید واژه- آشکار ساز نوری، پلاسمونیک، ساختارهای نانویی، گریتینگ

A new approach for absorption enhancement in plasmonic photodetectors

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Abstract- A new structure for absorption enhancement in plasmonic MSM photodetector is presented. This structure contains a layer of SiO_2 between gold and semiconductor layers. The SiO_2 layer creates a more suitable path for light to penetrate under the metal layer, transmits the wave to both sides of the device, involves a greater part of semiconductor in electron-hole generation, and increases the coupling of light into the semiconductor. This construction is simulated using Lumerical FDTD. Absorption enhancement in this paper is 4 times greater than similar structures.

Keywords: photodetector, surface plasmon polaritons, nanostructures, grating

1 Introduction

High-speed chip-to-chip connections and high-speed sampling are two main properties to make the metal-semiconductor-metal photodetectors (MSM-PDs) attractive for optical fiber communication systems [1, 2]. In the past decade, many experimental and theoretical works have been carried out to analyze Extraordinary Optical Transmission (EOT) through a subwavelength aperture and demonstrate light absorption enhancement through the nano-patterning of the metal fingers of the MSM photodetectors [3-5]. Recently, excitation and propagation of surface plasmon polaritons (SPPs) along the interface of a metallic-grating and a semiconductor material have been demonstrated using the finite-difference time-domain (FDTD) method [6, 7]. For instance, Bhat et al. presented a theoretical approach for light absorption enhancement of over 100 times, compared to the conventional MSM photodetectors using FDTD-based simulation of a subwavelength-aperture MSM photodetector structure [7]. These theoretical enhancements encouraged the researchers to design and fabricate novel high-speed high-responsivity MSM photodetector structures [8, 9].
In the present paper the initial model is adopted from [10]. Moreover, the optimization of the metal grating simulated in [11] is used. Then, our proposed structure is presented in which a layer of SiO_2 is added to the device. The three different structures are simulated with Lumerical FDTD and their light absorption is compared.
The rest of this paper is organized as follows. In Section 2, the previous MSM plasmonic photodetector structures and our proposed design are explained. In Section 3, the results for the absorption coefficient are presented and compared.Finally, we conclude our discussion in Section 4.

2 Structure Design

Tan et al. presented and optimized an MSM plasmonic photodetector structure which consists of three separated parts: the metal grating, the subwavelength aperture and the substrate, as shown in Fig. 1 [11]. The metal grating includes a perfect conductor whose grooves are parallel to the z-direction and the dimensions are optimized in order to couple the light at the desired wavelength and excite SPPs along the x-direction.

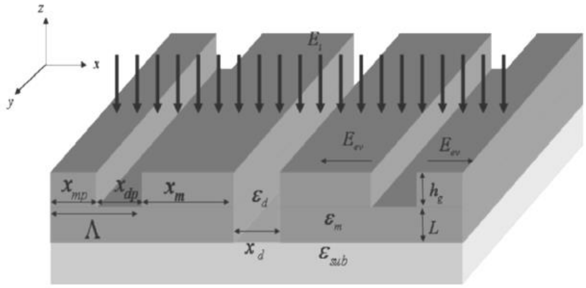

Figure 1: The MSM photodetector structure with the metal grating and a subwavelength aperture [11].

In a metal grating the wave vector of the SPPs is as follows [8]:

$$k_{sp} = \frac{\omega}{c}\sin\theta \pm j\,\frac{2\pi}{\Lambda} = \frac{\omega}{c}\sqrt{\frac{\varepsilon_m' \varepsilon_d}{\varepsilon_m' + \varepsilon_d}} \qquad (1)$$

Where Λ, ω, θ, and c are the grating period, angular frequency, light incidence angle, and speed of light in vacuum, respectively. $\varepsilon_m = \varepsilon_m' + i\,\varepsilon_m''$ is the permittivity of metal and ε_d is the air permittivity.
Each metal grating groove excites surface plasmon polaritons propagating along both positive and negative x directions mentioned as an electric field called E_{spp}. The intensity of the SPP wave is reduced exponentially with the propagation distance and has a penetration depth that depends on the material permittivity [11]. This limits the SPP triggered by the peripheral (non-central) grooves to propagate towards the sub-wavelength aperture, where the SPP wave interferes (couples) with the incident light (represented by the electric field E_i), as described in [3]. This collection of the SPP waves results in optical transmission enhancement through the subwavelength aperture. In fact, the metal grating acts as a wave collector, or a focusing lens at resonance frequency.
As shown in Fig. 2, the coupling of the SPP wave (E_{spp}) with the incident wave (E_i) results in a combined transmission of t_{12}.

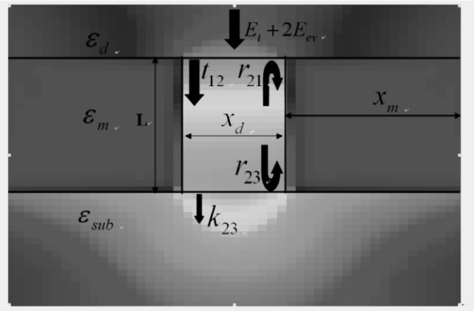
Figure 2: Extraordinary absorption model, based on the semi-analytical Fabry–Perot model proposed in [10]

Using the semi-analytic Fabry–Perot analysis [10], the modal expansion formalism [12], and the Green's tensor analysis [13], it is concluded in [11] that with the subwavelength aperture width (x_d) much smaller than the propagating wavelength (λ_0), light transmission enhancement and improved absorption in the semiconductor substrate can be obtained. On the other hand, in [14], Sturman et al. modelled the light transmission enhancement through the subwavelength aperture, accurately.
The change of parameters in Fig. 1 leads to change in the transmission of the light into the semiconductor at the desired wavelength. Therefore, the best values for the parameters are optimized in [11].
The proposed design in this paper is shown in Fig. 3 in which the optimized grating dimensions are adopted from [11] and [15] to achieve the best response from the grating part of the photodetector. Also, a SiO_2 layer is added under the metal (Au) contacts. Since SiO_2 is a dielectric and refuses the generated electron-hole pairs in the semiconductor to reach the metal contacts, two metal side walls are added in both sides of the device to collect the carriers. Figs. 3 and 4 show metal (Au) walls and the SiO_2 layer position more clearly, respectively.

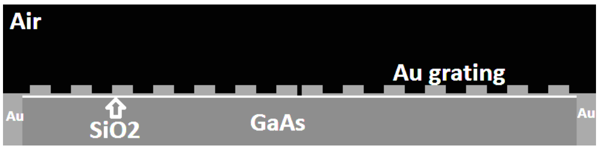

Figure 3: The proposed photodetector structure in which a SiO_2 layer and two metal walls are added

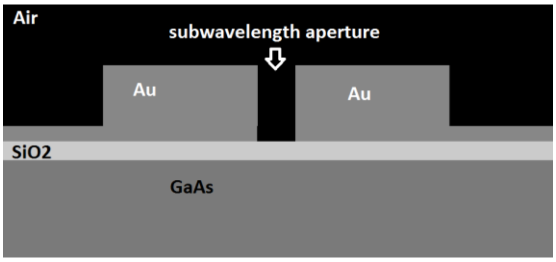

Figure 4: The SiO_2 layer position in the photodetector structure, the arrow shows the wave insertion toward the semiconductor

3 Results and Discussion

The idea of adding a SiO_2 layer at the end of the aperture is obtained from E-plain Tee divider which is used as a divider in microwave [16]. As shown in Fig. 2 in the conventional plasmonic photodetectors the greatest amount of absorption takes place exactly under the aperture, while Fig. 5 shows the travelling of the entered waves toward both sides of the device.

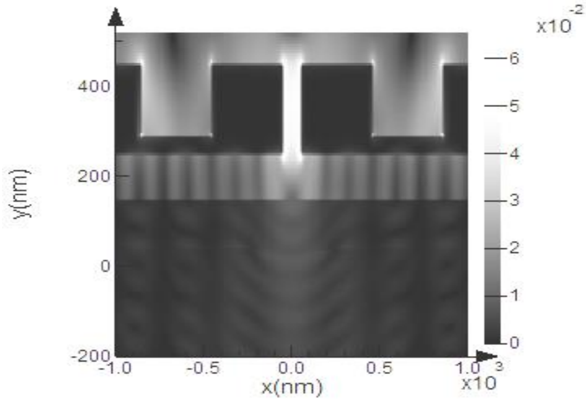

Figure 5 power transmission of the light toward both sides of the photodetector

The 100nm height SiO_2 layer makes the waves propagate more easily toward the sides of the device and a greater part of the semiconductor is involved in the light absorption and carrier generation. The expansion of light under the contacts clearly increases the light absorption. Fig. 6 shows the absorption enhancement compared with Fig. 1 structure in which the transmission is enhanced using metal grating, the conventional structure with no grating and the structure with SiO_2 layer without grating.
The absorption pick takes place at 868 nm using 2D simulation of Lumerical FDTD software with 5nm mesh size.

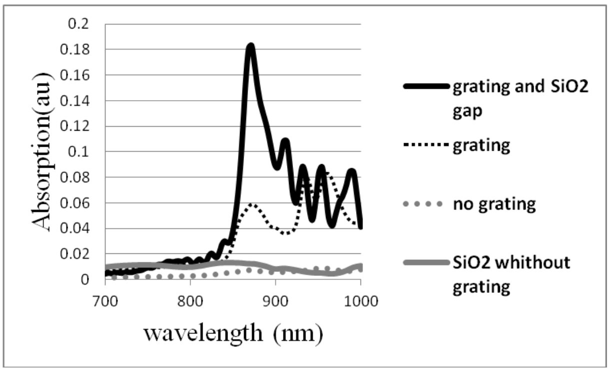

Figure 6: Absorption enhancement comparison in three structures; black solid line: the proposed structure with grating and SiO_2 layer, black dot line: the structure only with grating, gray dot line: conventional structure without grating, gray solid line: the structure with SiO_2 gap without grating

4 Conclusion

In this paper, we proposed a new design for a plasmonic photodetector by adding a SiO_2 layer under the metal grating. This layer provides 4 times improvement of the light absorption at 868nm in comparison with the similar structures.

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