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آشکارساز نوری تشدیدگر حلقوی شیاردار سیلیکنی با راندمان بالا مبتنی بر اثر گسیل داخلی فوتون

میترا حسینی‌فر [1]، وحید احمدی [2] و مجید ابن علی حیدری [3]

1. تهران، دانشگاه آزاد اسلامی واحد علوم و تحقیقات، دانشکده فنی و مهندسی، گروه الکترونیک

2. تهران، دانشگاه تربیت مدرس، دانشکده فنی و مهندسی، گروه الکترونیک

3. شهرکرد، دانشگاه شهرکرد، دانشکده فنی و مهندسی، گروه الکترونیک

چکیده – در این مقاله ساختار جدیدی برای آشکارسازهای سیلیکنی مبتنی بر اثر گسیل داخلی فوتون ارائه شده است. این ساختار موجبر حلقوی شیاردار مبتنی بر اثر گسیل داخلی فوتون نام دارد که قابلیت آشکارسازی امواج در حوزه مخابرات نوری را دارد. این ساختار متشکل از یک لایه نانومتری از شیار هوایی در سد شاتکی ساختار موجبر حلقوی می‌باشد. جذب فوتون به واسطه‌ی اثر گسیل داخلی فوتون در مرز بین فلز-نیمه هادی صورت می‌گیرد. این ساختار در برگیرنده ویژگی های اساسی ساختارهای موجبری، تشدیدگر حلقوی و موجبرهای شیاردار می‌باشد. در این مقاله به بررسی مشخصه های نوری و بازده کوانتومی این ساختار پرداخته و نتیجه می‌گیریم که این آشکارساز از بازده کوانتومی بالا و پاسخ طیفی انتخابی و تنظیم پذیر برخوردار است.

کلید واژه- موجبر حلقوی، اثر گسیل داخلی فوتون، شیار، بازده کوانتومی، مقیاس نانویی

High Efficiency Slotted Microring Si-Photodetector Based on Internal Photoemission Effect

M. Hosseinifar [1], V. Ahmadi [2], and M. Ebnali-Heidari [3]

1. Dept. of Electrical Eng., Science and Research Branch, Islamic Azad University, Tehran, Iran

2. Dept. of Electrical Eng., Tarbiat Modares University, Tehran, Iran

3. Dept. of Electrical Eng., Shahrekord University, Iran

Abstract- In this paper we propose an ultracompact integrated slotted-microring-internal photoemission effect photodetector (S-MR-IPE-PD) at the telecommunication wavelength of 1550 nm. The S-MR-IPE-PD is comprised of a nanometer-wide air slot over a Schottky barrier on CMOS-compatible microring resonator (MRR). The photon absorption is due to the IPE over a Schottky barrier at the metal/silicide -Si interface. Including the essential features of slot-waveguides and MR-based PDs, we can achieve excellent high-optical intensity, high speed and high quantum efficiency characteristics simultaneously. Photoresponse characteristics of S-MR-IPE-PDs which depend on device parameters and coupling conditions are investigated. The important features of the device, such as optical mode enhancement, efficiency enhancement and wavelength selectivity are discussed. Our numerical results prove that by using this PD, the low quantum efficiency, characterizing the devices based on the IPE can be enhanced efficiently. Additionally we show that by use of such a structure the optical field can be confined in a 30-nm wide air slot with enhanced optical mode.

Keywords: Microring resonator, internal photoemission effect, slot, nanoscale, quantum efficiency.

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Mitra Hosseinifar
m.hosseinifar@srbiau.ac.ir

Vahid Ahmadi
v_ahmadi@modares.ac.ir

Majid Ebnali-Heidari
ebnali-m@eng.sku.ac.ir

1 Introduction

Over recent years, the field of CMOS-compatible Si-based photodetectors (PDs) for optical communication has undergone intensive research efforts [1-2]. Among these efforts, the exploitation of the internal photoemission effect (IPE) over the metal-semiconductor Schottky barrier has attracted great attention. The need for high quantum efficiency in Si-based IPE-PDs has motivated the development of these detectors. Although some structures have been presented to enhance the QE of Si-based IPE-PDs[1-3], there is still a need for a Si-based IPE-PDs with more efficiencies. An alternative approach to enhance the IPE-based PD's QE is to use microring resonators (MRRs). MRR enhances the intensity of the optical field in the cavity and also act as a waveguide (WG) that will reduce the transit time which will increase PD's bandwidth [3-5].

In this paper, the design of Si-based slotted-microring-internal photoemission effect photodetector (S-MR-IPE-PD) is proposed. By means of slotted WGs, the optical field can be enhanced and confined in a low-refractive-index material. Our results prove that the low QE can be enhanced by placing the thin metal layer in S-MR-IPE-PD. The proposed structure is rather different with respect to MRR-IPE-PD [3]. In our device the air slot enhances the intensity of the optical field and as a result the absorption in metal layer. The main advantage of this device is its compatibility with CMOS based structures and Si-based PDs.

This paper is organized as follows. In section (2) we describe the structure. In section (3) the physical model for analysis of its optical response is explained and finally, in section (4) we present the calculated results and discussion.

2 Structure

Fig. 1(a) shows a schematic top view of the proposed S-MR-IPE-PD. A straight WG is used to couple light in to a slot- waveguide ring of radius R. The straight WG and microring are separated by coupling distance of g. Fig. 1(b) illustrates a cross-section of the straight-MRWG and the coupling region. Both straight WG and ring slot WGs consist of 300nm-thick, h, p-Si strips on a p^+-Si bottom cladding layer. The top of the whole device (cover) is exposed to the air. The inner and outer widths of the ring slot WG are W_{r1} and W_{r2}, respectively (symmetric slot WG), whereas the width of the straight WG is W_r. The slot-region width is W_s. The p-Si and metal/silicide strips are placed on p^+-Si pedestals of height p and widths equal to the corresponding p-Si strips.

Assuming fundamental mode propagates in straight WG. Optical field will be coupled to MRR of radius R at coupling region and will be enhanced and confined in the air-slot simultaneously. The MRR is covered partially by a nano-layer of metal/silicide of thickness d that forms a Schottky barrier with Si MRR. Additionally it is assumed that a single mode unidirectional field propagates in the ring slot WG and the coupling condition is lossless.

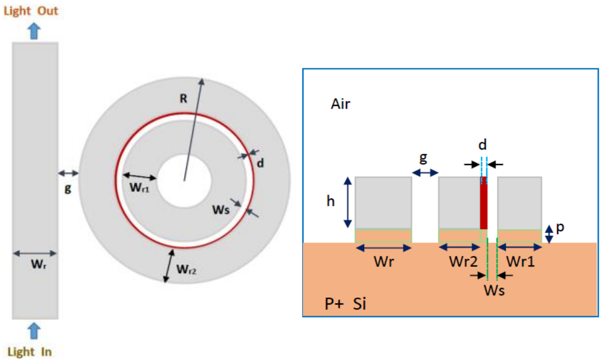

Figure 1: a) Schematic top view of the S-MR-IPE-PD
b) Schematic cross-section of the coupling region.

3 Modeling of S-MR-IPE-PD

3.1 Optical Mode

The optical mode of the MRR can be expressed as:

$$\text{mod}\, e = \frac{PF_{MR}}{PF_{SW}} \quad (1)$$

where PF_{MR} is the integration of MRR optical power flow and PF_{SW} is the integration of straight WG optical power flow.

3.2 Quantum Efficiency

Several research groups have modeled the efficiency of the IPE-based PDs [1-3]. In this work we use Scales's model to predict S-MR-IPE-PD efficiency, which is the more accurate and compatible with experimental results [2].

4 Results and Discussions

Here, we consider an S-MR-IPE-PD in which a fundamental mode of an optical field is launched into the straight WG and is assumed to couple to the MR. The optical field will be enhanced and confined in a 30-nm-wide air slot and will absorb simultaneously in a 5-nm-wide metal/silicide layer of the PD. The generated photocurrent is collected via contacts.

Fig. 2 plots the wavelength dependence of optical mode of a conventional MRR-IPE-PD and an S-MR-IPE-PD. In this work we use a finite element mode solver. Both structures have the same thickness of absorption layer, d=5nm. This figure shows that in the same wavelength the optical mode of the S-MR-IPE-PD is approximately 4 times higher than that of MRR-IPE-PD. This result reveals the optical enhancement due to the significant role of slotted–WGs [6].

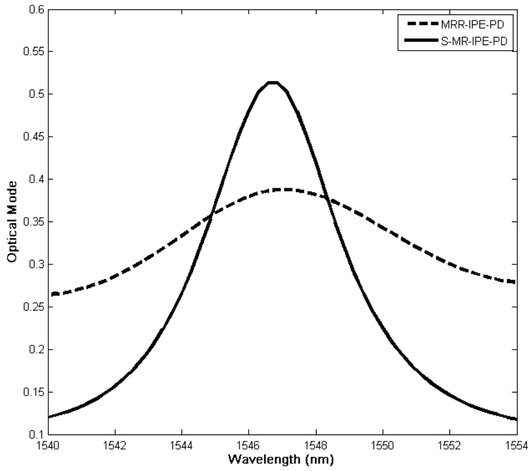

Figure 2: Calculated optical mode for an S-MR-IPE-PD and a conventional MRR-IPE-PD

Fig. 3 depicts the comparison between wavelength dependence of air-slotted-MRs (S-MR-PD) and S-MR-IPE-PDs. S-MR-PD doesn't have metal layer as its absorptive function, and in this regard its optical mode is nearly 7 times higher than that of S-MR-IPE-PD.

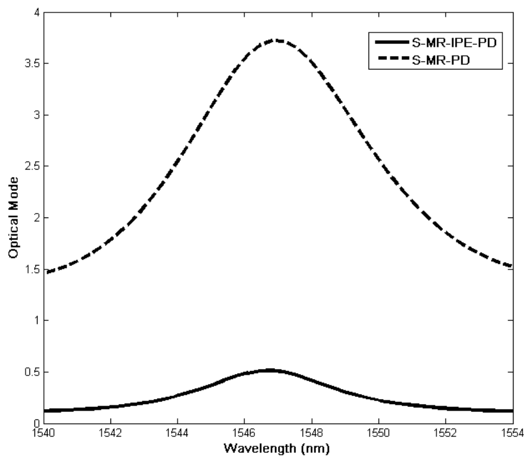

Figure 3: Calculated optical mode for a S-MR-IPE-PD and a S-MRR- PD

By considering MRR of R=5µm with various widths (300nm≤W≤500nm), the finite element numerical method is used to estimate the confinement factor, Γ as a function of W for 2nm thick layers of Pd_2Si, PtSi, $TaSi_2$ and $CoSi_2$ in both MRR-IPE-PD and S-MR-IPE-PD as shown in Fig. 4. The properties of silicides are given in [2]. The bending loss for TE-wave of 1550nm traveling inside these MRRs have been neglected [4].

According to the figure, as the waveguide width increases the mode is more confined in the wider MRR and hence Γ becomes smaller. Additionally for a given W, confinement inside each silicide nanolayer is more sensitive to the real part of its refractive index, and because of that in both structures the confinement factor for Pd_2Si is larger than other silicides, as the optical field penetrates more in Pd_2Si. The other important point is that for a given W, the Γ of S-MR-IPE-PD is much larger than MRR-IPE-PD. The fact behind this is in the S-MR-IPE-PD, the silicide nanolayer is embedded inside the WG in which fundamental part of mode is confined in it, whereas in MRR-IPE-PD a low evanescent mode propagates in the boundaries of the WG to overlap with silicide film.

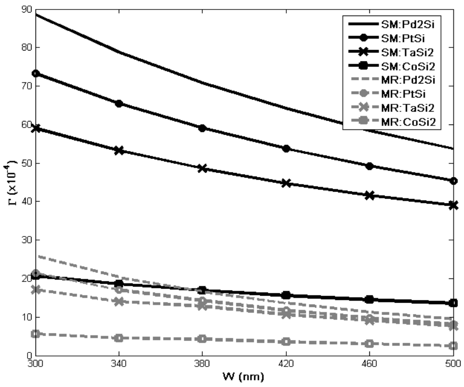

Figure 4: Confinement factor inside 3nm silicide layers as a function of W, for S-MR-IPE-PD and MRR-IPE-PD, for 1550nm.

Having calculated the confinement factor, now we can design the S-MR-IPE-PD for an optimized condition. The QE wavelength spectrums in critical coupling condition [5] of the same radius R=5µm, covered by 2nm thick layers of Pd_2Si for three different confinement factors are illustrated in Fig. 5. This figure reveals that, the smaller value of Γ results in narrower QE bandwidth and hence the larger the cavity quality factor.

5 Conclusion

In this paper, we have proposed a novel photodetector based on internal photoemission effect over a Schottky barrier formed between a 30-nm wide air slot, a nonolayer of metal/silicide and a CMOS-compatible Si microring resonator. We examined S-MR-IPE-PDs and compared the photoresponse to that of MRR-IPE-PD. We found that S-MR-IPE-PD can achieve higher optical mode, speed and quantum efficiency characteristics, in comparison with MRR-IPE-PD.

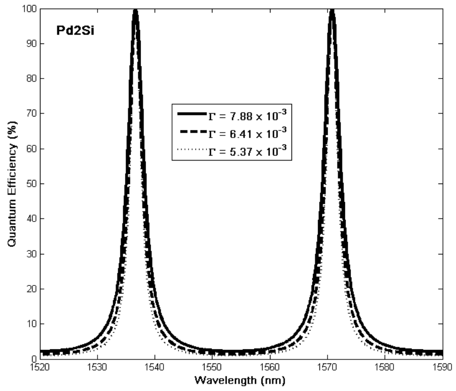

Figure 5: Wavelength dependence of QE in S-MR-IPE-PD for different confinement factors.

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