Numerical Study of the Evanescently Coupled One-Sided Junction Waveguide Photodiode

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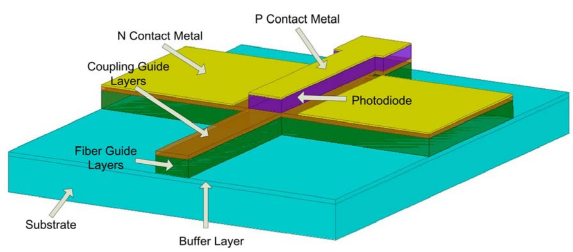
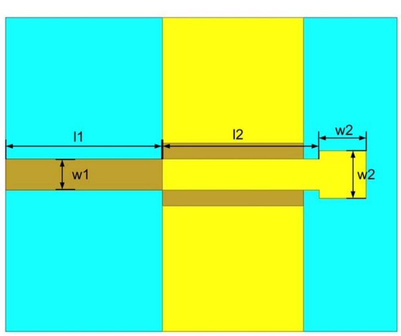
***Abstract*- The one-sided junction photodiode has a simple epitaxial layer structure, while maintaining the characteristics of high speed and high output power. An evanescently coupled one-sided junction waveguide photodiode is studied numerically and presented. The waveguide photodiode with 20 µm active region length leads to a responsivity of 0.435 A/W with a simulated bandwidth of 45 GHz.**

I. INTRODUCTION

High speed and high output power photodiodes are key components in various applications, including optical communications systems, radio-over-fiber links and photonics generation of terahertz signals, etc. Compared with back side illuminated photodiodes, waveguide photodiodes lead to a higher responsivity and efficiency. Bandwidth, output power and responsivity are the main figures of merit for waveguide photodiodes. Trade-off among these parameters should always be made during the design procedure of waveguide photodiode.



(a)



(b)

Figure 1. Evanescently coupled one-sided junction waveguide photodiode, (a) 3-D and (b) top view.

The waveguide photodiodes are studied by multiphysics simulation (optical and electrical). Lumerical FDTD is used to simulate the optical properties of waveguide photodiodes and calculate the photogeneration rate. Then the photogeneration rate is imported to Silvaco Atlas for electrical simulation. The simulated characteristics including internal optical power distribution, responsivity and bandwidth are given.

II. DEVICE STRUCTURE

TABLE I
EPITAXIAL LAYER STRUCTURE OF THE WAVEGUIDE PHOTODIODE

	Material	Thickness (nm)	Doping type and level
P-contact	InGaAs	50	P 1×10^{19}
Absorption	InGaAs	200	N 5×10^{15}
Transition	$In_{0.65}Ga_{0.35}As_{0.75}P_{0.25}$	10	N 5×10^{15}
Transition	$In_{0.77}Ga_{0.23}As_{0.5}P_{0.5}$	10	N 5×10^{15}
Transition	$In_{0.89}Ga_{0.11}As_{0.25}P_{0.75}$	10	N 5×10^{15}
Collection	InP	200	N 2×10^{16}
Coupling	$In_{0.77}Ga_{0.23}As_{0.5}P_{0.5}$	300	N 2×10^{18}
Coupling	InP	150	N 2×10^{18}
Fiber guide	7 layers of $In_{0.89}Ga_{0.11}As_{0.25}P_{0.75}$ interdigitated with 6 layers of InP	2000	Undoped
Buffer	InP	500	Undoped
Substrate	InP	300000	Undoped

Figure 1(a) shows the 3-D structure of an evanescently coupled one-sided junction waveguide photodiode. The optical waveguide coupling mechanism is similar to [1]. As shown in Fig. 1(a), light is injected into the fiber guide layers and coupling guide layers. And then the light is gradually evanescently coupled to the photodiode. The specific dimensions of waveguide photodiodes are given in Fig. 1(b). L1 and w1 are the length and width of fiber guide layers. L2 is the active region length of photodiode. W2 is the width of the square metal pad, which is connected to the external CPW pad. In this work, l1=20 µm, l2=20 µm, w1=4 µm and w2=6 µm. The epitaxial layer structure of the proposed evanescently coupled one-sided junction waveguide photodiode is given in TABLE I.

III. MULTIPHYSICS SIMULATION

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The design of waveguide photodiode involves optical simulation and electrical simulation (multiphysics simulation). Lumerical FDTD and Silvaco Atlas are utilized to perform the simulation and the numerical modeling procedure is similar to [2].

The internal optical power distribution is simulated by Lumerical FDTD and is given in Fig. 2. The injected light is gradually coupled towards the photodiode and then absorbed by the photodiode. Obviously, most of the energy is absorbed in the first half of the photodiode and a small portion of the energy travels towards the buffer layer and substrate, which results in optical loss. To achieve a better efficiency, both the fiber guide layers and the coupling guide layers should be optimized.

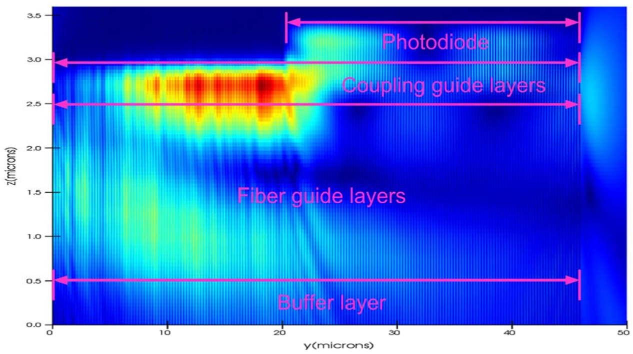

Figure 2. Internal optical power distribution of the waveguide photodiode.

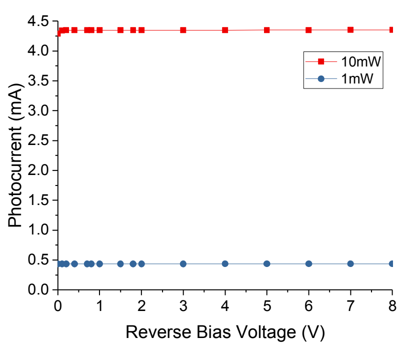

Figure 3. Photocurrent of the waveguide photodiode with an injected optical power of 1 mW and 10 mW.

The photogeneration rate of electron and hole pairs are calculated by Lumerical FDTD. Then, the photogeneration rate is imported to Silvaco Atlas to calculate the photocurrent. The photocurrent of the waveguide photodiode with a reverse bias voltage from 0 to 8 V is given in Fig. 3. At an injected optical power of 1 mW and 10 mW, the photocurrent is 0.435 mA and 4.35 mA. The corresponding responsivity is 0.435 A/W, which is reasonable for a waveguide photodiode with 20-µm length. The detailed analysis of the one-sided junction photodiode can be found in [3,4].

The relative response of the waveguide photodiode is simulated by Silvaco Atlas. The photodiode has an area of 116 μm^2 and the load resistance is set to 50 Ω. The simulated 3 dB bandwidth is 45 GHz, as shown in Fig. 4. To our knowledge, the bandwidth calculated by drift-diffusion equation is always underestimated. And the CPW pad also has an influence on the bandwidth, which results in the discrepancy between simulated and measured results [3].

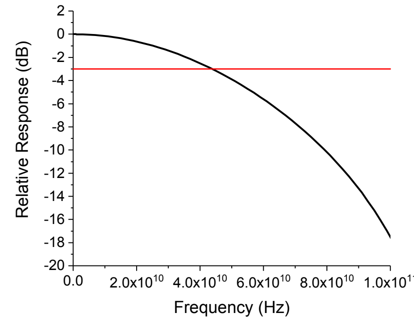

Figure 4. Relative response of the waveguide photodiode with 20 µm active region length.

IV. Conclusion

The numerical modeling study is performed on the evanescently coupled one-sided junction waveguide photodiode. The simulated internal optical power distribution shows that the injected optical power can be absorbed by the photodiode efficiently. The designed waveguide photodiode achieves a responsivity of 0.435 A/W and a bandwidth of 45 GHz. The numerical modeling procedure is an effective way to estimate the performance of the waveguide photodiode.

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