Two Color Photodiodes Mounted on the Micromachined Carrier

Žarko Lazić, Milče M. Smiljanić, Dušan Nešić, Ljubiša Zeković

***Abstract*— In this paper, two color detector based on silicon photodiodes is studied and fabricated. Standard IHTM photodiode's design is modified to allow mounting one photodiode above another using special micromachined carrier. The carrier is fabricated using wet silicon etching in 25% TMAH water solution and anodic bonding of etched silicon and Pyrex glass. The fabricated carrier also allows easy wire thermocompression bonding from the photodiode's pads to TO-5 housing. Output currents of the photodiodes were measured by applying light of 900 nm and 1060 nm. Obtained results verify applicability of the new packaging for two color detector.**

***Index Terms*—Two color detector, photodiodes, micromachined packaging, silicon, Pyrex glass**

I. Introduction

IN the Institute of Chemistry, Technology and Metallurgy (IHTM) various types of silicon photodiodes were explored and developed for decades [1]. In this work, we will study a modified IHTM silicon photodiodes as two color detectors [2-4]. Two color detectors represent a sandwich structure that contains two photodiodes arranged along the same optical axis and they measure different ranges of wavelengths. Commercially available detectors [3-4] are using two photodiodes based on silicon or silicon and InGaAs. These detectors are mostly utilized for remote temperature measurements and for wide wavelength ranges of detection. The temperature is measured using ratio of radiation intensities at two wavelengths or wavelengths ranges and comparing it with the standard black body radiation [3]. Special advantages of these optical remote temperature measurements are solving problems of physical obstacles on target's optical axes. Two color detectors are used in applications for flame temperature sensing, spectrophotometer, dual-wavelength detection and IR thermometers [3].

In this paper, we will explore design of the silicon-silicon photodiodes sandwich, in which the top silicon photodiode is placed above the other bottom photodiode, as shown in Fig.1. The idea of design is that the photons of shorter wavelengths must be absorbed in the top photodiode and the photons of longer wavelengths are absorbed in the bottom photodiode. The sandwich design is obtained using special carrier for photodiodes. Carrier is fabricated using processes of micromachining of silicon in 25% wt. TMAH water solution and anodic bonding of etched silicon and Pyrex glass. In order to provide electrical connections, design and fabrication of the photodiodes are modified. After mounting of sandwich carrier on the TO-5 housing, measurements were performed to confirm detection of two different wavelengths.

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II. Fabrication

In the research and development of two color detector we modified photodiodes using know-how of our previous commercial silicon photodiodes. Problem of thermocompression bonding of golden wires to aluminum electrical connection is solved with design of the lateral photodiodes. The IHTM standard photodiodes have electrical connections on the both sides-the top and the bottom. In two color detection the top photodiode must allow transmission of wavelengths to be absorbed by the bottom photodiode. For this reason, the bottom side of the top photodiode must be designed without any metallization and reflective layer.

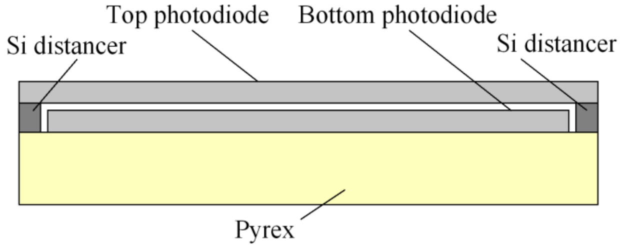

Fig. 1. Cross section of two photodiodes mounted on the micromachined carrier.

In order to simplify fabrication processes, the top and the bottom photodiodes are produced using the identical design, as shown in Fig.1-2. The photodiodes are in the shape of silicon rectangles with surface dimensions of 4000 μm x 3345 μm, as shown in Fig.1-2. The rectangular shape resolves the problem of thermocompression bonding of gold wires to both mounted photodiodes on fabricated carrier and TO-5 housing since both are rotated for 90˚ relative to each other, as shown

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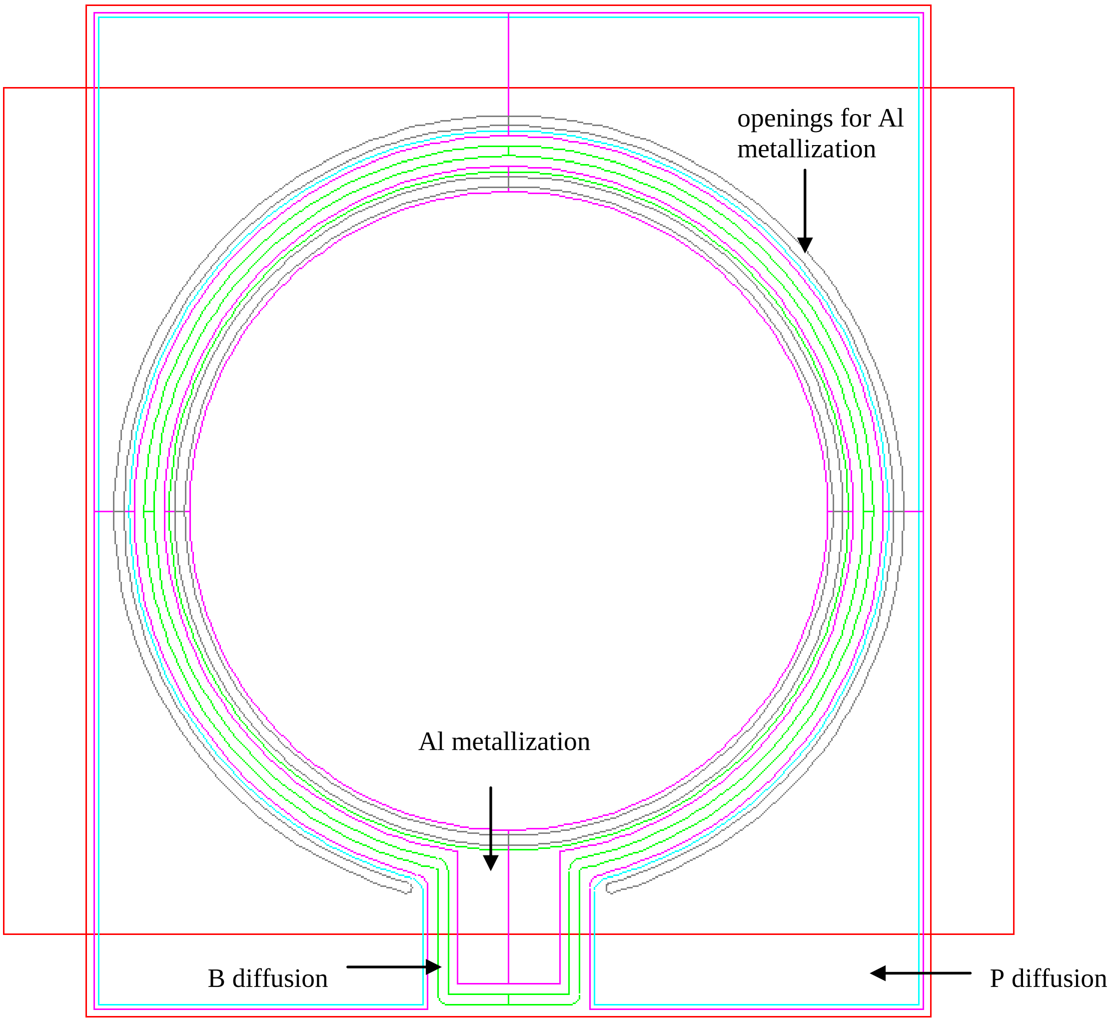

Fig. 2. Two color photodiodes design. Green color-I photolithographic process for boron diffusion. Blue color-II photolithographic process for phosphorus diffusion. Grey color-III photolithographic process for openings for Al metallization in SiO2. Pink color-IV photolithographic process for Al metallization. Red color-rectangular borders of sawed photodiode.

in Fig.2. We used two types of the silicon substrates in fabrication. For the top photodiodes, the silicon wafers of n type, resistivity of 2000 Ωcm and thickness of 180 µm are used. For the bottom photodiodes, we used silicon wafers of n type, resistivity of 500-1000 Ωcm and thickness of 300 µm. Prior to predetermined technological processes, the photolithographic processes were performed to define patterns given in Fig.2. The fabricated photodiodes were obtained according to following list of technological processes:

1. I wet thermal oxidation for boron diffusion (T=1100 °C, t=120 min)
2. I photolithographic process for boron diffusion
3. Boron diffusion (T=1025 °C, t=60 min)
4. II wet thermal oxidation for phosphorus diffusion (T=1100 °C, t=100 min)
5. II photolithographic process for phosphorus diffusion
6. Phosphorus diffusion (T=950 °C, t=60 min)
7. SiO_2 thinning on the top side and its removing on the bottom side of wafer
8. III photolithographic process for openings in SiO_2
9. Al sputtering
10. IV photolithographic process for Al metallization.

Finally, Au layer was sputtered only on the bottom side of the bottom photodiode as reflective layer.

Photodiodes' carrier is micromachined using anisotropic wet etching in 25% wt. water solution at the temperature of 80 °C [5-7]. We used phosphorus-doped {100}-oriented 3" silicon wafers with double-sided polished surfaces. The resistivity of the wafers is 1-5 Ωcm and its thickness is 400 µm. Prior to etching, we performed wet thermal oxidations to obtain SiO_2 masking layer of 1 µm and 0.5 µm thicknesses and three photolithographic processes to define patterns for double side etching. First, we performed etching to define appropriate cavities on the top side of silicon substrate. Then the thinner silicon dioxide was removed. Next, wafer had been double side etched until membrane of 50 µm was obtained. Etched wafer was anodically bonded to the Pyrex

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TABLE I
PHOTODIODES CURRENTS AND RATIOS OF CURRENTS FOR THE WAVELENGTHS OF 900 NM AND 1060 NM.

Two color detector		900 nm			1060 nm		
		Intensity I_1	Intensity I_2	Intensity I_3	Intensity I_1	Intensity I_2	Intensity I_3
1	I_{top}	8 µA	4 µA	850 nA	14.9 µA	2.32 µA	756 nA
	I_{bottom}	0.55 µA	0.265 µA	57.5 nA	5.1 µA	1.1 µA	395 nA
	Ratio	14.5	15.1	14.8	2.9	2.1	1.9
2	I_{top}	9.05 µA	3.4 µA	1.24 µA	12.55 µA	3.22 µA	995 nA
	I_{bottom}	1.15 µA	0.337 µA	0.128 µA	3.16 µA	1.56 µA	555 nA
	Ratio	7.9	10.1	9.7	4	2.1	1.8
3	I_{top}	5 µA	2.61 µA	800 nA	13.7 µA	3.22 µA	681 nA
	I_{bottom}	0.61 µA	0.33 µA	95 nA	6.15 µA	1.96 µA	467 nA
	Ratio	8.2	7.9	8.4	2.2	1.6	1.46

glass wafer, as shown in Fig.3. The thickness of Pyrex glass wafer is 700 µm. Finally, the last etching of the previously obtained membrane determines distancers on glass support, as shown in Fig.1. The distance between vertical etched silicon inner walls is 3345 µm. Finally, the Pyrex glass wafer was sawed into 4000 µm x 4000 µm carriers.

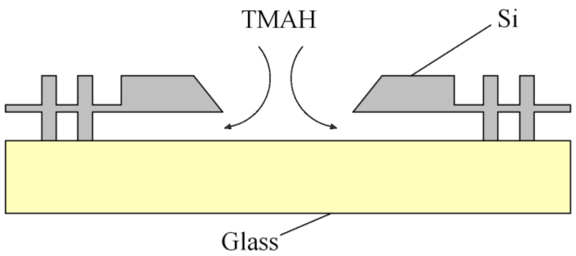

Fig. 3. Schematic picture of partly micromachined silicon wafer anodically bonded to Pyrex glass wafer.

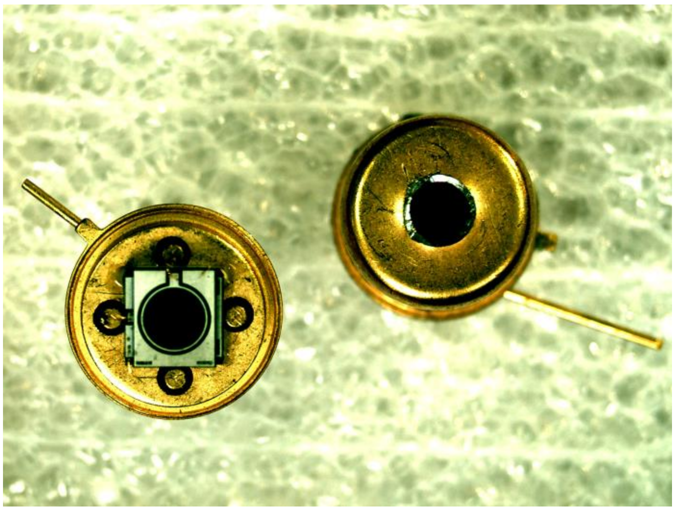

Fig. 4. Two photodiodes mounted on TO-5 housing with and without cap.

III. RESULTS AND DISCUSSION

The photodiodes were measured separately before mounting in order to confirm their quality and compare with IHTM commercial photodiodes. Sensitivities for both photodiodes were 0.65 A/W for 900 nm and 0.2-0.3 A/W for 1060 nm. Breakdown voltages of about 100 V were obtained. These parameters are similar to IHTM commercial photodiodes [1].

The top and bottom photodiodes are mounted on obtained carriers as shown in Fig.1. The carriers are then mounted on TO-5 housing, as shown in Fig.4,5 where the photodiodes are bonded to four pins using 25 µm gold wires. At the end, the cap with aperture was glued to TO-5 housing. Aperture is designed for the optical fiber as shown in Fig.5.

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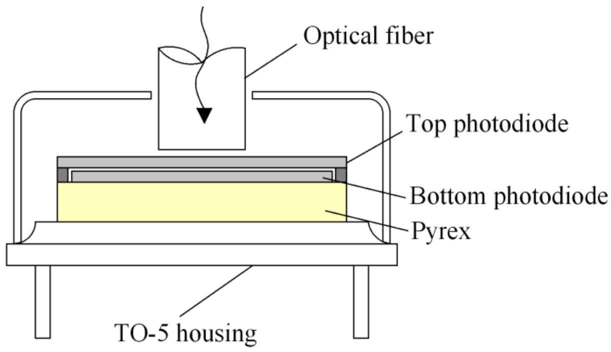

Fig. 5. Schematic picture of cross section packaging of mounted two photodiodes with optical fiber.

The light is applied through optical fiber in order to measure ratios between the photodiodes' output currents. We used the filters for 900 and 1060 nm when the light is applied. The obtained ratios between the photodiodes' output currents are given in Table 1 for three different detectors. For each two color detector ratios were measured for three different light intensities. From outputs and ratios given in Table 1, we can

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conclude that the designed carrier can be used as a part of packaging for two color detector. Our future work will be to improve our modified photodiodes presented in this paper in order to obtain better output characteristics.

IV. Conclusion

In this paper, we explored and developed two color detector based on silicon photodiodes. We modified IHTM photodiodes in order to allow mounting of one photodiode above another and easy thermocompression bonding to TO-5 housing. We fabricated special carrier for photodiodes using wet silicon etching in 25% TMAH water solution. Output currents of the produced two color detectors were measured by applying light with the wavelengths of 900 nm and 1060 nm. Performed measurements confirm usability of the new designed carrier for two color detector.

Acknowledgment

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References

[1] www.ihtm.bg.ac.rs

[2] D.B. Ponomarev, V.A. Zakharenko, “Silicon photodiode as the two-color detector”, *Journal of Physics: Conference Series*, Volume 643, 2nd International School and Conference Saint-Petersburg OPEN on Optoelectronics, Photonics, Engineering and Nanostructures (SPbOPEN2015), St Petersburg, Russia, 6–8 April 2015.

[3] www.osioptoelectronics.com

[4] www.hamamatsu.com

[5] M.M. Smiljanić, B. Radjenović, M. Radmilović-Radjenović, Ž. Lazić. V. Jović, “Simulation and experimental study of maskless convex corner compensation in TMAH water solution”, *J. Micromech. Microeng.* 24115003, 2014.

[6] M.M. Smiljanić, B. Radjenović, M. Radmilović-Radjenović, Ž. Lazić. V. Jović, “Evolution of Si crystallographic planes-etching of square and circle patterns in 25 wt % TMAH”, *Micromachines*10(2) 102, 2019.

[7] M.M. Smiljanić, Ž. Lazić, V. Jović, B. Radjenović, M. Radmilović-Radjenović, “Etching of Uncompensated Convex Corners with Sides along <n10> and <100> in 25 wt% TMAH at 80 °C”, *Micromachines* 11(3), 253, 2020.