

LINEAR PHOTODETECTOR ARRAYS INTEGRATED WITH OPTICAL WAVEGUIDES FOR PROXIMITY OPTICAL MICROSENSOR

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Abstract—Two linear photodetector arrays integrated with optical waveguide, designed as proximity/position optical microsensors are presented in this paper. Each of the two arrays consist in four silicon P^+NN^+ photodiodes, fabricated in an epitaxial silicon layer using standard Si device fabrication techniques and are integrated with SU8 optical waveguides. The optoelectrical characterization of every one photodetector of the linear array was realized by vertical illumination with a red radiation and good results have been obtained.

Keywords: optical proximity microsensor, PIN photodiode, optical waveguide, SU8, heterogeneous integration.

1. INTRODUCTION

The research in the field of optical position sensors based on silicon have gained a special advancement due to silicon's low cost manufacturing technology and the possibility to be integrated with different types of polymeric microphotonic components on silicon substrate. We present an optical proximity/position microsensor for micro-robotic applications as integration into a micro gripper arm or detection of the position of a gripper arm relative to an object. Our sensor can detect the position of an object along some axis. In our case the sensor one can detect a position in the range of 0 to 300 μm , as position sensor and with high precision in the range of 0 to twice the wavelength, as proximity sensor.

The optical microsensor principally consists in two linear silicon photodetector arrays, heterogeneous integrated with an optical waveguide designed with three different arms. The operation principle of this sensor consist is based on the light coupling in the central arm of the optical waveguide, where it is stabilized and filtered according to the waveguide thickness,

interaction with the object (reflection) of the radiation which exits from the principal arm, coupling of the reflected radiation, which comes back through the end of the waveguide and is splitted into the three arms of the optical waveguide. The light which pass through the optical waveguide is coupled in the photodetector element of the linear array and the photogenerated carriers are collected to the electrodes, giving the electrical signal, which is measured and processed in real time, Fig. 1. Several types of photodetector structures like PIN, metal-semiconductor-metal, avalanche photodiodes can be used to detect the radiation coupled from optical waveguide, [1]. PIN type photodiodes have the advantage of a high reponsivity which confer to the sensor a good sensibility. This is an important characteristic taking in consideration the low value of the optical signal which emerges from the waveguide.

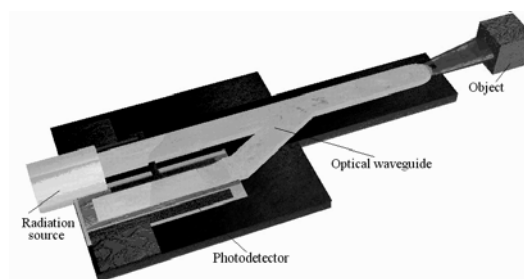


Fig. 1. 3D schematic view of the Optical Position Sensor.

For the sensor, each configuration of the two linear silicon photodetector arrays has four photodetector elements, composed of P^+NN^+ photodiodes. For the optical signal distribution to the photodiodes, optical interconnection lines need to be implemented. The optical splitter of the SU-8 waveguide integrated with the photodiodes has a Y branch shape. The emergent

light is coupled into the photodiodes. We proposed a segmented photodetector's area [2]. In order to obtain a small sensing area which is capable of beam position and angle tracking. We intend to use this area for microgripper arms position detection.

2. DEVICE FABRICATION

Linear photodetector arrays integrated with optical waveguides were fabricated in the silicon epitaxial wafers, using standard silicon device fabrication techniques. Every element of the photodetector arrays is a P^+NN^+ photodiode with an active area of $125 \times 125 \mu m^2$ with a distance of $35 \mu m$ in between. The photodiode structure is presented schematically in Fig. 2 and the layout of the sensor is presented in Fig. 3.

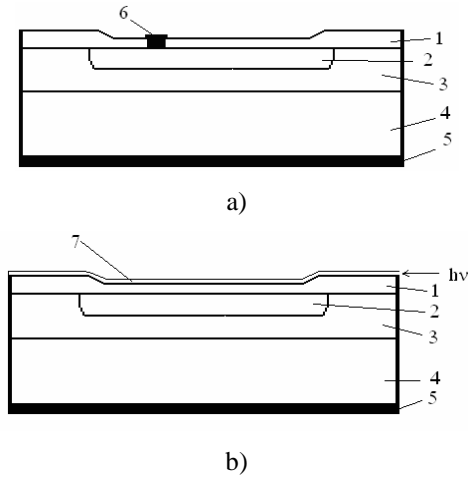


Fig. 2. Cross sections of one photodetector of linear array integrated with optical waveguide. a) region outside the waveguide; b) region with waveguide: 1- oxide; 2- P^+ diffusion layer, 3- N type epitaxial layer, 4- silicon substrate; 5- back side metallic contact, 6- metallic contact on the active area, 7- optical waveguide.

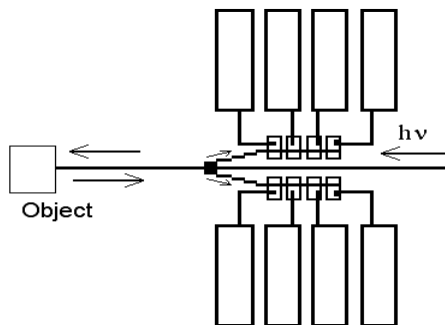


Fig. 3. The layout of the proximity optical microsensor.

The sensor was realized on n type silicon epitaxial wafers $\langle 111 \rangle$, with the epitaxial layer resistivity in the range of $17-21 \Omega cm$ and the thickness of $25-30 \mu m$. The wafers were thermally oxidized with a thickness of $1 \mu m$ at a temperature of $1100^\circ C$. The windows defining the active areas of the P^+NN^+ photodiodes were etched in SiO_2 . An important aspect was to obtain a small angle of the etching slope, where the waveguides cross over the active areas so that the light propagation losses to be minimized. An angle of about 12.5° was achieved by thermal treatment of the wafers at a temperature of $90^\circ C$, for 30 min.

A p^+ Boron diffusion from solid source (BN) with V/I in the range $4-5 \Omega$ to achieve the p-n junction was performed at a temperature of $1100^\circ C$ in steam. The junction depth was $1,6 \mu m$. Aluminum contact pads, with a thickness of $0.5 \mu m$, were configured on the active area. After the metal contact pads were patterned and etched, the wafers were annealed at $450^\circ C$ for 30 min in $(N_2+3\%H_2)$ forming gas.

The configuration of the linear photodetector arrays are presented in Fig. 4. In Fig. 5. is shown the same structure after the windows opening, in order to integrate the optical waveguide.

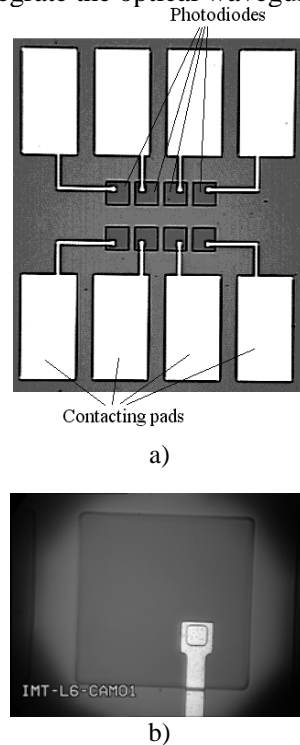


Fig. 4. Optical microscope picture of the linear photodetector arrays: a) entire structure; b) detail - one photodetector element.

From Fig. 5 b) it can be seen a smooth pass from oxidized region to the etched areas. An optical splitter with 3 branches was integrated with the P^+NN^+ photodiodes on the same silicon substrate.

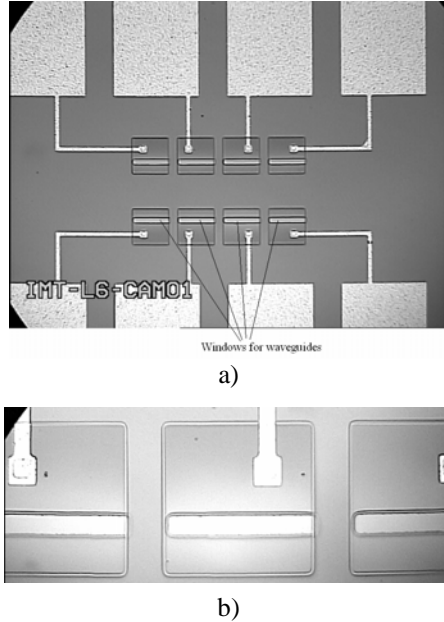


Fig. 5. Optical microscope picture of the two photodiodes linear arrays with opened windows for waveguide. a) entire structure; b) detail.

For the core of the optical waveguide was used a polymeric material SU8, an epoxy-based negative photoresist, which shows a great versatility in micromechanical structures and microfluidics [2]. SU-8 can be defined with very smooth sidewalls, by standard technological processes and it presents important features for optoelectronic applications like a high transparency in visible and near IR region of the electromagnetic spectrum and refractive index about 1.5 in visible region. This allows the realization of low loss strip waveguides circuits using the standard photolithography process [3-5]. In order to obtain the optical waveguide of 15 μm width with three arms (Fig. 6), a layer of SU-8 2002 was spin coated and hard baked on an hot plate, at 150°C, for 15 min. The thickness of SU-8 layer was about 2 μm . Photolithographic process were performed for achieving the proposed configuration.

In Fig. 6 is shown an optical microscope picture of the fabricated linear arrays, integrated with an optical waveguide with three arms – central arm for incident radiation which will be reflected by the object whose position is studied

and two arms passing over the photodiode active area, for evanescent light coupling.

The sensor structure was mounted on a metallic base and connected via bonding wires. for measurements

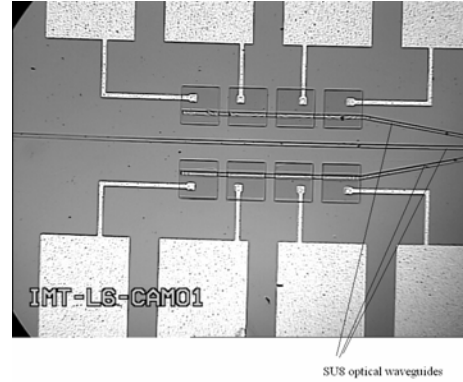


Fig. 6. Optical microscope picture of the achieved linear photodetector arrays integrated with SU8 optical waveguide.

3. RESULTS AND DISCUSSION

The realized structures of linear photodiodes arrays have been characterized by vertical illumination, before the waveguides deposition.

The optoelectric characterization of the photodiodes has shown a breakdown voltage greater than 90V at 100 μA and a dark current less than 0.02nA at 5V reverse bias.

The device has a very good rectifying characteristic with low absolute leakage current. A responsivity of 0.39A/W under red radiation of 630nm wavelength and 20V bias was achieved. The photocurrent was measured with an optical source with a power of 500 μW and a wavelength of 630nm.

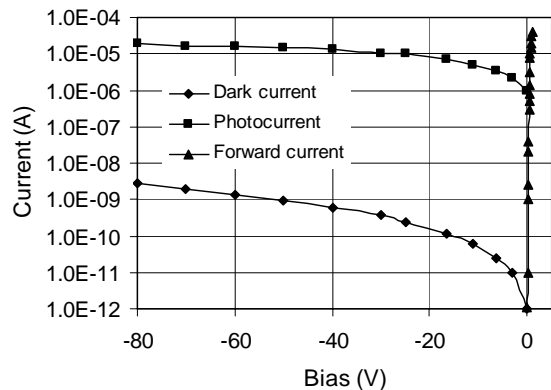


Fig. 7. Current – voltage characteristics of a photodetector element in the dark (blue) and under illumination of 650 nm (red) coupled vertical to the detector.

Current/voltage characteristics of one photodiode of the array, in dark and under vertical illumination are shown in Fig. 7. It can be seen that the photocurrent is nearly flat over a wide range of reverse bias voltage, greater than 20V. This is because this reverse bias voltage depletes 10 μ m which is the total absorption depth ($3/\alpha$) of red radiation of 650nm wavelength in silicon, where α is the absorption coefficient of this radiation in silicon, $\alpha = 3 \cdot 10^3 \text{ cm}^{-1}$.

Future work will consist in the realization of measurement set-up for the characterization of the optical coupling waveguide - photodiode arrays using a red radiation from a laser diode and the output of the photodiode wire connected to an amplifier, in order to measure the final signal.

4. CONCLUSIONS

Linear arrays of four P⁺NN⁺ photodiodes with an active area of 125 \times 125 μm^2 and 35 μm in between were developed based on simple, low cost technological processes, suitable for monolithic integration with C-MOS circuits. The photodetector arrays have been characterized by vertical illumination of the photodiodes with a red radiation. A high responsivity of the photodiodes of 0,39A/W assures an useful electrical signal which can be read and processed in real time. The linear arrays of photodetectors have heterogeneous been integrated with SU-8 polymeric optical waveguide.

The achieved optical position/proximity sensor, based on an original configuration, is destined to micro-robotic applications as integration into a micro gripper arm or detection of the position of gripper arms, relative to an object.

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