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OPTICAL COUPLING OF SILICON CHIPS BY MICROCHANNEL VIAS INTERPOSER

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I. INTRODUCTION

The performance increase is currently one of the main tasks of the integrated electronics development. Replacement of electronic interconnects to optical ones will improve the performance of integrated circuits (ICs) by eliminating the resistive-capacitive delay of the metal wiring. A significant expectations are connected with the silicon based optical interconnects implemented in the form of optocouples which includes Si light emitting sources and photoreceivers connected by the waveguides of different constructions. Among the advantages of such a system is its compatibility with the highly developed mass production CMOS technology. Classical approach in optocouple designing is that all three main elements such as light-emitting diode (LED), photodiode (PD), and waveguide (WG) are located in a horizontal plane [1-3]. Recently a new technology was proposed and now it is in intensive development.

We have developed and manufactured a system that provides optical interconnects between silicon chips based on silicon avalanche LEDs and silicon microchannel plate vias. Measurements showed a reproducible response of the optical signal of the avalanche LEDs registered by photodiodes on a silicon chip, which has no electrical commutation to another silicon chip on which the sources of the optical signal are located.

II. EXPERIMENTAL

Silicon chips were produced by the conventional CMOS technology. N-type monocrystalline silicon with a resistivity of 0.3 Ω·cm was used as initial substrate. SiO_2 layer of 0.8 μm thickness was formed on the silicon surface by thermal oxidation and regular windows were open in this layer by plasma etching. Then the aluminum/silicon composite film of 0.1 μm thickness was deposited over the SiO_2 layer by magnetron sputtering of aluminum/silicon alloy target with the Si content of 30 at. %. As a result, a composite film with Si nanoparticles embedded into Al host is formed [4]. After that a pure aluminum film of 1 μm thickness was deposited over the composite film.

The deposited films were subjected to anodic treatment in a 20 % aqueous solution of phosphoric acid via preformed photoresist masks at their surfaces. Such treatment led to the oxidation of the deposited films in unmasked areas. It's known that aluminum and silicon have the various velocities of oxidation. Therefore the anodic treatment of Al/Si film resulted in formation of nanostructured composite material, containing clusters of slightly oxidized nanoparticles of Si embedded into the alumina matrix [4]. Not anodized areas protected by the photoresist mask formed metal electrodes between anodized regions. The photoresist mask has been removed after anodizing.

Along with the silicon chips with diode structures microchannel wafers are also produced. Microchannel wafers formation was carried out using electrochemical anodization and subsequent thinning of silicon wafers by mechanical polishing.

The structure parameters of the developed devices were analyzed by scanning electron microscope (SEM) Hitachi H-800. The current-voltage characteristics of the Schottky diodes were measured by the oscilloscope characteriograph L2-56.

III. RESULTS AND DISCUSSION

The developed structure consists of two silicon chips with certain number of Schottky diodes, which can operate in LED or PD mode depending on the biasing. These silicon chips with sets of Schottky diodes are separated by the Si optical interposer. The fragment of construction shown in Figure 1 includes two Schottky contacts and an anodic alumina layer separating aluminum electrodes. The anodic alumina layer contains silicon nanoparticles that emit light in the Schottky contact avalanche breakdown mode (LED). These Schottky contacts at a reverse bias below breakdown state (in this case up to 12 V) are sensitive to an external light signal, and therefore can be used as photodiodes (PD) [5, 6]. It should be noted that the light emission was also observed at forward bias of Schottky diodes but its intensity was largely inferior to the light emission upon reverse bias.

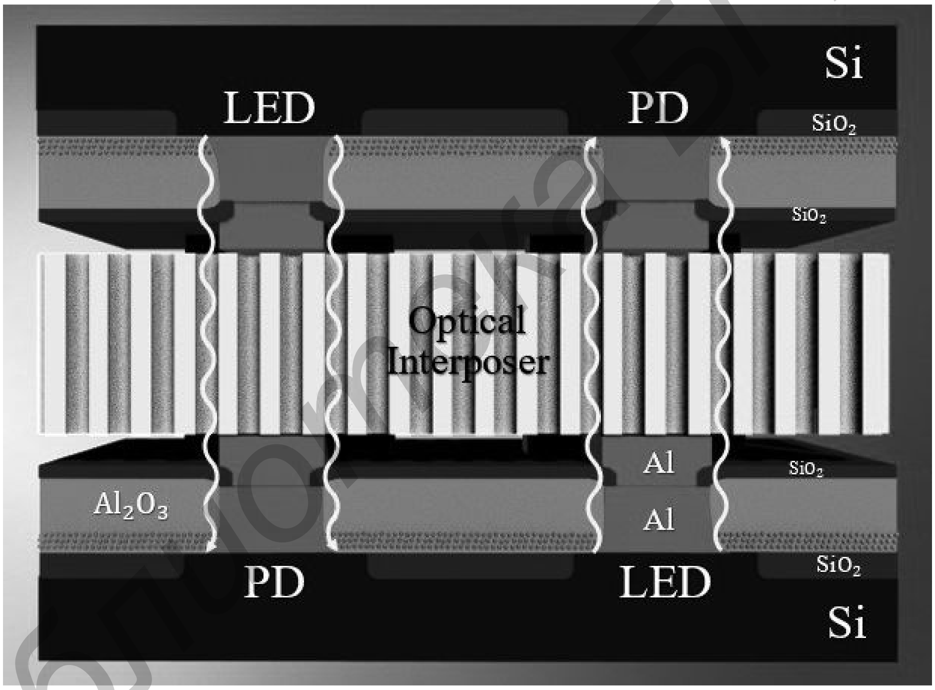
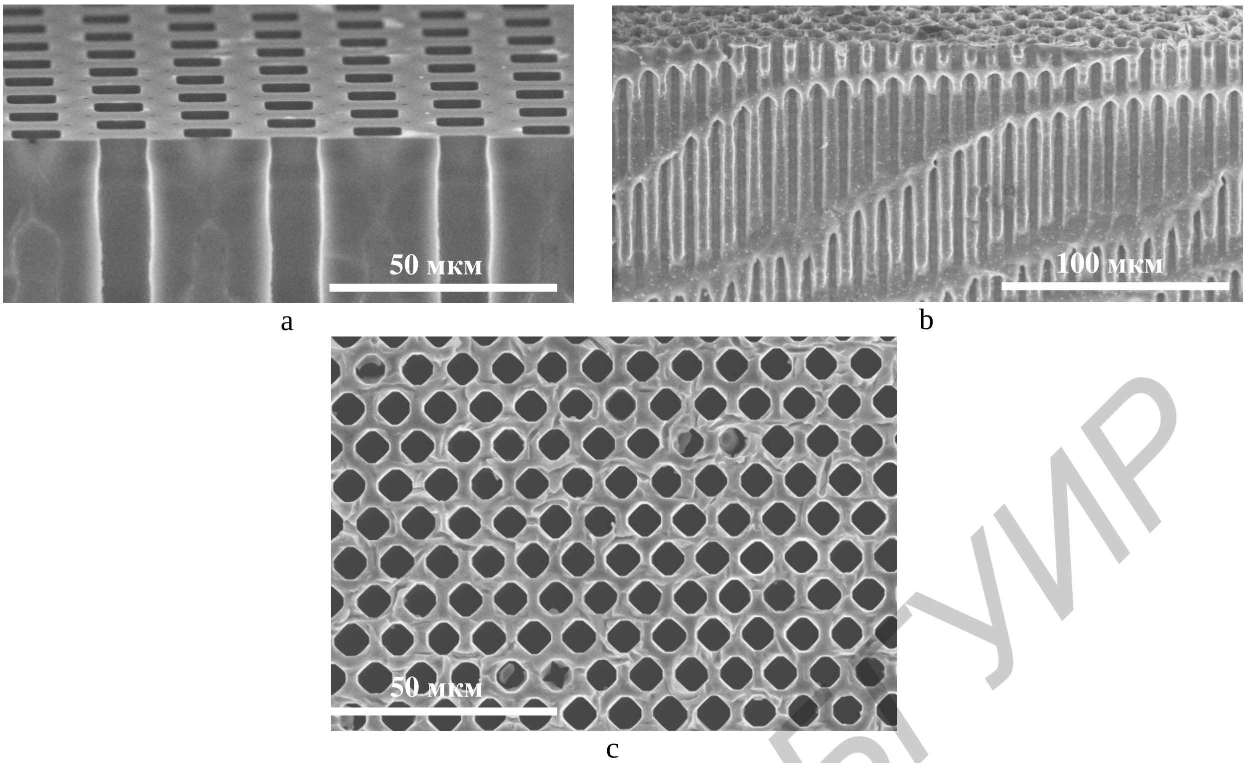


Figure 1 – Schematic representation of the experimental structure of interchip optical interconnects

Figure 2 shows SEM images of the microchannel silicon wafer, providing an optical signal transmission in the vertical direction relative to the surface of silicon chips. The microchannel wafers are 100-150 µm thick with through-holes (vias) with diameters of 5-6 µm. The distance between the centers of vias is 10 µm. The vias area occupies 20-25 % of the entire surface of the wafer. These wafers are capable of transmitting an optical signal through the vias with the transmission ratio of 15-20 %. Such microchannel wafers called interposer, as they can be used to implement the commutation of "stackable" silicon ICs that has been demonstrated previously by filling the microchannels with copper [7].



a

b

c

Figure 2 – Top (a), cross-section (b) and bottom (c) images of the silicon microchannel wafer used for optical interconnects between silicon chips

Figure 3 shows the current-voltage characteristics of the avalanche diodes operating in the light signal detection mode. The optical signal is detected in the reverse bias range from 0 to 12 V as seen from the characteristics.

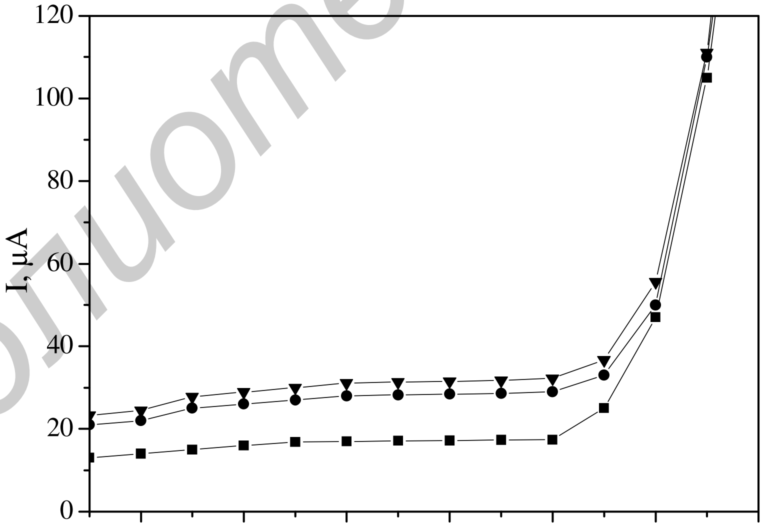


Figure 3 – The current-voltage characteristics of the avalanche diodes with different methods of light exposure: squares – the dark characteristic, circles – light exposure with avalanche LEDs at a current of 30 mA; triangles – light exposure with a tungsten lamp.

The current-voltage characteristics with light exposure and without it do not differ after exceeding the reverse bias of 12 V, due to the appearance of self light emission in the investigated structures. Current-voltage characteristic of the diodes with exposure from an external light source (a tungsten lamp) that provides surface irradiance of 100 mW/cm^2 is also shown in Figure 3. As can be seen from the characteristics, the response of the diodes to radiation from the tungsten lamp is comparable with the response to radiation from avalanche LED at the bias voltage of 15 V and current of 30 mA, which indicates the proportionality of optical flow of the both light sources.

Taking into account that the avalanche LED was used as external light source at the current of 30 mA and investigated Shottky diode in the PD mode (at bias of 10 V) showed photocurrent of 30 μA (Figure 3), the current conversion efficiency of the developed SP structure, defined by the ratio of PD current to LED current, is equel to 0.1 % what is good enough for optical interconnection.

IV. CONCLUSION

The design and manufacturing technology of optical interconnects between silicon chips have been developed. Among the main characteristics of the developed system it should be noted that the ratio of the current conversion reaches 0.1 %, which opens up new possibilities for the development of silicon optoelectronics.

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