Photosensitive properties of avalanche LEDs based on nanostructured silicon

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Introduction

Avalanche LEDs have attracted the attention of scientific community due to their fast time response (less than 1 ps). It allows to use avalanche LEDs for optical interconnects in silicon chips and between silicon chips. In this case avalanched LEDs can be used as light sources as well as light detectors [1]. We have studied the photosensitive properties of avalanched LEDs in this work.

Methods

General schematic view of the developed 3-D SP structure is presented in Figure 1. It consists of two silicon chips with a certain number of Schottky diodes, which can operate both in LED and PD modes depending on the biasing. These silicon chips with sets of Schottky diodes are separated by the Si optical interposer.

Silicon chips were produced by the conventional CMOS technology. N-type monocrystalline Si wafers with the resistivity of 0.3 Ω·cm were used as substrates. SiO_2 layer of 0.8 μm thickness was formed on the silicon surface by thermal oxidation. Windows of the dimensions from 0.4 mm^2 to 10^{-4} mm^2 were opened in SiO_2 layer by plasma etching using the first set of photoresist masks. Then Al+Si composite film of 0.1 μm thickness was deposited over the SiO_2 layer by magnetron sputtering of an alloy target with the Si content of 30 at.%. As a result, a composite film with Si nanoparticles embedded into Al host matrix was formed. After that Al film of 1.0 μm thickness was deposited over the composite film.

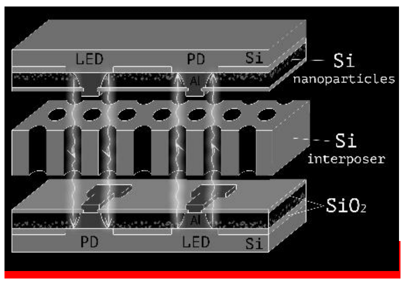

Figure 1. 3-D SP structure with vertical optical interconnects through microchannel vias interposer.

By using the second set of masks, the surface of the deposited films which should serve as a metal contact to the Si substrate, were protected by photoresist. Non protected surface of the films was subjected to the anodic treatment in the 20% aqueous solution of orthophosphoric acid. Such treatment led to the oxidation of the composite material. Since Al and Si are known to have different oxidation rates, the anodic oxidation of Al+Si film resulted in formation of nanostructured composite material containing clusters of slightly oxidised Si nanoparticles embedded into the alumina (Al_2O_3) matrix.

Along with the silicon chips, SP structure contains an optical interposer made of Si wafer of 100 – 150 μm thickness with microchannels (vias) of 5 – 6 μm diameter. The distance between their centers is 10 μm. The optical interposer is used to implement the commutation of "stackable" silicon ICs that has been demonstrated previously by filling the vias by copper. In the case of empty vias these wafers are capable to transmit an optical signal with the transmission ratio of 15 – 20%. The microchannels in the interposer are produced by well adapted technology in 3-D structures including electrochemical etching of Si through a photoresist mask followed by thinning of the wafer by mechanical polishing.

The structure of the developed devices was analyzed by a scanning electron microscope (SEM) Hitachi H-800. The current-voltage characteristics of the Schottky diodes were recorded by the oscilloscope characteriograph L2-56 at room temperature. Radio frequency generator, a photomultiplier or avalanche PD and digital oscilloscope have been used to measure the LED response.

Figure 2 shows SEM images of the microchannel Si wafer providing an optical signal transmission in the vertical direction relative to the surface of the chips.

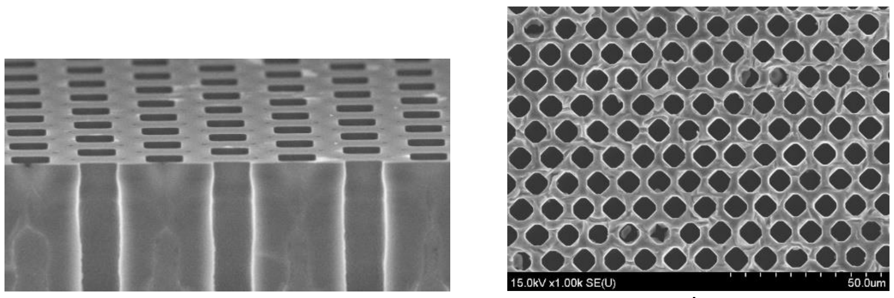

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Figure 2. Cross-section (a) and bottom (b) images of the silicon microchannel wafer used for optical interconnects between silicon chips.

The vias are occupying 20 – 25% of the entire wafer surface. It results in the partial transmission of the visible light through these vertical channels.

Results

The photosensitive properties have been measured in avalanche LEDs fabricated by the technology described in [2, 3]. The photocurrent and photovoltage responses have been registered at light exposition from the neighbor LED. Figure 3-a shows the photocurrent in investigated diodes versus light power of neighbor diodes. Photocurrent was measured at diode bias 1V and for different temperatures. Figure 3-b shows the photovoltage versus light power of the neighbor LED at different temperatures. The low temperatures are more attractive for diode operation. Thus the developed avalanche diodes can operate as a light source at bias more than avalanche breakdown voltage as well as photodetectors or photovoltage cells at bias less than avalanche breakdown voltage.

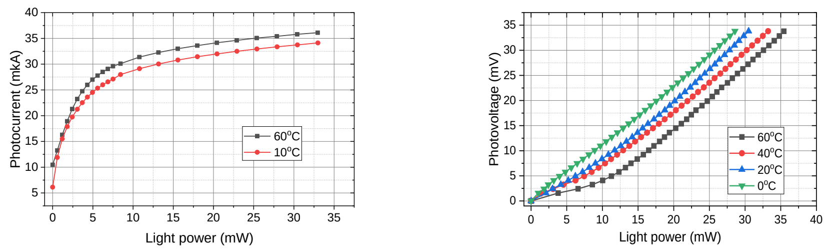

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Figure 3. Photocurrent (a) and photovoltage (b) in investigated diodes versus external light power.

Conclussions

The performed studying showed the perspective of avalanche LED applications for light signal processing in silicon photonics [4,5].

References

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