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Membrane Characterization of Transparent Photodiodes

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Summary:
The paper reports the design, technology and mechanical and optical measurements on a transparent photodetector. We prepared different box layer thicknesses (500 nm, 250 nm, and 20 nm) and investigate the resulting membrane bow. OBIC measurements show the location-dependent photocurrent distribution on the membrane.

Keywords: photodiode, transparent, silicon-on-insulator, OBIC

Introduction

Interferometry enables very precise displacement measurements. In practice, the accuracy of the alignment of the components and their positional fidelity determine the achieved measurement accuracy. Due to its simple design without beam splitter and interference-prone reference beam path, the standing wave interferometer (SWIF) offers many advantages [1]. Very compact and robust systems can be achieved with this principle. A fixed laser shines light onto a movable mirror. The light reflected from the mirror forms a standing wave with the incident laser light [2]. By moving the mirror, the maxima and minima of the standing wave changes their position. With a suitable detector, the position of the standing wave in space can be recorded [1]. This enables a displacement measurement by knowing the displacement of the mirror. The basic requirement for this is a partial transparency of the detector.

Technology

The wavelength used for displacement measurement is 633 nm. To ensure the required transparency of the detector at this wavelength, the absorbing silicon layer must not be thicker than 600 nm. There is also another boundary condition: The thinner the detector, the more sensitive it is to the standing wave. If the thickness of the sensor is exactly the distance between maxima and minima, no signal change can be detected when the mirror is displaced. The optimal sensor thickness corresponds to $\lambda/4$ [1]. Using a helium-neon laser (633 nm) and the refractive index of silicon, this corresponds to 42 nm of silicon. To fabricate this thin silicon layer, the 500 nm thick device layer of an SOI wafer is thermally oxidized. The oxidation process “consumes” silicon - that means the remaining device layer gets thinner. Subsequently, the resulting silicon oxide can be selectively removed by wet etching. Several optically transparent layers are deposited to optimize the reflective properties. The layer stack is shown in cross-section in Figure 1. The doped regions are schematically drawn with the colors red and blue. Silicon removal from the backside is done by plasma-assisted etching. The box layer was etched to investigate different stress states of the membrane. Three different thicknesses are created and examined: 500 nm (not etched), 250 nm and 20 nm. To improve the optical properties, a further silicon nitride layer is deposited on the back of the membrane.

Three silicon device thicknesses were manufactured: 562 nm, 294 nm and 42 nm.

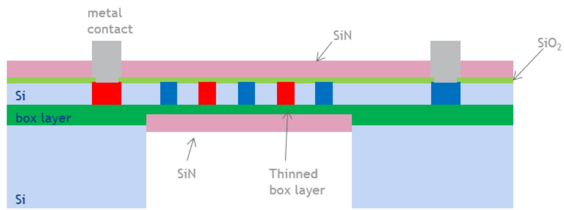

Figure 1: Layer stack of the transparent detector on SOI material. The red and blue areas in the silicon layer indicate boron and phosphorus doping, respectively. The box layer was etched in some samples to 250 nm or 20 nm thickness.

Chip Design

An example design of the transparent photodiode is shown in Figure 2. The depletion zone is formed between the doped fingers. And the capacitance of the photodiode can be adjusted by the spacing of the doped regions. Thus, the capacitance of the diode can be significantly reduced, resulting in a higher cutoff frequency. Membrane sizes were 1 mm, 0.8 mm and

0.6 mm. Distances between doped areas are available from 5 µm to 50 µm.

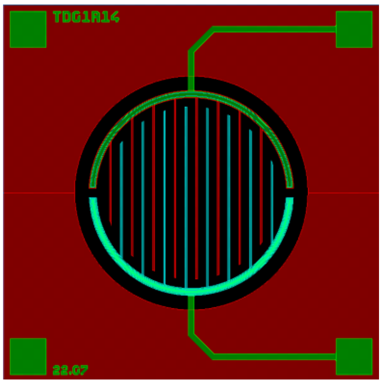

Figure 2: Design of a transparent photodiode with 50 µm distance between the doped regions and 1 mm membrane diameter. Red: boron doped, blue: phosphorus doped, green: metallization.

Membrane deformation

Caused by mechanical stress of the different layers (Figure 1), the membrane deforms after etching. Membrane geometry measurement was done with a laser scanning microscope. The bow of the membranes for different box layer thickness and 462 nm silicon is shown in Figure 3 as a line scan through the center of the chip. The greatest mechanical stress and thus deformation occurs at 20 nm box layer. Smallest bow appear at 250 nm.

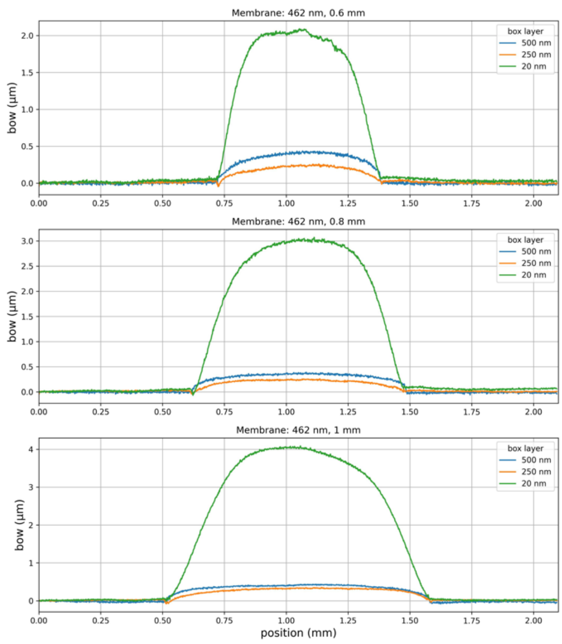

Figure 3: Comparison of the bow of different membrane diameters (1 mm, 0.8 mm, 0.6 mm) and box layer thicknesses of a 462 nm silicon thickness device.

OBIC measurement

The location dependent photocurrent on the membrane was determined with an optical induced beam current (OBIC) setup. The spot size of the 633 nm laser was about 6 µm with an optical power of 3 mW. The location dependent photocurrent is shown in Figure 4. The colors in the background define the different regions. Boron doping is located in the red region, phosphorus doping in the blue region. Light detection takes place only in the grey colored depletion region. This measurement was done in photoconductance mode.

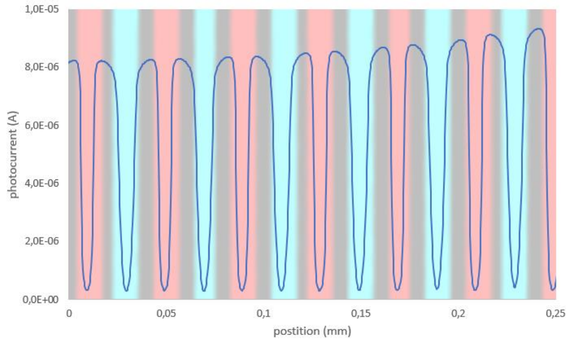

Figure 4: OBIC measurement of a photodiode with 10 µm spacing between the doping regions (10 µm).

References

[1] I. Ortlepp (2020): Mikrointerferometer auf Basis von interferenzoptischen Stehende-Welle-Sensoren. Ilmenau. Online unter: https://www.db-thueringen.de/receive/dbt_mods_00045571.

[2] I. Ortlepp *u. a.*, „Miniatur-Stehende-Welle-Interferometer auf Basis schneller, transparenter Photodioden“, *18 GMAITG-Fachtag. Sensoren Messsyst. 2016*, S. 418–424, 2016, doi: 10.5162/sensoren2016/6.1.2

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