SINGLE SUBSTRATE INTEGRATION OF OPTICAL WAVEGUIDES, MICROFLUIDIC CIRCUITRY AND PHOTODIODES

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ABSTRACT
We present a device with integrated buried optical waveguides, a microfluidic channel and photodiodes. This device can, for instance, be used as detection unit for absorption measurements on very small volumes (sub nanoliter) of fluid. The fabricated waveguide and diode structures exhibit a low noise equivalent power of 0.5 nW (488 nm, 10 Hz), demonstrating the possibility of using this setup for low light level measurements.

Keywords: Backside photodiode, Optical Waveguide, Integration, Micromachining

1. INTRODUCTION
Measurement of optical power is used in three of the most popular optical measurement techniques for bio/chemical measurements: absorption, chemiluminescence and fluorescence. Our device (Figure 1) uses buried optical waveguides to facilitate measurements of optical power after interaction with a fluid. The only work to our knowledge where miniaturized devices for measurement of optical power with waveguides, microfluidic channels and photodiodes have been realized is in the work of Leistiko and Friis [1] whose devices used waveguide cores with germanium and thus were limited to the longer wavelength part of the spectrum; they also used mesa diodes requiring metal on both sides of the device. The device we present can be used with light from 220 nm to 950 nm [2]. This range is due to a UV transparent core made of silicon oxynitride (SiON). We have previously described the coupling scheme [3] but this device is the first component realized with the coupler. The photodiodes are backside photodiodes only requiring metal on the backside of the device [4, 5]. The microfluidic channel is realized in the same silica glass layers as used for the waveguides.

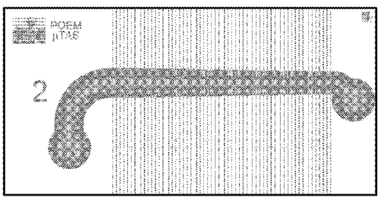

Figure 1: Layout of the top part of the device showing the waveguides (vertical lines) and the microfluidic channel (center). The foot-print of the chip is 10 mm by 20 mm.

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2. THEORY

Waveguiding is accomplished in a buried waveguide, by having a core strip, embedded in a media with a lower refractive index. For these waveguides the difference in refractive index is approximately 5×10^{-2} meaning that the guided light is fairly tightly bound in the waveguide.

The coupler structure is responsible for coupling light from the waveguide into the silicon substrate. The coupler works by a purely geometrical effect. It is constructed as a hole with sloped sidewalls. Since the waveguide is unable to keep the light guided when exposed to the bend near the coupler edge, most of the light will be coupled out and will be hitting the silicon at an angle close to normal. This means that a lot of light is transferred to the silicon substrate where it is absorbed and results in generation of electron-hole pairs.

The backside photodiodes set up a sweep-out region on the backside of the chip. This area will collect any excess carriers in the silicon crystal. These excess carriers may then be measured as a current in an external circuit [5].

3. EXPERIMENTAL

The fabrication was based on high purity silicon substrate (FZ, n-type, ρ >500 Ωcm, (100) 300 μm thick, double side polished). Diode dopings were made by ion implantation of boron and phosphorous using photoresist as masking layer (Figure 2a).

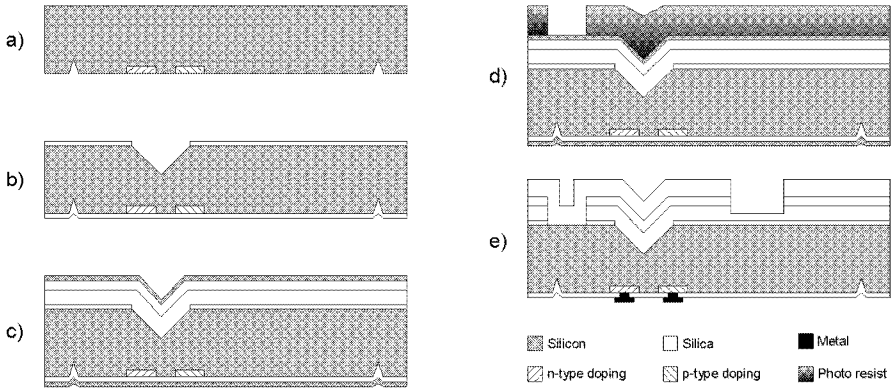

Figure 2: Sketch of the fabrication process (not to scale). Alignment marks were etched and doped regions created a). SiO_2 was used to mask for KOH etch of the coupler structure b). Buffer (n=1.46) and SiON core (n=1.50) were deposited, annealed (1000°C, 3 h) and capped by LPCVD pSi c). Photoresist was used to mask for the RIE etch realizing the core d). Strip of pSi and application of cladding top layer subsequently the channel was etched. Finally, a passivation layer was grown and metal contacts were made e).

The coupler structure (Figure 2 b) was realized using potassium hydroxide (KOH) orientation dependent wet etchning. Waveguides and fluidic circuitry was realized using plasma enhanced chemical vapor deposition (PECVD) and reactive ion etching (RIE). The deep etches were masked by polysilicon. After waveguide realization, a high-quality thermal oxide was grown by dry oxidation.
Contact holes were masked and etched using hydrofluoric acid. The metal was applied using a lift-off approach and electron beam deposition of a metal sandwich of titanium/platinum/gold with thickness of 20/50/150 nm respectively. Finally, the whole structure was forming gas annealed at 450°C. Cleaving using a diamond scriber was used to separate the chips from each other and also resulted in smooth waveguide facets. A picture of a finished chip is shown in figure 3.

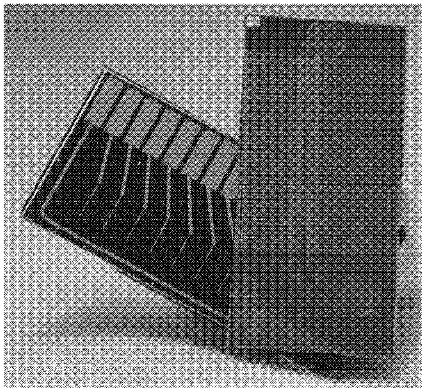

Figure 3: A picture showing the front and backside of the finished chip. The waveguides can be seen as horizontal lines. The coupler structures can be seen on the right-hand side of the chip. The chip size is 10 mm by 20 mm.

4. RESULTS AND DISCUSSION

The finished devices were characterized by measuring the sensitivity of a photodiode (Figure 4). The upper curve shows the sensitivity for light striking the photodiode from normal incidence. The wave pattern for longer wavelengths is due to interference effects of the thick silicon dioxide layers on top. The lower curve shows the sensitivity for light coupling through the waveguide. As can be seen the overall sensitivity was quite high, about a quarter of that for normal incidence, and this

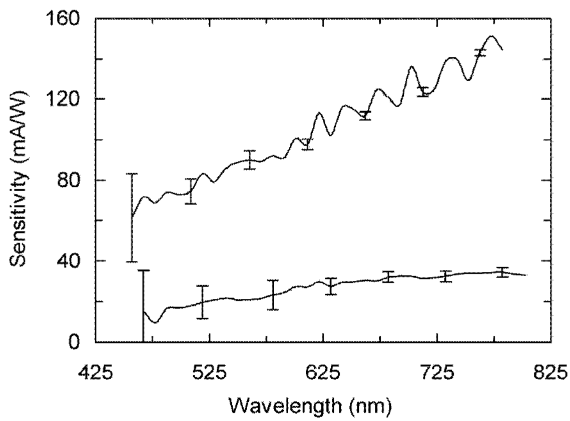

Figure 4: Sensitivity of a photodiode. The upper curve is for normal angle of incidence; the bottom curve is measured for guided light.

indicates low losses in the waveguide structure. The noise equivalent power (NEP) for detection of light passing through the waveguide was 0.5 nW (488 nm, 10 Hz) demonstrating the possibilities for high-detectivity measurements. The noise may be further reduced by using gas or solid-phase dopant sources instead of the implantations and also by introducing guardring structures around the photosensitive part of the diodes.

5. CONCLUSIONS

We have described a design and the fabrication steps leading to the realization of a highly integrated device requiring only a light source in order to make optical power measurements on very small volumes of liquid. The photodiodes may be improved by optimization and use of guarding structures to achieve even better noise equivalent power.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Leistiko, O., Friis, P., *"Bio/Chemical microsystems with integrated photodiode arrays of improved sensitivity and functionality"*, presented at SPIE Micro- and Nanofabricated Structures and Devices for Biomedical Environmental Applications II, San Jose, California, pp. 10-19, 1999.

[2] Mogensen, K. B., Friis, P., Hübner, J., Petersen, N., Jorgensen, A. M., Telleman, P., Kutter, J. P., *"Ultraviolet transparent silicon oxynitride waveguides for biochemical microsystems"*, Optics Letters, vol. 26, pp. 716-718, 2001.

[3] Mogensen, K. B., Jorgensen, A. M., Petersen, N. J., Geschke, O., Kutter, J. P., *"Design, integration and performance evaluation of optical detection elements for miniaturized biochemical devices"*, presented at First International Symposium on Science and Technology of Dielectrics in Emerging Fields, Paris, France, pp. 17-30, 2003.

[4] Jorgensen, A. M., Petersen, D., Geschke, O., *"An integrated chemiluminescence detector for measuring enzymatically generated hydrogen peroxide"*, presented at MicroTAS 2002, Nara, Japan, pp. 891-893, 2002.

[5] Jorgensen, A. M., Mogensen, K. B., Kutter, J. P., Geschke, O., *"A biochemical microdevice with an integrated chemiluminescence detector"*, Sensors and Actuators, vol. B90, pp. 15-23, 2003.