Integrated Silicon Photodiodes with Polymer (PMMA) Waveguides for Optical Interconnections and Sensing Applications

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Summary

To fabricate compact heterogeneous photonic sub-systems on a chip we fabricated polymer waveguides onto photodiodes on Si-wafers and characterized their optical properties. In first tests a detectable photocurrent could be measured. The results are encouraging for further optimization.

Introduction

Polymer optical waveguides are receiving much attention for planar photonic and optoelectronic applications such as optical interconnections and signal processing for biosensors [1-3]. This is due to their advantage of low cost fabrication and the possibility of heterogeneous integration with optoelectronic devices, micromechanical structures and microfluidics [4,5]. So far we fabricated polymer waveguides in a single layer of methacrylate polymer such as poly(methyl methacrylate) (PMMA) and alicyclic methacrylate copolymer (OPTOREZ from Hitachi Chemical) via deep-UV exposure [6-8]. By using lithographic techniques with standard photomasks a local and controllable increase of the refractive index in the exposed areas of the polymer surface could be achieved. The single polymer layer serves as substrate and waveguide as well, without requiring further steps like etching and development.

Fabrication of the polymer waveguides on silicon photodiodes directly allows the development of compact integrated subsystems for optical interconnections or sensors with optical read-out.

In this work, we investigate the heterogeneous integration of PMMA waveguides with silicon photodiodes for compact photonic integrated circuits.

Discussion

The integrated structure of a PMMA waveguide and a p+n photodiode is shown schematically in Fig. 1. The optical isolation between the PMMA waveguide and the silicon substrate is provided by a SiO_2 layer 1.5 – 2 µm thick. On top of the active area of the photodiode, this layer is removed to allow a gradually transfer of the optical power from the waveguide into the photodiode by leaky wave coupling [9]. A controlled degree of coupling within a reasonable coupling length can be achieved with a tapered geometry, and, if necessary, with a thin remaining isolation layer. The leakage parameter, α_g, is

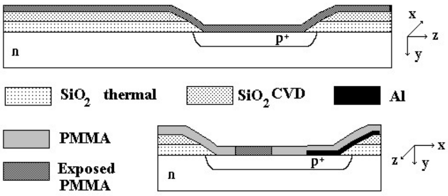

Fig.1. Integrated PMMA waveguide with silicon p+n photodiode

defined as the amount of the power that is lost per unit length divided by the power carried in the guide. The lost power is transferred in the silicon photodetector, as the silicon refractive index is greater than that of the waveguide. In the coupling region the power carried in the waveguide is:

$$P_g(z) = P_0 \cdot \exp(-\alpha_g \cdot z) \quad (1)$$

and the power density transferred in the photodetector is:

$$\partial P / \partial z = P_0 \cdot \alpha_g \cdot \exp(-\alpha_g \cdot z) \quad (2)$$

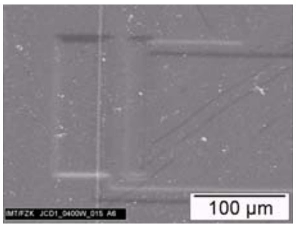

Fig.2 SEM photograph of PMMA waveguide on photodiode

For multi mode waveguides there is a leakage parameter for each mode. The required parameters were determined using OptiFDTD software (Optiwave). It was found that the coupling efficiency increases when the core thickness decreases.

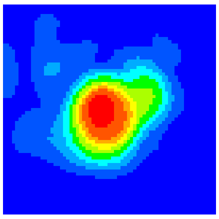

Fig.3 Near-field photograph of PMMA waveguide

The structures were fabricated on n-type Si wafers 3-5 Ωcm using p-well CMOS compatible processes. An SEM image of a PMMA waveguide fabricated on the photodiode is shown in Fig. 2. AFM measurements proved that the PMMA waveguide follows the topography of the photodiode smoothly: While the uncoated photodiode shows a local step of 1.2 µm from the top of the SiO_2 layer to the photodiode surface, after coating with PMMA and subsequent generating of the waveguide, this step showed a height of still more than 900 nm. Thus, the light guiding layer is still thin enough to allow an efficient leaky wave coupling. For near-field pattern measurement we fabricated PMMA waveguides directly on the SiO_2 layer without any photodiode devices. The length of the straight waveguide was 4 mm and the width was 7.5 µm. The near-field photograph of PMMA waveguide measured at 634 nm is shown in Fig. 3. Preliminary tests with a none-optimized waveguide showed a detectable photocurrent at the photodiode.

Conclusions

We have investigated the integration of photodiodes and polymer waveguides for the compact heterogeneous photonic sub-systems on a chip. We fabricated the PMMA waveguides on photodiodes on Si-wafer and characterized the optical properties of the waveguide. The coupling between waveguide and the photodiode was verified.

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