Thin Film InGaAs/InAlAs Photodetectors Integrated on a Silicon-on-Insulator Waveguide Substrate

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Abstract *We present compact and efficient InGaAs/InAlAs metal-semiconductor-metal photodetectors coupled with Silicon-on-Insulator waveguides. The responsivity of 25μm long detectors is 1.0A/W at a wavelength of 1.55μm. The dark current is 3.0nA at 5V bias.*

Introduction

Silicon-on-Insulator (SOI) is an attractive platform for the fabrication of very compact and high density waveguide circuits due to the large refractive index contrast. Moreover, these waveguide circuits can be fabricated using standard CMOS processing techniques resulting in low cost, high volume and high yield manufacturing [1]. Since Si is transparent at typical telecom wavelengths around 1300 and 1550nm, other materials need to be integrated on the SOI substrate to obtain efficient photodetection at these wavelengths.

The two most promising wafer scale approaches at the moment are Ge-on-SOI and III-V-on-SOI detectors [2]. Ge-on-SOI detectors are fabricated by means of heteroepitaxial growth of Ge on Si. Due to the lattice mismatch between both materials, special growth strategies need to be applied which often involve elevated temperatures. Dislocation defects caused by the lattice mismatch and the lack of a high-quality passivation layer for Ge also make it difficult to achieve a low dark current [3]. These problems are not present in III-V-on-SOI detectors as presented in this paper. InGaAs is the material of choice for the fabrication of low dark current and efficient near-infrared photodetectors and it can be integrated on the SOI platform by means of a low-temperature (250°C) DVS-BCB bonding process without creating defects or dislocations in the epitaxial III-V layers. On top of that, III-V semiconductors remain the material of choice for the fabrication of SOI waveguide integrated laser diodes. This way, laser diodes and detectors could be fabricated in the same processing steps, using the same III-V technologies.

In this paper, we report a compact InGaAs/InAlAs metal-semiconductor-metal (MSM) detector. This thin film device is heterogeneously integrated on top of a 220nm high SOI waveguide as will be described in the following sections.

Heterogeneous integration

The heterogeneous integration approach we propose is described in Fig. 1.

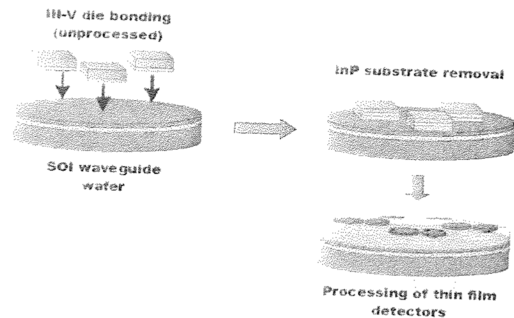

Fig. 1. Heterogeneous integration process flow.

It consists of bonding unprocessed III-V dies (epitaxial layers down) onto a processed SOI substrate by means of DVS-BCB [4]. This is the only non-wafer scale process within the integration procedure but because the dies are unprocessed, the alignment accuracy required for this step is limited, so a rapid pick-and-place routine can be used. After bonding, the InP substrates are removed, obtaining defect free epitaxial thin films bonded on a SOI waveguide wafer. Subsequently, the photodetectors are defined using wafer scale processes and lithographically aligned to the underlying SOI waveguides.

Detector design and fabrication

Detailed simulation results of this thin film MSM detector were the subject of a previous paper [5].

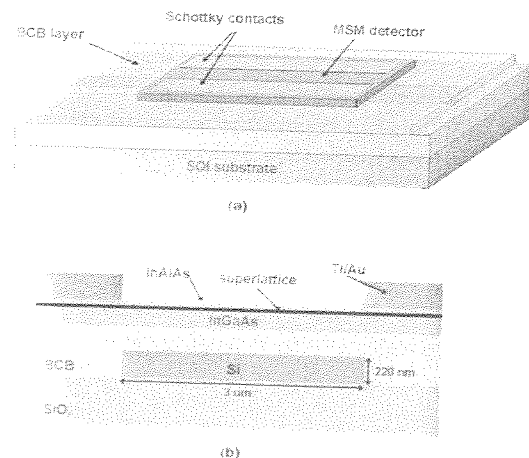

Fig. 2. Schematical top view (a) and cross-section (b).

A schematical view of the device is shown in Fig. 2. Light from a 3μm wide, 220nm deeply etched SOI waveguide is coupled into the thin film detector waveguide on top of it. The SOI waveguide and the detector are separated by a 130nm thick DVS-BCB layer. The detector layer stack has a height of 205nm with 2 coplanar (Ti/Au) Schottky contacts on top. The spacing between these Schottky contacts is 3μm. The functioning of the design is based on the principle of directional coupling: by making use of a thin DVS-BCB bonding layer and by proper design to obtain phase matching between the fundamental mode in the SOI waveguide and detector waveguide, efficient optical coupling will occur. Lateral confinement in the detector waveguide is caused by the Ti/Au metal contacts [5]. The detector layer stack was designed in order to obtain phase matching and consist of a 40nm InAlAs Schottky barrier enhancement layer on top of 20nm InAlAs/InGaAs graded superlattice layer on a 145nm InGaAs absorption layer. All layers are undoped.

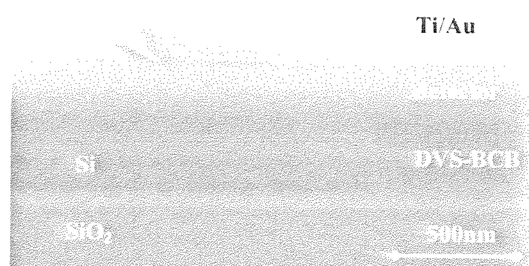

Fig. 3. Cross-section SEM image of thin film MSM detector on top a 3μm wide SOI waveguide.

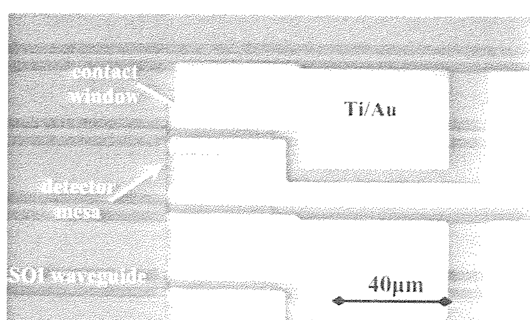

Fig. 4. Top view of three 40μm long detectors.

The fabrication starts with bonding a detector die on a SOI substrate by means of 130nm thick DVS-BCB layer. The sample is cured in a nitrogen environment at a temperature of 250°C for 1h [4]. After removal of the InP substrate, a 200nm InGaAs etch-stop layer and a 50nm InP sacrificial layer are removed by selective wet etching followed by etching the detector mesa down to the DVS-BCB bonding layer. A DVS-BCB insulation layer is spun on top and contact windows are opened. Finally, the coplanar Schottky contacts are defined. Fig. 3. shows a cross-section of the fabricated device (right half) and Fig. 4. is a top view on three 40μm long detectors on top of 3μm wide SOI waveguides with a spacing of 30μm.

Measurements

We measured different detectors with lengths ranging from 25μm up to 40μm. Light was coupled from a standard single mode fiber into 10μm wide ridge waveguides using shallowly etched fiber couplers. These waveguides are then tapered down to 3μm wide waveguides using adiabatic linear tapers.

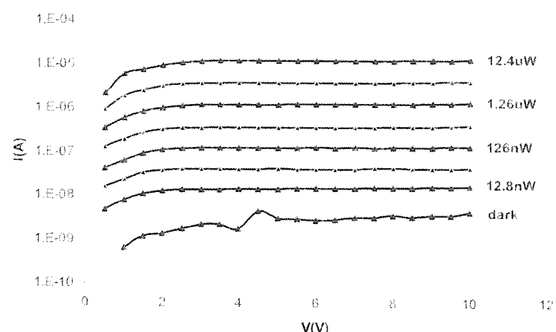

Fig. 5. I/V characteristics of a 25μm long detector.

Fig. 5. shows the I/V characteristics of a 25μm long detector for different illumination conditions. The dark current is 3.0nA at a bias voltage of 5V. The power coupled into the SOI waveguide was varied from 12.8nW up to 12.4μW in steps of 5dB. Taking into account a maximum fiber coupler efficiency of 25% with an error margin of +/-10%, the detector responsivity is 1.0A/W (+/-10%) at 1.55μm. This responsivity showed no major change for different detectors with lengths ranging from 25μm to 40μm.

Conclusions

We presented very compact and efficient SOI waveguide coupled photodetectors. The measured responsivity is 1.0A/W at 1.55μm and the dark current is 3.0nA at a bias voltage of 5V. The planar structure of the MSM detector results in an easy processing with only three lithography sequences.

References

1 R. Baets et al, IEEE International conference on Group IV Photonics, (2005), pp. 168-170.

2 G. Roelkens et al, Optics Express, Vol.13 (2005), pp. 10102-10108.

3 Jalali et al, Journal of Lightwave Techology, Vol.24 (2006), pp.4600-4615.

4 G. Roelkens et al, Journal of the Electrochemical Society, Vol.153 (2006), pp. G1015-G1019.

5 J. Brouckaert et al, "Thin Film III-V Photodetectors Integrated on Silicon-on-Insulator Photonic IC's," Journal of Lightwave Technology, to be published.

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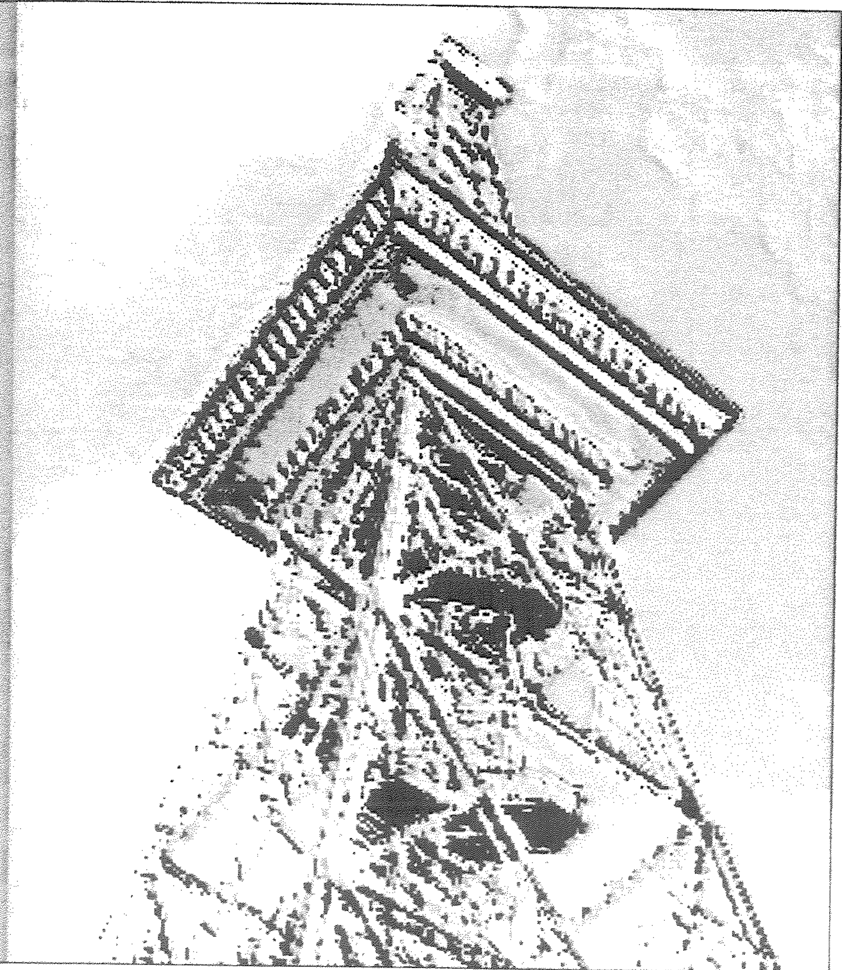

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