Photo-spectrometer based on the integration of InP/InGaAs photodetectors onto a Silicon-on-insulator etched diffraction grating

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Abstract—**We present the design and simulation results of an integrated wavelength demultiplexer. The device's major components, which include the Silicon-on-insulator (SOI) etched diffraction grating and waveguide integrated InP/InGaAs MSM photodetectors are discussed in detail. The Silicon-on-insulator diffraction grating is fabricated using standard CMOS processes. The photodetectors are integrated on top of the SOI waveguide circuitry using benzocyclobutene (BCB) as a bonding agent. This integration can be done using wafer scale processing technologies, which is important to increase reliability and decrease cost. The photo-spectrometer-on-a-chip can be used as an optical channel monitor in modern wavelength division multiplexing (WDM) telecommunications networks: it provides real-time information on system performance at the optical layer. Another application is liquid or gas sample identification based on infrared spectroscopy.**

Keywords—**Photo-spectrometer, etched diffraction grating, MSM photodetector**

I. Introduction

Optical communications by wavelength division multiplexing (WDM), which uses a number of wavelengths and a signal on each wavelength channel for data transmission, has made massive progress as a high-speed, high-capacity optical communication system for the Internet Age. These WDM telecommunication networks need cheap and reliable wavelength selective monitors at different locations in the network. Typically, such a device would tap out a small fraction of the WDM signal, spectrally disperse it and detect the optical signal in each individual frequency channel.

Liquid and gas sample identification is another important application for photo-spectrometers. The aim is to apply the general technique of infrared absorbance spectroscopy on the micro scale.

Current photo-spectrometers based on bulk optical components, MEMS or monolithically integrated waveguide devices are not satisfactory because of their size, limited reliability or high price. The approach we present in this paper: integration of InP/InGaAs photodetectors on a SOI diffraction grating using wafer scale processing technologies can lead to small, efficient, accurate, sensitive, reliable and inexpensive photo-spectrometers.

We will briefly describe the design of the diffraction grating (section II) and then discuss the integration of photodetectors onto the SOI chip in section III.

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II. Etched Diffraction Grating (EDG)

SOI is a very promising platform for fabricating the diffraction grating described in the introduction. The platform allows to fabricate nanophotonic optical components: passive optical waveguide circuits can be fabricated using standard CMOS technology and the high index contrast of these waveguides enables compact optical circuits [1].

A. Principle of operation

The grating is the heart of the spectrometer. Like a prism that utilizes the wavelength dependence of the optical properties of light (refractive index) present in certain materials, an EDG utilizes the coherence properties of light to spatially separate different wavelengths.

Figure 1 shows a schematic diagram illustrating the etched diffraction grating design. Light couples into an input waveguide at the left of the figure and propagates to the middle of the chip. Here, the ridge of the input guide ends and connects with an unetched planar waveguide region. The light propagates in the unetched region until it reaches the grating at the far right of the chip. The curved Roland circle grating both diffracts and focuses the light onto one of a series of output waveguides situated near the input waveguide [2].

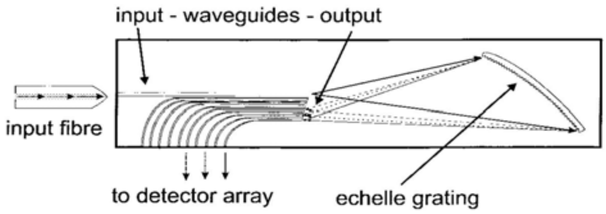

Figure 1: Schematic diagram of an etched grating planar waveguide demultiplexer

B. Design example – simulation result

An Etched Diffraction Grating is designed based on the Rowland Circle configuration [3]. We use the scalar diffraction theory to verify the efficiency of the design. Figure 2 shows the transmission characteristics of a demultiplexer with 1 input waveguide and 20 output waveguides, both in- and output waveguides are 3µm wide. The channel spacing is 3.2nm. The size of the diffraction grating, consisting of 150 facets totally, is about 500µm. The distance from the input waveguide to the center of the grating is 1060µm.

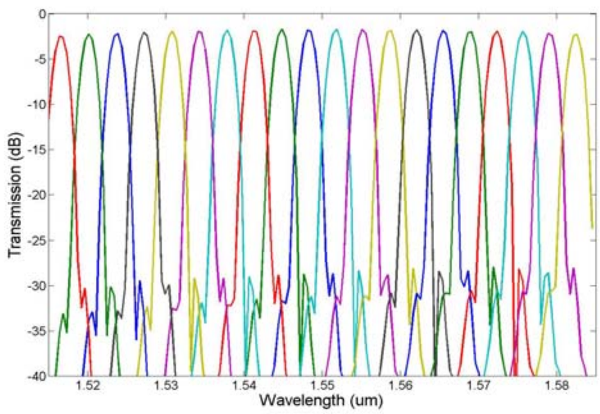

Figure 2: Transmission to the 20 output channels of the EDG

Important parameters as diffraction loss, crosstalk, channel spacing and loss variation over the total wavelength range can be extracted from the simulation results. This design has a diffraction loss of about 2dB for the central channel (1550nm), 26dB crosstalk and a loss variation over the total wavelength range of 0.6dB. First devices have to confirm these results.

III. Waveguide integrated MSM photodetectors

Silicon hasn't got the appropriate optical properties to allow efficient light detection in the near infrared wavelength range. Therefore, III-V semiconductors like InP or GaAs have to be integrated onto the SOI chip.

A. Heterogeneous integration

While the diffraction grating spatially separates the different wavelengths, photodetectors have to be integrated on the photonic chip to convert the optical signals into electrical signals. Figure 3 shows the process flow for heterogeneous integration. In a first step, unprocessed III-V dies are bonded on top of the SOI chip, using a polymer, benzocyclobutene (BCB) as a bonding agent. This is the only non-wafer scale process within the integration procedure but the alignment accuracy required for this step is limited, typically > 100µm, so a rapid pick-and-place routine can be used. After bonding, the III-V semiconductor substrate is removed until the epitaxial layer stack is reached. Subsequently, the photodetectors are defined using wafer scale processes and lithographically aligned to the underlying SOI waveguides.

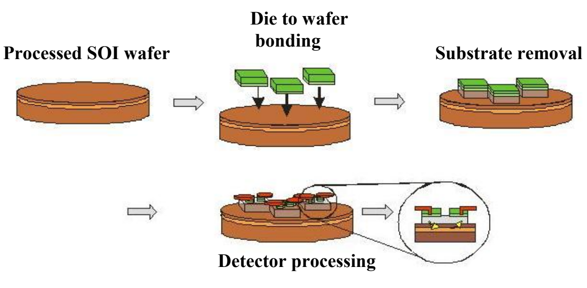

Figure 3: Heterogeneous integration of InP/InGaAs detectors and SOI photonic IC's

B. MSM detector

A metal-semiconductor-metal (MSM) photodetector consists of two or more identically Schottky contacts on top of an absorbing semiconductor layer (InGaAs in our case).

By using a very thin BCB bonding layer (200nm) between the absorbing InGaAs material and the silicon waveguide and by proper design of the detector geometry, there is phase matching between the mode in the Silicon waveguide and the detector mode on top of it. As light couples from the waveguide into the detector, it is absorbed in the InGaAs material and electrical carriers are collected by the Schottky contacts on top (Figure 4).

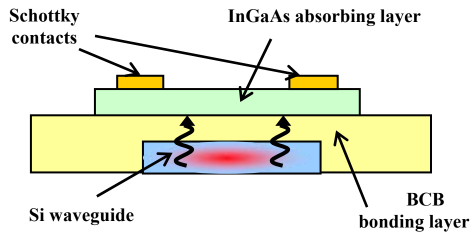

Figure 4: MSM detector above Si waveguide

C. Simulation results

Fimmwave, a fully vectorial simulation tool based on eigenmode expansion, was used to assess the achievable efficiency of the proposed detector structure. Figure 5 shows the absorbed power in function of the detector length: 95% of the power is absorbed in a 15µm long detector.

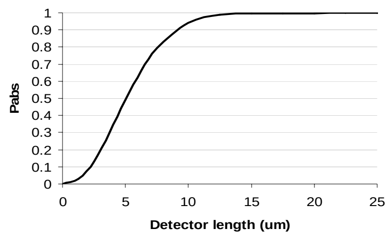

Figure 5: Absorbed power versus detector length

IV. Conclusions

We demonstrated that heterogeneous integration of MSM photodetectors on a SOI etched diffraction grating can lead to a compact and efficient integrated wavelength demultiplexer. Making use of wafer scale processing techniques, this can lead to reliable and inexpensive devices with applications in the field of telecommunications and sensing.

Acknowledgements

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References

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