Silicon-on-Insulator spectrometers with integrated GaInAsSb photodiode array for wideband operation from 1500 to 2300 nm.

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Abstract: Four echelle-type spectrometers with heterogeneously integrated GaInAsSb photodetectors on a silicon-on-insulator chip is realized. The operating wavelengths stretch from 1500 to 2300 nm. A maximum channel crosstalk of -10 dB, dark current of -2.5 μA and responsivity of 0.61 A/W at 1530 nm and 0.7 A/W at 2200 nm were obtained.

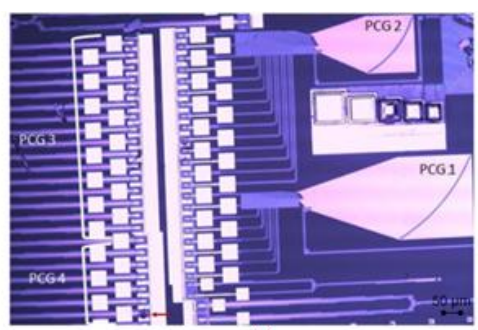
OCIS codes: (130.3120) Integrated optics devices; (300.6190) Spectrometers

1. Introduction

In recent years, there is an increasing interest in sensing of biological molecules with compact lab-on-a-chip systems. A key technique to identify organic molecules in the near infrared is absorption spectroscopy. The vibrational absorptions of the C-H bond are e.g. present between 1530 and 1820 nm. To enable on-chip absorption spectroscopy, miniaturization of a spectrometer is necessary. An interesting platform for the fabrication of miniature spectrometers is silicon-on-insulator (SOI). The fabrication of SOI chips is CMOS-compatible, thus allowing mass fabrication at low cost and the high index contrast allows very small sensor footprints. This in turn gives way to assemble a large amount of spectrometers on a single chip to span a wide operational wavelength range. The latter is especially relevant to distinguish between interfering molecules in a mixture. In addition, SOI is transparent in the short-wave infrared (SWIR, 2000-2500 nm). This makes it possible to access typically stronger absorption features in the SWIR [1]. Given that high performance echelle-type spectrometers have been demonstrated in the telecommunication band [2], scaling of these wavelength demultiplexers into the SWIR gives access to important spectral information. In this work, we designed a set of four planar concave grating (PCG), also known as echelle grating, spectrometers to operate between 1500 nm and 2300 nm. These passive demultiplexers are combined with a GaInAsSb photodiode array that is sensitive in the same wide wavelength span. The GaInAsSb p-i-n photodiodes are heterogeneously integrated using benzocyclobutene (DVS-BCB) as an adhesive bonding layer.

	PCG 1	PCG 2	PCG 3	PCG 4
center λ [nm]	1550	1650	2125	2320
resolution [nm]	3.2	7	6	5
number of channels	8	14	16	8
wire width [μm]	0.45	0.5	0.8	0.8
aperture width [μm]	2	2	3	3
free spectral range [nm]	115	121	150	60
DBR period [nm]	600	340	500	540
footprint [mm^2]	0.56	0.24	0.54	1.04

(a)



(b)

Figure 1: **(a)** table listing the planar concave grating design parameters **(b)** microscope picture of the fabricated chip

2. Wavelength demultiplexers

The planar concave gratings are integrated on a single chip that was fabricated in a CMOS pilot line on a 200 mm SOI wafer, comprising a 220-nm-thick Si waveguide layer on a 2 um buried oxide layer. The chip is covered with an additional 1.6 μm thick top oxide cladding. The table in figure 1.a. lists the design parameters of the four different planar concave gratings. The PCG design is based on the Rowland geometry with one stigmatic (i.e. aberration-free) point [3]. The entrance and exit waveguides with shallowly etched apertures are positioned along the Rowland circle with a radius R and the curved grating follows a circle with a radius of 2R. All PCGs are designed for TE polarization and have a grating with distributed Bragg reflector (DBR) facets. These DBR facets reduce the insertion loss by increasing the reflectivity of the grating [4]. The design strategy was to keep the demultiplexers as compact as possible for the given channel resolution to minimize phase errors. The in- and outputs of the PCGs are grating couplers optimized for the central operation wavelength. PCG 2 and 3 are preceded by a waveguide spiral for evanescent sensing of the absorption features of biodiesel. A modest insertion loss of 5 to 7 dB and a low crosstalk level of -16 dB is obtained for all designs.

3. Photodiode performance

The detector array consists of p-i-n photodiodes with a 500 nm thick intrinsic $Ga_{0.79}In_{0.21}As_{0.19}Sb_{0.81}$ absorption layer and metal contacts composed of Au with Ti(2 nm)/Pt(35 nm). The active material has a bandgap of 2.65 μm at room temperature and is grown by molecular beam epitaxy on a GaSb substrate. The integration of the photodetectors is realized through an epitaxial layer transfer process using BCB adhesive bonding. The photodiodes are integrated on top of the output grating couplers of the PCGs. The fabrication details of both the epi-stack and bonding procedure can be found in [5]. The mean photodiode dark current at room temperature at a bias voltage of -1V is around -2.5 μA for a mesa size of 17x50 μm^2 and -3 μA for a mesa size of 26x64 μm^2. The on-chip responsivity at a bias voltage of -0.5V was measured to be 0.61 A/W at 1530 nm and 0.7 A/W at 2324 nm.

4. Spectrometer performance

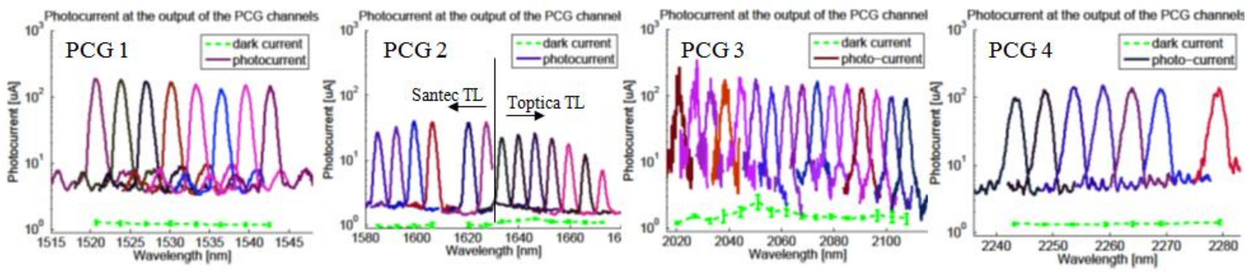


Figure 2: Electro-optic characterization of the spectrometers. The curves represent the photocurrent that is obtained when 1 mW is injected in the entrance waveguide and after transmission through the waveguide spiral and PCG. The rms dark current of the respective photodetectors is indicated by the green line.

The spectrometers are characterized by injecting light through the input grating coupler of the PCG and measuring the photocurrent of the photodiode on top of the output grating coupler at a bias voltage of -0.1V. The result of this measurement is shown in figure 2. A total of 46 photodiodes are characterized with a failure of only two photodiodes. The dark current is below 2 μA for all photodiodes. Two different lasers were needed to measure PCG2, leading to a small amplitude discrepancy. The laser used for PCG 3 was unstable below 2050 nm, which impacted the smoothness of the measurement. Good channel uniformity with a maximum crosstalk level of -10 dB is obtained for all spectrometers.

5. Conclusion

We demonstrated a set of four planar concave grating spectrometers with an integrated GaInAsSb photodiode array to cover a wide wavelength range from 1500 nm to 2300 nm. The fabricated spectrometers show good performance with high channel uniformity, photodiode responsivities up to 0.7 A/W and high processing yield. This enables the use of these spectrometers for real-life applications.

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