d two wind farms for a tube attached to one of). An access to the IEC al cable data like current entional temperature and end, this equipment will

y of mid-voltage power herent source and trans- e to mechanical damage a 5 Mpixel CMOS cam- transmission, reflection is under consideration.

ensitive Fiber-Optic Current

ctive. *Journal of Lightwave*

l optical fibre systems. *4th*

the modal-noise probability
t 1980.

constrained speckle. *Optics*

l optics, 16(7):1761, January

sor for fiber optic vibration

for embedment in concrete.

ion in vibrating waveguides.

Integrated spectrometer on Silicon on Insulator

Günay Yurtsever, Roel Baets
Ghent University – IMEC, Photonics Research Group, Department of Information Technology (INTEC)
,Sint-Pietersnieuwstraat 41, 9000 Gent, Belgium

We present design of a micro spectrometer implemented in silicon on insulator with 512 channels and 0.1 nm resolution. The spectrometer consists of a fine resolution ring resonator cascaded with two coarse resolution arrayed waveguide gratings. The ring resonator is thermally tuned using a metal heater. The size of the device is 0.6 mm x 2 mm. Such devices can be used to realize low cost and compact spectroscopic systems.

Introduction

Spectral analysis is a widely used technique in numerous applications including chemical and biological analysis, optical metrology and spectral imaging. The optical spectrometer is often a core part of the instruments used in these applications and affects the cost and the size of the systems. Today, the most widely used spectrometers are based on free space optics which are bulky and expensive. Miniaturization of spectrometers is desirable to design optical systems that are more compact and cost effective.

Recent progress of integrated optics based multichannel demultiplexers for telecom applications can be utilized to develop spectrometers for other applications. Integrated optical spectrometers are advantageous for mass production, dense output channels and integration with other optical components. Such demultiplexers have been implemented mainly as arrayed waveguide gratings (AWGs) and planar concave gratings (PCGs). Using silica on silicon a PCG with 256 channels, 0.2 nm channel spacing and -10dB insertion loss has been demonstrated [1]. Although PCGs take few times less area compared to AWGs, difficulties in fabricating vertical grating facets and consequent large insertion loss has shifted the focus on AWG designs. A silica based AWG with 400 channels, 25GHz channel spacing and -3.8 dB insertion loss was demonstrated [2]. The number of channels can be increased by cascading multiples AWGs. Takada et al. demonstrated a 5-GHz spaced 4200 channel demultiplexer with -7dB loss [3]. Such devices can also be designed for high index contrast material systems such as silicon on insulator (SOI), reducing the size of the device almost by more than ten times. Nanophotonic silicon on insulator (SOI) is a versatile platform for a variety of integrated photonic components [4]. However, the dramatic decrease in the size makes the components sensitive to fabrication related random errors. As a result of this limitation, channel spacing of AWG or PCGs with acceptable performance is larger than 100 GHz. Narrow spectral filters with < 0.1 nm 3dB bandwidth can be implemented on SOI using ring resonators. Cascaded ring resonators and coarse AWG or PCGs is a viable solution for high resolution large FSR spectrometer on chip [5, 6]. Compared to AWGs, PCGs with a higher FSR have been demonstrated, however AWGs show a lower insertion loss.

In this article we report on a design of a spectrometer that consists of cascaded ring resonator, directional coupler and two AWGs.

Design

The concept of the spectrometer is illustrated in Figure 1. Light is coupled to the spectrometer through a grating fiber coupler which has 3dB bandwidth of 46 nm and 25% coupling efficiency. The size of the grating coupler is 10 µm and is tapered to a single mode waveguide. The single mode rib waveguides are etched 220 nm deep and 450 nm wide with deep UV lithography. Before the ring resonator, the waveguide is tapered to a 70 nm shallow etched 450 nm wide waveguide which has lower backscattering compared to the deep etched waveguide [7]. The ring resonator together with its add and drop ports consists of shallow etched waveguides. Thanks to reduced backscattering, ring resonators with shallow etched waveguides do not show peak splitting [8].

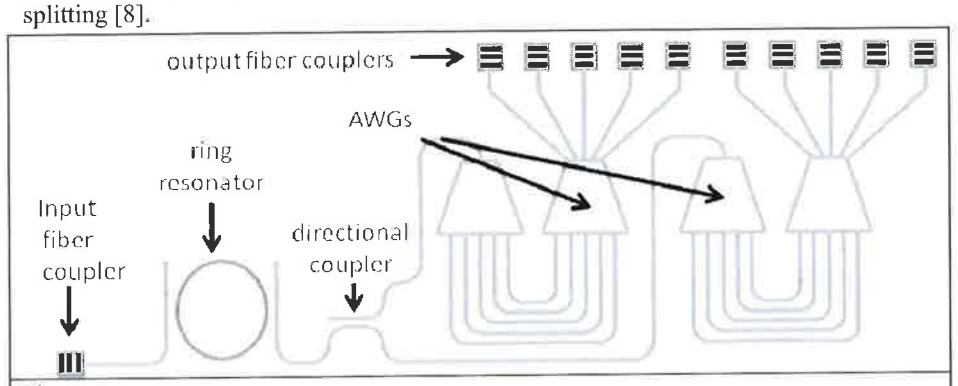

Figure 1.

The ring resonator has been designed with a radius of 31.2 µm which corresponds to a free spectral range (FSR) of 400 GHz. To obtain 0.1 nm FWHM, considering the waveguide and coupler losses, the gap between the bus and resonator waveguides was chosen as 600 nm. Simulated drop port transmission spectrum is given in Figure 2a. A metallic heater will be used to tune the resonance of the ring over its FSR. The ring resonator can be followed by a single AWG to realize a spectrometer. However, while the ring is thermally tuned and the peak of the ring resonator moves away from the peak of the AWG, the output power will be attenuated. As a result, the adjacent channel of the ring will have a significant influence on the output.

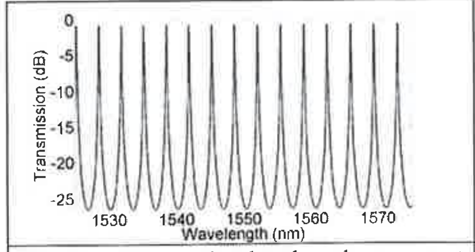

Figure 2a. Simulated drop port transmission spectrum of the ring resonator

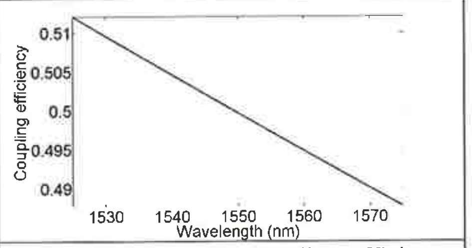

Figure 2b. Simulated coupling efficiency of the directional coupler

This situation can be alleviated by using two AWGs if their center wavelengths differ by half channel spacing. After the ring resonator, the light is split by a 50/50 directional coupler and sent to the AWGs. The spectral response of the directional coupler is given in Figure 2b.The AWGs have 16 channels with 400 GHz channel spacing, which corresponds to 51.2 nm bandwidth. One of the AWGs has a center wavelength of 1550 nm while the center wavelength of the other AWG is shifted by 1.6 nm, which corresponds to 200 GHz at that wavelength. The output channels of the AWGs are accessed via fiber grating couplers. The simulated transmission spectrum of the AWGs is shown in Figure3. The insertion loss is less than 1 dB. The size of the spectrometer on the fabrication mask is 0.6 mm x 2 mm.

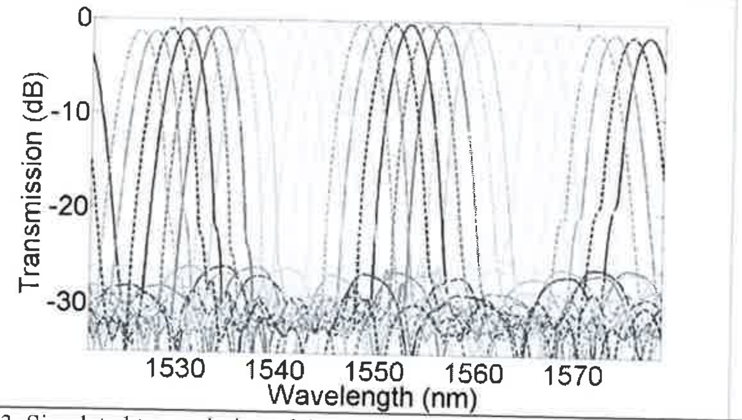

Figure 3. Simulated transmission of the AWGs. The AWG centered at 1550 (dashed lines), the AWG centered at 1551.6 nm (solid lines).

By cascading the spectral responses of all components (grating coupler effect is omitted) the spectral response of the complete system is obtained, see Figure 4. A small mismatch of FSR is added to the ring resonator, as it might not be feasible to match the FSR of the AWGs and the ring resonator. In cases where the peak of the resonator is far from the peak of the AWGs, more than one ring resonances appear to be significant. In such cases the output of the other AWG can be used.

The spectrometer will be fabricated in near future and characterized. The spectral response of the components may deviate from the simulations, however through calibration and software algorithms such limitations can be overcome.

Conclusions

We have proposed a very compact high resolution spectrometer that can be fabricated using CMOS process compatible deep UV lithography. Despite the sensitivity to fabrication errors, cascaded microring resonator and AWGs bring advantages of both sides and offer a small size, low cost spectrometer solution.

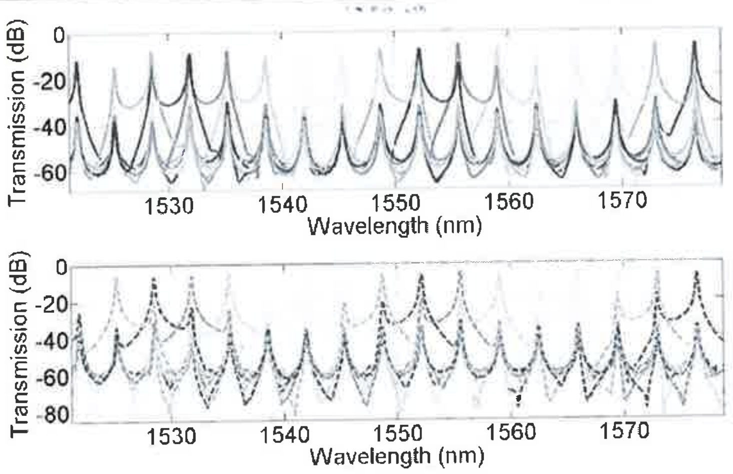

Figure 4.Simulated spectral response of the spectrometer. Output channels of the AWG centered at 1550 (solid lines), output channels of the AWG centered at 1551.6 nm (dashed lines).

Acknowledgements

Part of this work has been supported by Methusalem Program, funded by the Flemish Government, Belgium. We would like to thank Dr. Wim Bogaerts and Shibnath Pathak for AWG design and simulation.

References

[1] S. Janz et al., "Planar waveguide echelle gratings in silica-on-silicon," IEEE Photonics Technology Letters, vol. 16, no. 2, 503–505, 2004.

[2] Y. Hida et al., "400-channel arrayed-waveguide grating with 25 GHz spacing using 1.5%-Δ waveguides on 6-inch Si wafer," Electronics Letters, vol.37, vol. 9, 576-577, 2001.

[3] K. Takada, M. Abe, T. Shibata, and K. Okamoto, "10-GHz-Spaced 1010-Channel Tandem AWG Filter Consisting of One Primary and Ten Secondary AWGs", IEEE Photonics Technology Letters, vol. 13, 577-578, 2001.

[4] W. Bogaerts, et al."Nanophotonic waveguides in silicon-on-insulator fabricated with CMOS technology," Journal of Lightwave. Technology, vol. 23, no. 1, 401–412, 2005.

[5] G. Yurtsever, et al. "Compact demultiplexer using cascaded planar concave grating and ring resonators on SOI," in Proceedings of the LEOS 2009 -22nd Annual Meeting of the IEEE Lasers and Electro-Optics Society, 497-498, 2009.

[6] Bernardo B.C. Kyotoku, L. Chen and M. Lipson, "Sub-nm resolution cavity enhanced microspectrometer," Optics Express, vol. 18, 102-107, 2010.

[7] W. Bogaerts, S. Selvaraja, "Compact Single-mode Silicon Hybrid Rib/Strip Waveguide with Adiabatic Bends," IEEE Photonics Journal, vol. 3, 422-232, 2011.

[8] B.E. Little, J.P. Laine, and S.T. Chu, "Surface-roughness-induced contradirectional coupling in ring and disk resonators,"Optics Letters, vol. 22, 4-6, 1997.