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High-Resolution Integrated Spectrometers in Silicon-Oxynitride

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Abstract: Arrayed waveguide grating spectrometers operating around 800 nm and 1300 nm are demonstrated, with the highest resolution (0.16 nm) and largest free spectral range (77 nm) achieved in silicon-oxynitride technology to date.

OCIS codes: (130.0130) Integrated Optics; (130.7408) Wavelength Filtering Devices

1. Introduction

Spectrometers play an important role in a wide variety of fields. The most important integrated optical implementation of a spectrometer is the arrayed waveguide grating (AWG), whose operation principle is explained in Ref. [1]. With its excellent performance and compactness, the AWG has a high potential for various spectroscopic applications [1]. Different material systems have been exploited for realizing AWGs to decrease the crosstalk level, insertion loss, channel spacing, and total device size, while improving polarization independence [2-4].

In this work, we present two AWG spectrometers for the spectral ranges near 800 nm and 1300 nm, using silicon-oxynitride (SiON) technology. Device size and extra fabrication steps are reduced markedly compared to silica-based AWGs. Better crosstalk and loss values are obtained compared to SOI-based AWGs. To the best of our knowledge, here we demonstrate the highest resolution (0.16 nm) and largest FSR (77 nm) in SiON based AWGs for both spectral ranges reported so far.

2. Design

We aim at applying these AWG spectrometers in an on-chip spectral-domain optical coherence tomography (OCT) system [5]. The spectral ranges of 1300 nm and 800 nm were selected for imaging skin and retina, respectively. The free spectral range (FSR) and wavelength resolution ($\Delta\lambda$) of the AWGs were determined according to the envisaged depth resolution of 37 μm and 30 μm (determined by the full width half maximum values of the transmission spectrum of the AWGs) and 1-mm depth range (determined by the wavelength spacing per output waveguide) of the OCT systems operating at 1300 nm and 800 nm, respectively. The remaining design parameters of the devices were calculated using the standard equations for AWGs [1] and are given in Table 1.

Table 1. AWG design parameters

Parameters	AWG @ 800 nm	AWG @ 1300 nm
Channel spacing ($\Delta\lambda$)	0.16 nm	0.4 nm
Central wavelength (λ_c)	800 nm	1300 nm
Free spectral range (FSR)	20 nm	78 nm
Diffraction order (m)	40	17
Focal length (R)	11 mm	12.3 mm
Path length difference (ΔL)	21.8 μm	15 μm
Number of arrayed waveguides (M)	500	650
Number of output channels (N)	125	195
Height of waveguide core	800 nm	800 nm
Width of waveguide core	1.5 μm	2 μm

The AWG spectrometers use single-mode SiON channel waveguides with the parameters listed in Table 1. For maximum device compactness, the refractive index of the core layer was chosen as high as possible, consistent with the single-mode condition. The minimum spacings between the arrayed waveguides and between the output waveguides were optimized using the beam propagation method in order to reduce loss and crosstalk values.

3. Measurements and Results

The schematic of the optical measurement set-up is given in Fig. 1a. The measurements were performed by coupling

TE-polarized light from a broadband source (Fianium SC450) into the AWG with a single-mode polarization-maintaining fiber. The output signal was sent through a single-mode fiber to an optical spectrum analyzer. The transmission spectra measured at the output channels were normalized with respect to the transmission of a curved channel waveguide. Measurement results are summarized in Table 2.

Table 2. Measurement and simulation results of fabricated AWG spectrometers

Parameters	AWG@ 800 nm		AWG @ 1300 nm	
	Simulation	Measurement	Simulation	Measurement
Channel spacing (Δλ)	0.16 nm	0.16 nm	0.4 nm	0.38 nm
Free spectral range (FSR)	20 nm	19.4 nm	78 nm	77 nm
Central crosstalk	-35 dB	-22 dB	-37 dB	-25 dB
Central excess loss	2.6 dB	3.2 dB	1.8 dB	2.5 dB
3-dB bandwidth	0.05	0.07 nm	0.18 nm	0.2 nm

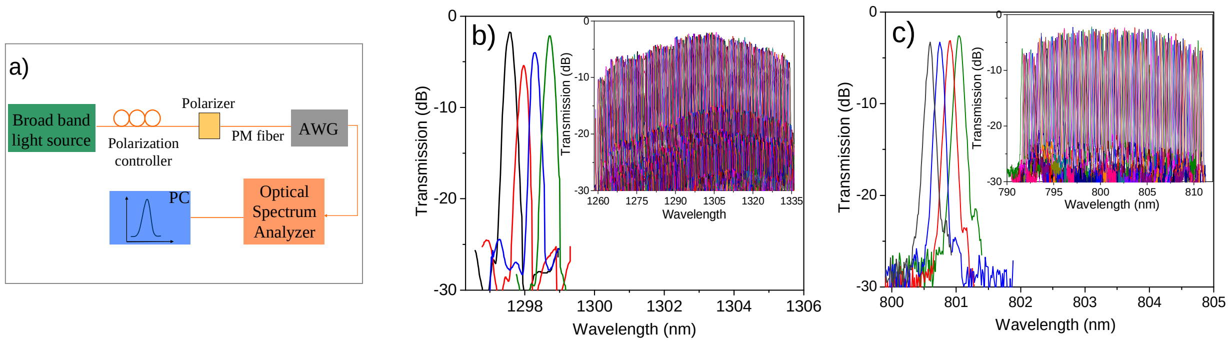

Fig. 1. a) Optical measurement set-up. Measured **b)** 1300-nm and **c)** 800-nm AWG performance for TE polarized light at the central channels (normalized with respect to a curved waveguide). The insets show the complete FSR of 77 nm and 19.4nm, respectively.

The transmission spectra of both devices are presented in Figs. 1b and c. The measured values of resolution and FSR are consistent with the design and simulation results. We observed small random differences between the peak values of the transmission spectra of the different output channels, because the optical transmission of each output channel was measured individually with a single butt-coupled fiber. Although the fiber-chip coupling efficiency was maximized each time, the intensity variations could not be eliminated completely. Besides, a 10-dB increase of the measured compared to the calculated crosstalk value was found, caused mainly by phase errors due to nonuniformity of the refractive index and thickness of the core layer.

4. Conclusions

We have designed, fabricated, and characterized SiON-based AWGs for the 800 nm and 1300 nm spectral regions. The measured results are in good agreement with the simulation results. High wavelength resolution (0.16 nm) and large FSR value (77 nm) have been achieved. Compared to silica technology, we have achieved smaller foot-prints with a simpler fabrication technique. Moreover, the measured crosstalk and excess loss values are significantly better than in SOI-based AWGs. Exploiting the wide optical transparency range of SiON, we have demonstrated that this material system can be used as a platform for different spectral ranges without device performance degradation. Such an integrated AWG spectrometer forms the core of an on-chip spectral-domain OCT system [5].

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5. References

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