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O-Band CWDM Echelle Grating Demultiplexers on SiNOI Exhibiting Quasi-Absolute Thermal Insensitiveness

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Abstract

In this communication, we report about the design, fabrication, and testing of O-Band echelle grating (de-)multiplexers for CWDM4 on 200 mm silicon nitride-on-insulator (SiNOI) platform. Experimental results clearly show very efficient thermal insensitiveness of devices performance thermally-dependent wavelengths detuning below 10 pm/°C.

1. Introduction

Silicon-based photonic integrated circuits (Si-PICs) pave the way towards a brand-new optoelectronics featuring a significant integration potential with cost-effective complementary metal-oxide-semiconductor (CMOS) technology [1], [2]. Moreover, enabling the implementation - over small footprints - of optical functions constituting the whole silicon photonics toolbox such as optical resonators and laser integration [3], input/output (I/O) couplers [4], high-speed modulators [5], Si-Ge photodiodes [6], as well as filters and wavelength (de)multiplexers [7].

Concerning the latter, wavelength-division multiplexing (WDM) is an essential building block for broadband datacenter rack-to-rack optical interconnects. Notably, provided a thermal environment which may well differ between the transmitter and the receiver blocks constituting the link, wavelength demultiplexers (WMUX) at the receiver need to be capable of operating in the very same way, whatever the differential in thermal environment conditions across the link. For this reason, WMUX have to respect two key conditions capable to satisfy such systems requirements.

First, WMUX channels transmission bandwidth at the receiver should be sufficiently large (~10 nm) to compensate for the wavelength detuning of the emitters at the transmitter side of the link - such as DFB lasers - all over their operational windows caused by driving currents, self-heating and environment temperature. Second, a nearly absolute thermal insensitiveness of the WMUX device performance itself has to be ensured across the link over the widest possible temperature range. In other terms, devices have to exhibit the smallest thermal chromatic dispersion (pm/°C), in order to ensure system requirements under any thermal condition applied to the optical link. In this paper, we present 4-channels 20-nm-spaced (CWDM4) Echelle Grating (EG) WMUX to operate in the O-band (1310 nm) designed for the ITU-T G.695 grid and fabricated on 200 mm Silicon Nitride-on-Insulator (SiNOI). Taking advantage of PECVD SiN_x low thermo-optic coefficient compared to silicon [7], quasi thermally-insensitive WMUX can be obtained.

2. EG architecture and fabrication

EGs are diffraction grating spectrometers whose principle is based upon phase matching the light reflected from neighboring facets. Using a slab waveguide as free propagation region (FPR), we describe a simple grating on a classic Rowland mounting by the following equation:

$$d(\sin(\theta_i)+\sin(\theta_m))=\frac{m\lambda}{n_{eff}(\lambda)},$$

where θ_i (70°) and θ_m (88°) are the angles of incidence and diffraction of the mth (3rd) diffraction order, λ is the wavelength in free space, d (1.76 µm) is the grating teeth spacing and n_{eff} (1.748) is the effective index of the slab mode at 1310 nm, while the Rowland mounting radius is 55 µm. In addition, the grating teeth were blazed, chirped and oriented to focus the light into the selected diffraction order and dimensioned according to proximity of neighboring teeth in order to reduce cross-shadowing, thus enhancing performances. In order to increase grating teeth reflectivity given the reduced index of contrast between silicon nitride core and silica claddings, distributed Bragg mirrors (DBRs) with a grating period of 400 nm and a filling factor of nearly 50 % were implemented behind each grating teeth in order to increase nominal reflectivity up to R = 86 % and thus reducing the demultiplexer insertion losses.

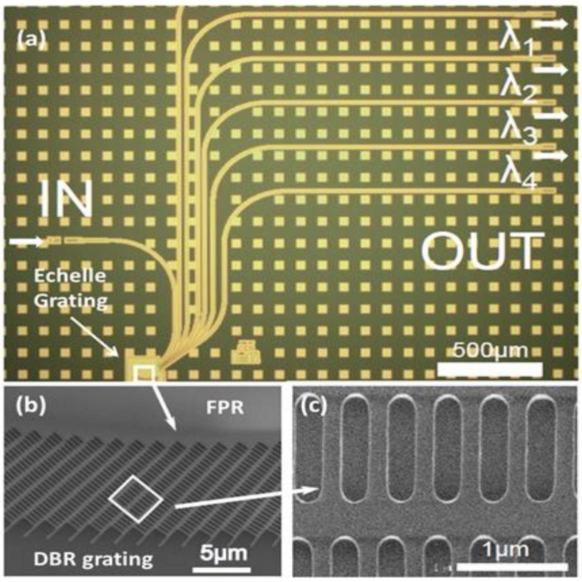

Fig. 1 (a) Optical microscope image of the CWDM4 EG demultiplexers on SiNOI using (b, c) 1st-order DBR-assisted facets for increased reflectance along the grating curve.

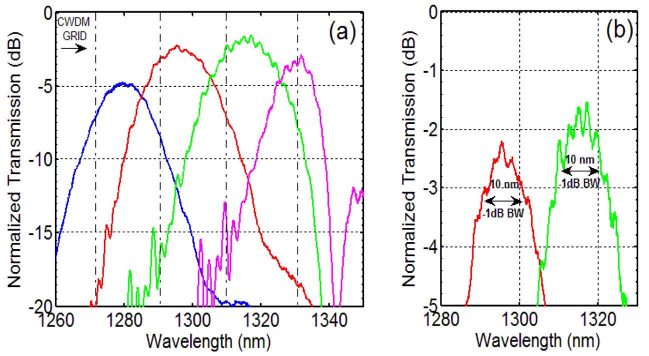

Fig. 2 (a) O-band 4 *x* 20 nm CWDM EG transmission spectrum (b) exhibiting a -1dB bandwidth of nearly 10 nm. Vertical dotted lines represent the nominal ITU grid.

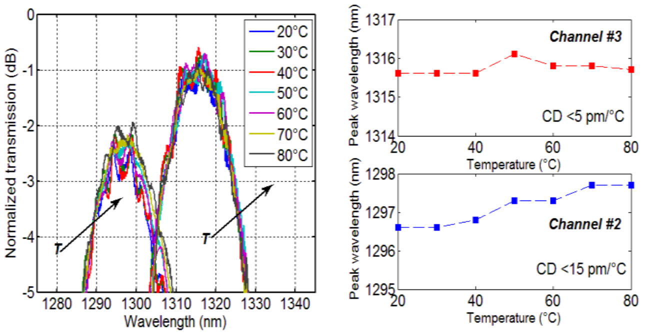

Fig. 3 (left) Temperature-dependent EG transmission spectra. (right) Channels #2 and #3 center wavelengths obtained from parabolic fitting. A close-to-zero thermal chromatic dispersion (CD) averaging 10 pm/°C is observed between 20 °C and 80 °C.

The grating has been conceived and simulated within the EPIPPROP [8] environment via a 3-D vectorial approach. The EG designs were optimized for 4 *x* 20 nm spaced CWDM channels at 1.31 µm on SOI. I/O waveguides were modelled via finite-difference method (FDM) and film-mode matching (FMM) for waveguides tapering and nearest neighbor coupling evaluation. Concerning the EG model, the resultant phase and field profile are propagated using Huygens-Fresnel theory from points along the input plane to points defined along the front face of the grating.
The fabrication process made use of CMOS 200-mm pilot lines processing tools on Si wafers, characterized by 600-nm-thick PECVD-deposited SiNx film over 2.5-µm-thick buried oxide (BOX). 248-nm deep-UV (DUV) and CF_4-CH_2F_2-O_2 chemistry-based reactive-ion etching are used for the silicon nitride patterning followed. The whole architecture including the free propagation region, input/output (I/O) access waveguides and the DBR-facets of the EG have been etched down till BOX. High-density plasma (HDP) silica deposition at 400 °C is used for SiNx encapsulation.
Figure 1 shows an optical image of the fabricated EG demultiplexer, while optical transmission spectra over the 4 channels of the CWDM demultiplexer are reported in Figure 2.

The device shows insertion losses varying between 1.5 dB to 4.7 dB across the four channels, interchannel crosstalk averaging -10 dB (when measured at the center wavelength of each channel), non-uniformity of 3 dB and a -1 dB bandwidth (-1 dB BW) of nearly 10 nm. Such wide bandwidth - while maintaining low losses - allows compensating for wavelength drifts due to the different thermal environments between the transmitter and the receiver as well as the detuning of emitters at the transmitter side of the link.
As showed in Fig. 3, the EG show a quasi-absolute thermal insensitiveness in the temperature operation range from 20 °C up to 80 °C, highlighting the thermal robustness of such SiNOI EG devices. A thermally-dependent wavelength detuning averaging less than 10 pm/°C over different channels has been estimated, thus 6*x* times less than similar devices when realized on standard SOI [7].

3. Conclusions and perspectives

In this communication authors present for the first time CWDM4 EG demultiplexers for receiver applications realized on 200 mm SiNOI platform exhibiting ultra-low temperature-dependent chromatic dispersion estimated below 10 pm/°C. Moreover, performances are not affected by thermal drifts which make the device almost ideal for board-to-board applications without the need for an active control of the transmitter/receiver thermal environments. Among valuable perspectives, further work is expected in increasing the optical quality of the current PECVD nitride film in order to reduce insertion losses dramatically to less than 1 dB. Moreover, the use of 193-nm DUV lithography would help in reducing the astigmatism and crosstalk of the EG (notably for the last channel) thanks to an improved patterning.

Acknowledgements

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