

Thermo-optic tuning of wavelength (de)multiplexers on InP membrane

Yuqing Jiao¹, Yandan Jiang¹, Jos van der Tol¹

¹ COBRA Research Institute, Eindhoven University of Technology, The Netherlands

In this contribution precise wavelength control of planar concave grating (PCG) wavelength demultiplexers using a thermo-optic tuning technique is reported. The devices are based on an InP photonic membrane technology. Thermal control from the micro-heaters on top of the devices is investigated for the first time in the InP membrane platform.

Introduction

The InP membrane on Si (IMOS) technology [1] is regarded as the next generation InP generic photonic integration platform. The IMOS technology is advantageous in terms of the high integration density and potential of co-integration with electronics. Arrayed waveguide grating (AWG) [2] and the planar concave grating (PCG) [3] are the two important devices for implementing wavelength division multiplexing (WDM) functionality in this photonic integrated platform.

Precise wavelength control and long-term wavelength stability are needed when these demultiplexers are used in practical applications. Due to fabrication errors and environmental influence, the wavelength response of a demultiplexer will shift and this shift must be compensated. Furthermore, in some cases, especially when the devices are closely integrated with lasers, which can generate a significant amount of heat, the wavelength response of the device needs to be corrected. Furthermore the tunable AWGs and PCGs can also be used as intra-cavity filters in tunable lasers [4]. Therefore, a method for precise wavelength control and tuning of those devices on the IMOS platform is desired.

There are mainly two methods for wavelength tuning: thermo-optic tuning [5] and electro-optic tuning [4]. Electro-optic tuning provides a fast tuning operation in the order of picosecond. However, this usually requires a p-n junction which can cause extra loss and increase fabrication complexity for the IMOS passive devices. Thermo-optic (TO) tuning can enable low optical loss and simple fabrication. The tuning speed of the TO effect is in the order of milliseconds. For practical applications as mentioned above this is sufficient. Thermo-optic tuning can be achieved by heating up the waveguides and thereby changing its effective refractive index. This change in the effective index of the waveguides tunes the wavelength behaviour of the devices.

In this contribution, the fabrication and characterization of TO heaters in IMOS waveguides are reported. Thermal control from the micro-heater on top of a PCG device is demonstrated, showing for the first time precise wavelength control of InP membrane devices.

Device realization

A typical cross-sectional view of an IMOS waveguide is shown in Fig. 1 (a). It consists of a 300 nm thick InP (refractive index $n=3.16$) membrane on top of a 1.85 μm thick SiO₂ ($n=1.44$) buffer layer, which is deposited on a silicon ($n=3.45$) substrate. The width w of the waveguide is dependent on the specific device, e.g., for a PCG demultiplexer, w is

very large ($w \gg \lambda$) in the slab region. Fig. 1 (b) shows the membrane structure of an IMOS with a micro-heater on top. A 1 μm thick optical buffer layer is deposited on the InP layer and metal layers are patterned on top of this buffer layer. The width of the metal heater is 3 μm .

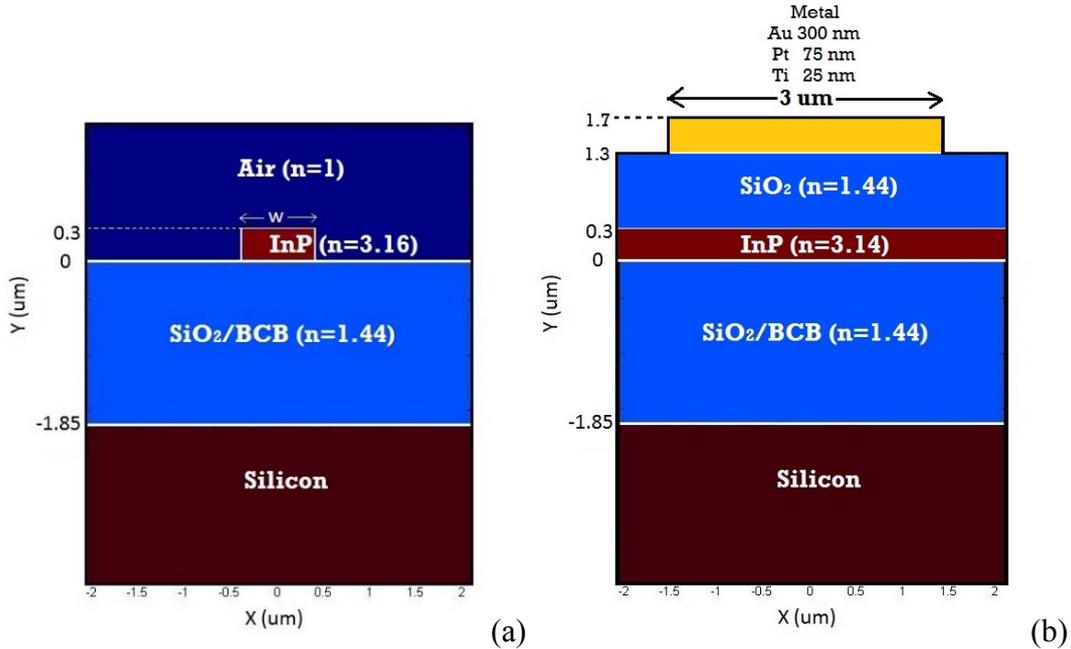


Fig. 1 (a) Cross-section of an IMOS waveguide. (b) Membrane structure of IMOS with micro-heater on top.

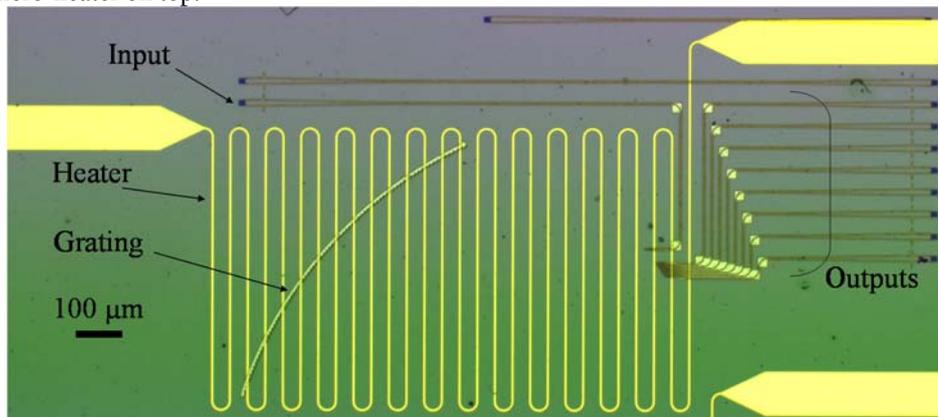


Fig. 2 Microscope picture of the fabricated PCG device.

The design concept and layout structure of the PCG device on IMOS can be found in [3]. The PCG is designed with 8 channels. Fiber grating-couplers are designed for TE-polarized light, with a central wavelength of 1550 nm. The thermal controller is based on ohmic heating of the metal under current injection.

The fabrication of the devices starts with the bonding of the InP membrane. First a silicon carrier wafer is cleaned and covered with a 1.8 μm thick SiO₂ layer deposited with plasma enhanced chemical vapor deposition (PECVD). The InP layer is then bonded to the SiO₂ surface with a 50 nm thick BCB adhesive layer in between. The IMOS devices are fabricated in this membrane using electron-beam lithography (EBL) [6] and reactive-ion etching (RIE) [7]. After that a 1 μm thick SiO₂ layer is deposited on the InP membrane as the optical buffer layer, on top of which the metal layer is evaporated and patterned using a lift-off technique. The metal layer consists of 25 nm Ti, 75 nm Pt and 300 nm Au

as has been used in our standard fabrication process. A microscope picture of the fabricated PCG device is shown in Fig. 2.

Device characterization

The sample is placed on a copper block, which is thermally stabilized with a thermal-electric controller (TEC). Probe needles are used to realize electrical contacting to the metal micro-heaters. The injected current from the current source heats up the metal, as well as the membrane device underneath the metal. Input and output optical fibers are placed at a fixed angle of 10 degrees with respect to the surface normal of the chip. Light is coupled into and out of the device through these fibers. In this experiment, the optical source is an erbium-doped fiber amplifier (EDFA) and the detector can be a power meter or an optical spectrum analyzer.

The current source is able to provide current injection with a maximum 40 V voltage output. The relation between current and voltage is not linear, because the resistance of metal varies with temperature. The resistance of micro-heater is 314 Ω when current is lower than 10 mA. It increases up to approximately 400 Ω at a current of 90 mA.

The transmission spectra of the eight output channels in the PCG are shown in Fig. 3 at two current settings (zero current and 70 mA current through the micro-heater). During the measurement the temperature at the backside of the chip is stabilized at 300 K. It can be seen that there is no degradation of the filter characteristics (e.g., passband shape, channel crosstalk) after the device is heated. The wavelength shift of a single channel (the left-most channel in Fig. 3) in the PCG device is shown in Fig. 4(a) as the current increases from 0 mA to 90 mA with an increment of 10 mA. The wavelength shift due to the thermal tuning is linear with respect to the applied heating power ($I^2 \cdot R$), as shown in Fig. 4(b). We are able to shift the wavelength response of the PCG device over 3.7 nm with a current of 90 mA. This tuning range is already sufficient for compensation of fabrication errors and for correction of channel wavelengths under environmental disturbances.

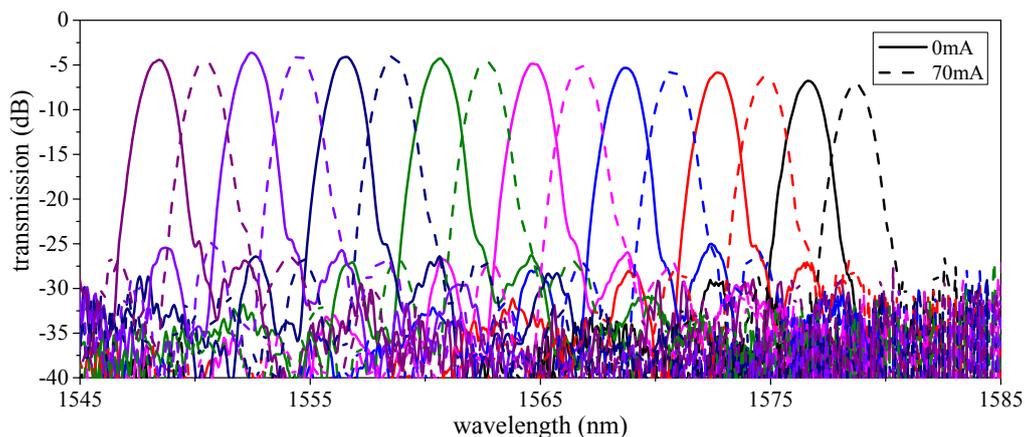


Fig. 3 Transmission spectra of the eight output channels in the PCG, with zero current (solid lines) and with 70 mA current (dashed lines) through the micro-heater.

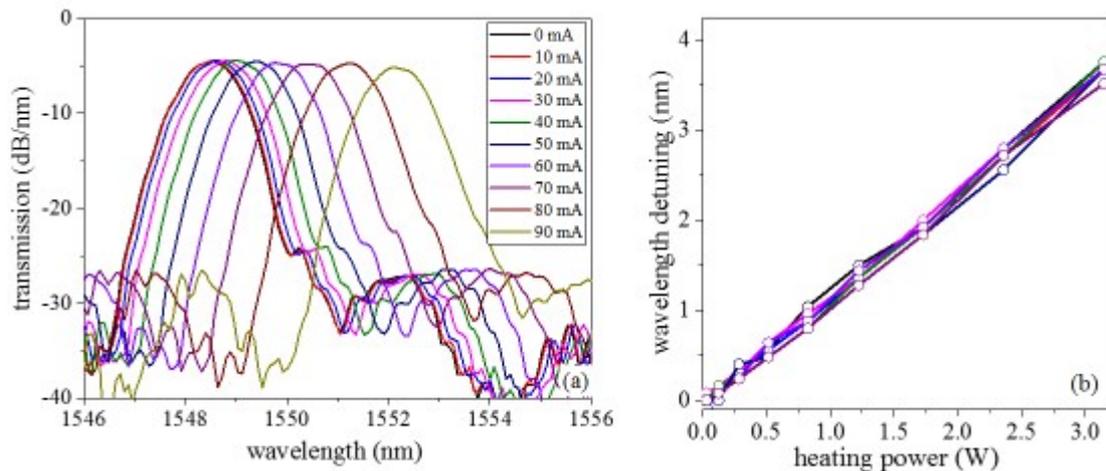


Fig. 4 (a) Wavelength shift of a single channel (the left-most channel in Fig. 3) in the PCG device. (b) The wavelength detuning in the PCG, as a function of the heating power generated in the micro-heater. All data from the eight channels are included.

Conclusion

In this contribution the thermal-optic tuning of IMOS PCG devices is realized, validated and precisely controlled using micro-heater structures. The spectra shows no degradation at all under thermal tuning. The overall achievements in this work can be a very useful guideline for future design, fabrication and operation of thermally tunable IMOS devices.

References

- [1] J. van der Tol, J. Pello, S. Bhat, Y. Jiao, D. Heiss, G. Roelkens, H. Ambrosius, and M. Smit, "Photonic integration in indium-phosphide membranes on silicon (IMOS)," in *Proc. SPIE 8988, Integrated Optics: Devices, Materials, and Technologies XVIII*, 2014, pp. 89880M-89880M-17.
- [2] M. Kohtoku, H. Sanjoh, S. Oku, Y. Kadota, Y. Yoshikuni, and Y. Shibata, "InP-based 64-channel arrayed waveguide grating with 50 GHz channel spacing and up to -20 dB crosstalk," *Electronics Letters*, vol. 33, pp. 1786-1787, 1997.
- [3] J. Pello, M. Muneeb, S. Keyvaninia, J. J. G. M. van der Tol, G. Roelkens, and M. K. Smit, "Planar Concave Grating Demultiplexers on an InP-Membrane-on-Silicon Photonic Platform," *IEEE Photonics Technology Letters*, vol. 25, pp. 1969-1972, 2013.
- [4] B. W. Tilma, Y. Jiao, P. J. van Veldhoven, B. Smalbrugge, H. P. M. M. Ambrosius, P. J. Thijs, X. J. M. Leijtens, R. Nötzel, M. K. Smit, and E. A. J. M. Bente, "InP-based monolithically integrated tunable wavelength filters in the 1.6 – $1.8\mu\text{m}$ wavelength region for tunable laser purposes," *Journal of Lightwave Technology*, vol. 29, pp. 2818-2830, 2011.
- [5] W. Green, R. Lee, G. DeRose, A. Scherer, and A. Yariv, "Hybrid InGaAsP-InP Mach-Zehnder Racetrack Resonator for Thermo-optic Switching and Coupling Control," *Optics Express*, vol. 13, pp. 1651-1659, 2005.
- [6] Y. Jiao, J. Pello, A. M. Mejia, L. Shen, B. Smalbrugge, E. J. Geluk, M. Smit, and J. van der Tol, "Fullerene-assisted electron-beam lithography for pattern improvement and loss reduction in InP membrane waveguide devices," *Optics Letters*, vol. 39, pp. 1645-1648, 2014.
- [7] Y. Jiao, T. de Vries, R.-S. Unger, L. Shen, H. Ambrosius, C. Radu, M. Arens, M. Smit, and J. van der Tol, "Vertical and Smooth Single-Step Reactive Ion Etching Process for InP Membrane Waveguides," *Journal of The Electrochemical Society*, vol. 162, pp. E90-E95, January 1, 2015 2015.