InP Membrane on Silicon (IMOS) Photonics

(Invited paper)

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ABSTRACT

InP membranes have appeared in the last decade as a viable integrated photonics platform, suitable for adding photonic functions to silicon electronics. It combines the strengths of silicon photonics (high index contrasts and therefore small footprint devices) with those of generic InP-platforms (monolithic integration of active and passive devices). A range of functionalities has been developed on this platform, which goes by the name of IMOS (Indium phosphide Membrane on Silicon). Competitive performances have been demonstrated for lasers, fast detectors, waveguides, filters, couplers, modulators etc. The present contribution describes the recent developments in this platform regarding the technology and results. Among the latest results are record low propagation losses, improved input/output grating couplers, a variety of laser structures and improved wavelength demuliplexers These developments demonstrate that IMOS has a high potential to deliver photonic integrated circuits to a wide variety of application fields, e.g. telecom, datacom, sensing, terahertz and many others.

Keywords: Photonic integration, Indium Phosphide, Membranes, Lasers, Waveguides.

1. INTRODUCTION

Higher integration densities in silicon electronics lead to an impeding communications bottleneck [1]. Optical interconnects are therefore proposed, to be combined with electronic chips. This has given rise to SOI (Silicon-On-Insulator) photonics. However, within SOI-platforms light sources are not available, hence solutions based on heterogeneously integration with III-V semiconductor are developed [2]. However, it is possible to create a III-V photonic layer separate from the silicon, as a thin membrane on top of the CMOS-chip [3]. This technique, InP-Membrane On Silicon (IMOS), avoids the need for photonic waveguides in the silicon. It provides a full set of photonic functions and is implemented with a flexible bonding technique that provides thermal isolation. IMOS allows small footprint and low power consuming devices. The technique does not interfere with standard processing of electronic circuits. Here we will present the recent developments of IMOS.

2. IMOS CONCEPT

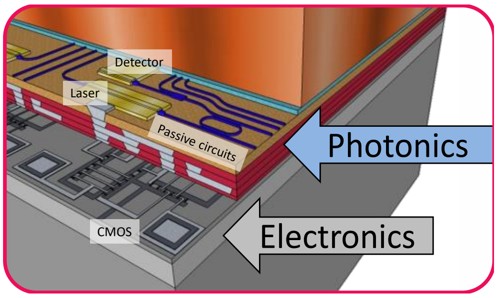

Fig. 1. Artists' impression of the InP membrane platform, with high-confinement active and passive photonic components in the InP membrane circuit, and in close connection with CMOS electronics [3].

The basic idea of the IMOS platform is depicted in Figure 1. Using post-processing techniques a thin membrane of InP is bonded with a polymer (BCB in our case) to a CMOS wafer. The membrane photonic layer contains both active (lasers, detectors, modulators) and passive (waveguides, filters, couplers, demultiplexers) devices. Only electrical contacts are needed between the electronic and photonic layers, which substantially reduces alignment requirements as compared to optical couplings. The technology developed to realize these membrane circuits is described in [4,5]. Using optimized E-beam lithography and plasma etching, processing of both sides of the membrane and careful bonding to silicon carrier wafers, high quality waveguides and a range of well-performing photonic devices are demonstrated. Here we will present mostly our latest results on active and passive devices.

3. EARLIER RESULTS

Table I reports on a number of the devices that have been realized before in the IMOS-platform. They showed several record performances for InP-based membrane photonics [3]. General characteristics are the small footprints, as a consequence of the high index contrast in the membrane, large electrical bandwidth and reproducibility in the realizations, demonstrating the high quality of the developed technology.

Table I: Realized IMOS devices [3]

Device	**Dimensions**	**Main performance parameters**	**Remarks**
UTC-Photodiode	10×3 μm^2	0.7 A/W responsivity >67 GHz bandwidth	3 dB bandwidth extrapolated to 110 GHz
90° bend	0.96 μm radius	0.13 dB/90°	Low loss and reflection
Arrayed Waveguide Grating	0.2 mm^2	10 dB loss	10 dB crosstalk
Planar Concave grating	400x600 μm^2	4 dB loss	25 dB crosstalk Thermal tuning over 3.7 nm
Polarization converter	5 μm long	<1 dB loss	Conversion 99%
Ring resonator	7 μm radius		Q-factor 15500
1x2 MMI coupler	2×3 μm	0.6 dB loss	

4. NEW DEVELOPMENTS

IMOS technology has improved to allow a wider range of devices, and better performance parameters. On top of that also the yield of the processing is improved, especially by introducing state-of the art techniques for BCB-bonding of the membranes. Here we will highlight some of the latest achievements.

4.1 Wafer scanner technology

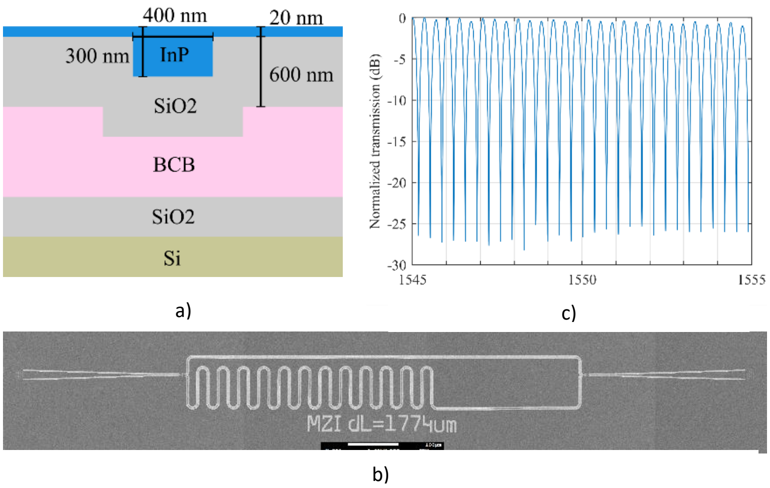

Fig. 2. Results from wafer scanner lithography. a) Cross-section of IMOS waveguide, b) MZI-structure for loss measurement, c) spectral response of the MZI.

The propagation loss of high contrast waveguide devices is critically dependent on the lithography, because of the high modal overlap with the sidewall roughness. Using special E-beam resists [4] low losses were obtained. Now we have realized devices with even better performances, using an ASML PAS5500/1100B scanner lithography tool. Figure 2a shows the cross-section of an IMOS waveguide. The propagation loss was measured with an MZ-interferometer (fig. 2b), by analyzing its spectral response (Fig. 2c). Record low values for InP-membrane waveguides of 1 dB/cm were found, suggesting a much reduced roughness.

4.2 Arrayed Waveguide Grating

Wavelength demultiplexers using the AWG-principle are challenging for membrane platforms. This is because the phase noise in the high contrast waveguides of the array can be large due to sidewall roughness. Also, a phase error can occur due to poor definition of the array arms. Using the wafer scanner lithography it is however possible to reduce the roughness and improve feature size control, resulting in better performance. Figure 3 (Left) shows a realized AWG with this technique, while figure 3 (Right) gives the measured spectral response. Losses of 3.5 dB and crosstalk levels of better than 20 dB are obtained; much improved w.r.t. the device reported in Table 1.

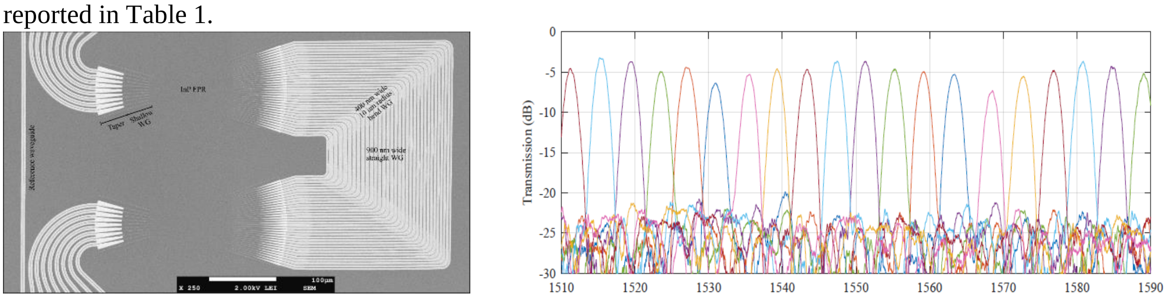

Fig. 3. Left: The AWG realized with wafer scanner. Right t: spectral response of the AWG.

4.4 Grating coupler

It is convenient to use grating couplers for optical interfacing of membrane waveguides with optical fibres. They can be flexibly placed in the circuits, allowing optimal use of space. However, there is a loss penalty associated with this. By using an apodized focusing grating coupler with metal back-reflector the transmission losses were reduced to less than 1.5 dB. Figure 4 depicts the realized grating coupler and the measured transmission spectra.

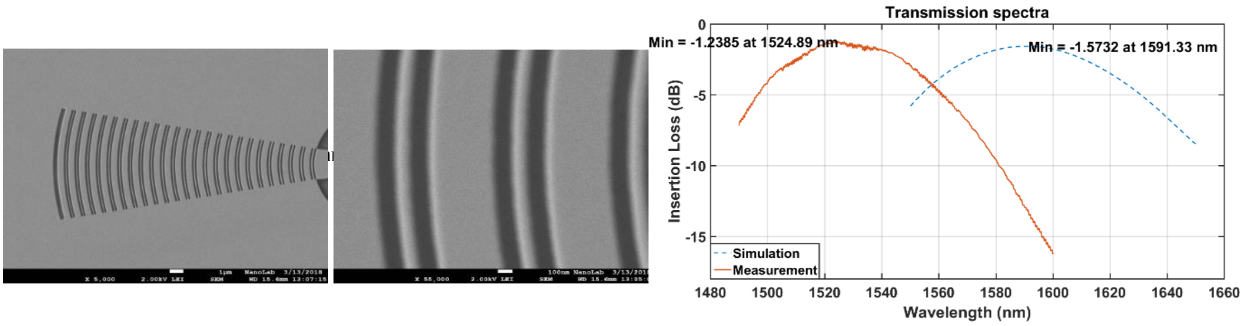

Fig. 4. Grating coupler using apodization, sub-wavelength structuring and a metal back reflector. Left: transmission spectra.

4.5 Lasers

Based on processing both sides of the membrane a SOA structure was developed, using a twin-guide approach. This SOA was used in various laser structures, which are given in Table 2.

Table.2. Recently demonstrated lasers on IMOS

	Circuit configuration	Threshold current density	Output power in waveguide	Side mode suppression ratio (SMSR)	Tunability
DBR laser	500 µm long amplifier + PhC reflectors	2 kA/cm^2	1 mW	30 dB	/
DFB laser	1 mm long cavity with quarter-λ shifted DFB grating	2.5 kA/cm^2	10 mW	60 dB	/
Tunable laser	500 µm long amplifier + micro-ring Vernier filters	2.4 kA/cm^2	0.44 mW	45 dB highest; > 30 dB over tuning range	25 nm

The DFB laser is depicted in figure 5, together with a measured spectrum, that shows a high SMSR.

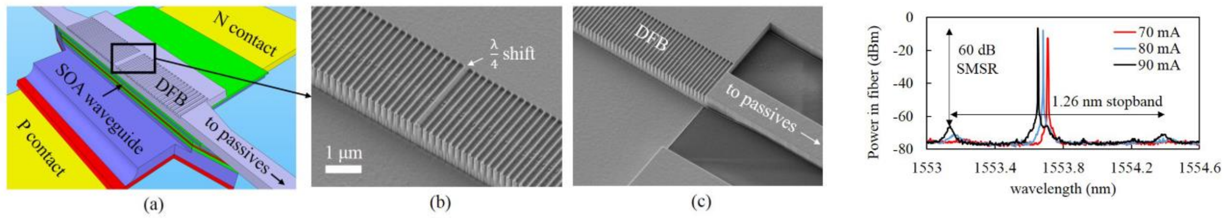

Fig. 5. DFB-laser. From left to right: schematic, DFB-grating, output connection, spectrum.

5. CONCLUSIONS

The latest developments of IMOS, a membrane based photonic integration platform are presented. Waveguide loss as low as 1 dB/cm is obtained as well as improved performance on demultiplexers and grating couplers. Furthermore the integration of SOAs into various laser cavities is shown, with good results.

8. References

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