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Transparent Monitoring of Light in Integrated Optics

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Abstract: We demonstrate transparent monitoring of light in photonic integrated circuits, based on silicon and indium phosphide platforms, by means of a novel integrated photonic probe. In silicon waveguides our transparent probe enables light observation over 30 dB dynamic range, down to -20 dBm sensitivity, and on a microsecond time scale. Application to the tuning of the resonant wavelength of a silicon microring resonator is shown.

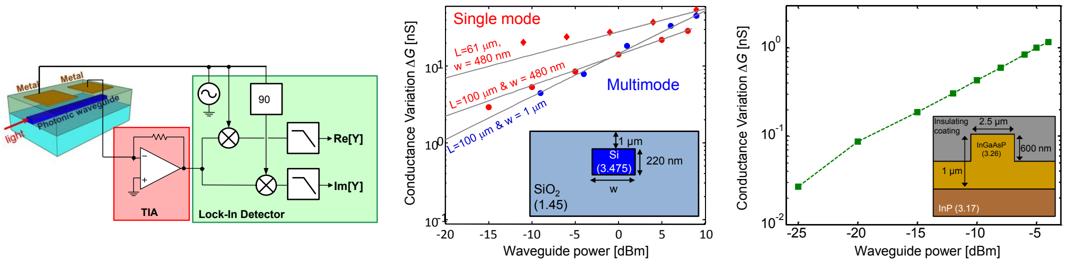
1. Introduction

Photonic integrated circuits are fundamental building blocks enabling high-speed, low power and small footprint wavelength division multiplexing (WDM) optical interconnects. However, because of their strong sensitivity to fabrication tolerances, thermal drifts, laser fluctuations, crosstalk effects etc., their operation needs to be continuously monitored and stabilized. Active tuning techniques for the feedback control of the resonator wavelength have been recently demonstrated [1-2], however they require the use of tap photodetectors to monitor the current status of the circuit, condition that should be avoided for large scale integration circuits, where hundreds of components are integrated on the same chip.

In this contribution we demonstrate a ContactLess Integrated Photonics Probe (CLIPP), that neither taps additional photons from the waveguide nor introduces significant perturbations of the optical field [3]. Our technique, that exploits the measurement of the variation of the waveguide electric conductance associated with intrinsic surface-state absorption (SSA), is inherently CMOS compatible, enables multi-point light monitoring on chip, and proves its utility for the tuning and control of photonic integrated devices.

2. The CLIPP concept

Figure 1(a) shows a schematic view of the CLIPP, that consists simply of two metal electrodes placed on top a photonic waveguide (here demonstrated for Si and InP technologies) covered by an insulating top cladding layer. The inset of Fig. 1(b) reports the case of a Si waveguide where two Au electrodes are deposited on top of a Si core waveguide (w = 480 nm, h = 220 nm) surrounded by SiO_2. The metal pads are placed at 1 µm distance from the Si core to avoid any additional optical loss, and at a mutual distance of 100 µm. Owing to the typical doping of SOI wafers (10^{15} cm^{-3}), in the electrical domain the Si core acts essentially as a resistor of conductance G, whereas the insulating top cladding provides an access capacitance from the metal to the Si core.



(a) (b) (c)

Fig. 1: (a) Schematic view of the CLIPP integrated with a generic photonic waveguide and measurement setup composed of a transimpedance amplifier (TIA) and a lock-in detector. (b) Light induced conductance change measured by the CLIPP in a Si waveguide as a function of the optical power for single and multimode waveguides and different CLIPP configurations and (c) in a InGaAsP/InP waveguide (coated with Si_3N_4).

As the light propagates in the waveguide, carriers are generated at the Si core boundaries by intrinsic surface-state-absorption (SSA) mechanisms, thus modifying the electric conductance G of the waveguide. No specific treatment was performed at the Si/SiO_2 interface. In order to measure the conductance change ΔG induced by optical power P, one of the CLIPP electrodes is excited with an electrical signal (voltage V_e = 1 V, and frequency f_e = 1 MHz), while the electric current at the other electrode is collected by means of a transimpedance amplifier (TIA) and a lock-in detector, measuring the complex (amplitude and phase) electric admittance Y. The electrical frequency f_e was chosen in order to bypass the access capacitance (~ 5 fF), thus probing directly the conductance of the Si core.

Figure 1(b) shows the measured ΔG as a function of optical power P on TE polarization and at a 1550 nm wavelength, for single (w = 480 nm) and multimode (w = 1 µm) waveguides and different distances L between the CLIPP electrodes. Light monitoring was performed over a dynamic range of 3 orders of magnitude, down to -20 dBm, thanks to a sensitivity in the conductance measurement of better than 1 nS. The non-invasive behavior of the CLIPP was confirmed by the absence of a significant modulation effects in the output optical signal at the electric read-out frequency f_e: in fact, with a driving voltage of 1 V, the CLIPP introduces a phase perturbation as low as 0.4 mrad, corresponding to less than 0.2 ppm change of the waveguide effective index [3]. This negligible perturbation, that is induced by a tiny electro-optic effect, is comparable to that that would be induced by a temperature change smaller than 3 mK, that is far below the thermal stability of conventional thermoelectric coolers.

The CLIPP effectiveness was also demonstrated for InGaAsP/InP waveguides [Fig. 1(c)], here covered with Si_3N_4, where light induced ΔG was measured across 20 dB dynamic range and down to -25 dBm.

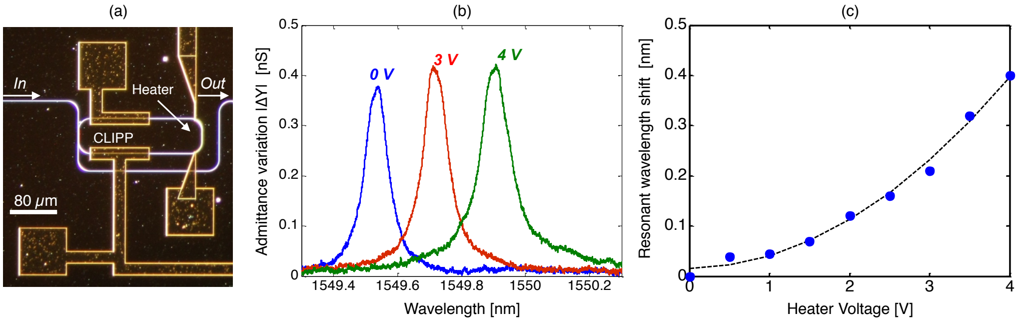


Fig. 2: (a) Top-view photograph of the Si ring resonator, onto which a CLIPP and a thermal actuator are integrated; (b) spectral response of the resonator measured by the CLIPP for different voltage applied to the heater; (c) resonant wavelength shift measured by the CLIPP when the heater is driven from 0 to 4 V.

3. Tuning of a Si resonator wavelength

Transparent monitoring of light can be exploited for the tuning of the spectral response of microring resonators. Figure 2(a) shows a top-view photograph of a Si ring resonator, in an all-pass-filter configuration, onto which a CLIPP and a thermal actuator are integrated. The resonator is 516 µm long (free-spectral-range FSR = 138.6 GHz) and has a linewidth of 87 pm (10.8 GHz). The CLIPP, that is placed inside the resonator, enables to monitor the light stored inside the ring, that is not accessible with an external photodetector or optical-spectrum-analyzers. As the thermal actuator is driven from 0 to 4 V, the ring spectral response, that is measured by the CLIPP, redshifts accordingly [Fig. 2(b), showing the magnitude of the electrical admittance variation $|\Delta Y|$]. Neither a change in the quality factor of the resonator (that is around 18000) is observed when the CLIPP and the heater are switched on, nor a significant crosstalk between the heater and the CLIPP electrical signals. Figure 2(c) reports the resonant wavelength of the filter, measured with the CLIPP, exhibiting a quadratic dependence with the heater voltage, as expected.

4. Conclusion

We demonstrated transparent monitoring of light in Si and InP photonic waveguides by means of a novel non-invasive detector, that neither taps additional photons, nor introduces significant perturbations of the optical field. Furthermore, we show the utility of the CLIPP to assist the tuning of the transfer function of a Si resonator.

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