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Switching and cross-talk characteristics of compact thermal tuners on a Silicon Nitride platform

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Abstract: Thermal tuners with footprint of 270x5 μm^2 and switching power of 350 mW are reported on Silicon Nitride, with thermal-cross talk, in terms of induced phase change in adjacent devices of less than one order of magnitude at distances over 20 μm.

Aiming at the reconfiguration of photonic integrated circuits (PICs), various physical mechanisms exist: electro-absorption/refraction are faster and use less energy, however the thermo-optic effect over the refractive index is larger, and induces less losses [1]. Most of the approaches in the literature, propose long and wide tuners for linear phase-shift vs. driving power: 2mm [2], 12mm [3], >600μm [4]. Long heaters are contrary to compact PICs and cost. A common given figure given in the literature is the switching power to obtain a phase shift of π (P_π). In this paper the relation of P_π with the heater cross-section is shown. Moreover, for increased density on chip, the thermal cross-talk, not reported previously, is investigated. To asses on properties of the tuners, a test die with Mach-Zehnder Interferometer (MZI) test structures was fabricated, Fig. 1(a). The devices are fabricated on 100mm Si wafer, composed of a SiO_2 buffer (2.0 μm thick, n=1.464) grown by thermal, following a LPCVD Si_3N_4 layer with thickness 300nm (n= 2.01) and a 1.5 μm thick SiO_2 (n=1.45) deposited by PECVD. The metal layer stack is 30nm Cr and 100nm Au. The tuners are composed of three metal sections, named pads (100x100 μm^2) with tapers (W_l=45μm to w_a=w_h+2μm, length 21.5μm), curved access (r_a=50μm, w_a to w_h) and heater (L_hxw_h). Heaters of widths 5, 6, 7 and 8μm, and lengths of 120, 130, 170, 220, 270 and 320μm are included. The optical phase change due to the temperature gradient is expressed as:

$$\frac{\Delta\phi}{2\pi} = \frac{1}{\lambda}\Delta\bar{n}L_h = \frac{1}{\lambda}\frac{\partial\bar{n}}{\partial T_c}\Delta T_c(P, L_h, w_h)L_h \quad (1)$$

where $\partial\bar{n}/\partial T_c$ is the rate of change of the effective index $\bar{n}$ vs the waveguide core temperature T_c, $\Delta T_c(P,L_h,w_h)$ is the core temperature change induced by a heater driven with power P. Using PhoeniX OptoDesigner and COMSOL Multi Physics for a strip waveguide (1.0x0.3μm^2), $\partial\bar{n}/\partial T_c \simeq$ 3.05 $\cdot 10^{-5}$ K^{-1} and a heat transfer efficiency from heater to core of 58% were obtained. $\Delta T_c(P,L_h,w_h)$ was investigated with simulations for w_h=5μm and 8μm for driving power P=297.62mW, resulting in $\Delta T_c \cong$11°C more for w_h=5 μm, Fig. 1(b)(c), concluding narrow heaters concentrate heat.

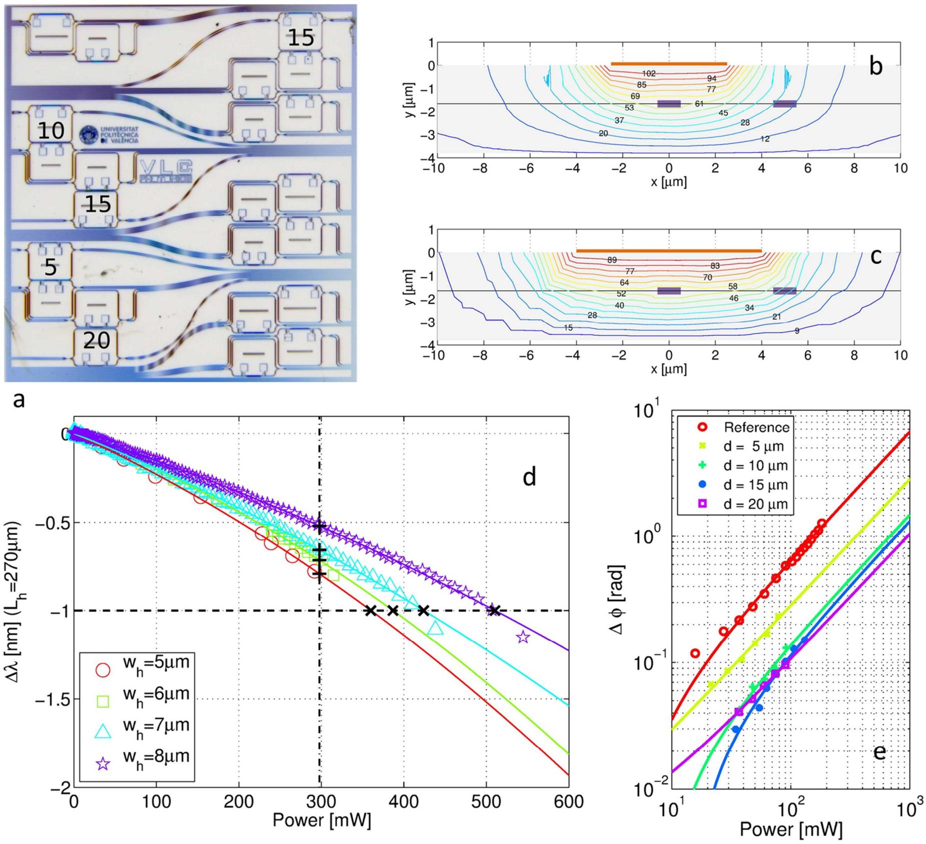

Fig. 43. Test chip 5.5x5.5 mm² (a) temperature gradient for P=297.5 mW for a heater of L_h=270µm and w_h=5 µm (b) and w_h=8 µm (c) switching power (d) and cross-talk (e)

Next, P_π was investigated through measurements of the optical spectral response for the MZIs, Fig. 1(d). As shown in Fig. 1(b)(c) reducing the w_h increases ΔT_c, so less power is required for a π shift (horizontal dashed line, cross symbols). Analog, for a fixed P, the shift is always larger for narrow heaters (vertical dash-dot line and plus signs). Devices with L_h<270µm were not resilient due to temperature increased resistivity leading to non-reversible heater damage. Thermal cross-talk was experimentally investigated with the pairs of MZIs in Fig. 1(e) labeled as 5, 10, 15 and 20. All these MZIs have heaters with w_h=5µm and L_h=130µm (compact and providing high ΔT_c). From the results, two conclusions are derived. Firstly and as expected, increasing the distance between reduces the amount of crosstalk. The distance required for an influence of less than one order of magnitude is above 20µm. Secondly, the relative distance between curves is constant with increasing powers, leading to the conclusion that the heat conduction through the materials is independent of the drive power.

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