INDUCED TRANSPARENCY IN DOUBLE-RING PHOTONIC SWITCHES FOR OPTICAL NETWORKS-ON-CHIP

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Introduction

Optical Networks-on-Chip (ONoC) have become a popular subject of research and development as a viable option for increasing bandwidth, lowering latency and reducing power consumption for communication subsystems realized on integrated circuits [1]. In particular, the promising efforts of topology optimization towards minimizing power consumption [2] make ONoC technologies interesting for future applications in avionics and harsh environments. In this paper, we discuss the advantage of employing the well-known coupled-resonator-induced transparency (CRIT) effect [3-4] in ONoC architectures, which allows a reduction in the temperature change required to achieve ON/OFF switching by up to an order of magnitude.

Photonic Switch using CRIT Effect

Figure 1 (a), (b) shows the operation of a standard 2x2 photonic switching element consisting of two crossing waveguides coupled to two micro-rings resonators, as it is commonly employed in ONoC. When the round-trip optical path inside the micro-rings is equal to multiples of 2π, micro-rings are in resonance, and the photonic element is switched ON, otherwise it is switched OFF. This type of switching requires a significant phase shift in the round-trip optical path, and thus, implying the usage of a strong thermo-optical effect (which unfortunately is relatively slow), and non-negligible power consumption.

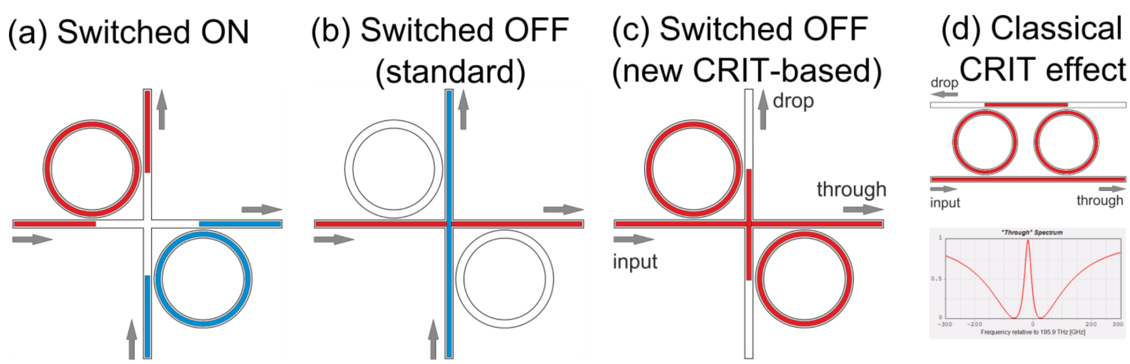

Figure 1. 2x2 photonic switching element in different operation modes (a)-(c), two parallel micro-ring resonators exhibiting a classical CRIT effect (d)

We found that a properly designed 2x2 photonic switching element can exhibit the CRIT effect (Figure 1 (c)). This is very similar to that discovered for a structure with two parallel micro-ring resonators [3-4], as shown in Figure 1 (d). Actually, for an ideal waveguide intersection (no back reflections, no crosstalk), both structures are topologically equivalent. It has been shown [5] that the CRIT effect can be very fruitful in applications such as modulators and reconfigurable wavelength routers. For ONoC, its potential for reducing switching power compared to standard switching techniques makes the use of the CRIT effect very attractive.

We studied the CRIT effect in 2x2 photonic switching elements analytically and using numerical simulations realized in VPIcomponentMaker Photonic Circuits [6]. Despite numerous complications introduced by back reflections and crosstalk in real waveguide crossings, we found that employing the CRIT effect represents a very attractive practical alternative that allows a significant reduction in switching power. This is illustrated in Figure 2. While a standard switching mechanism (Figure 2 (a), (b))

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requires a temperature change of 13ºC in each ring to achieve 20dB signal modulation, the switch utilizing the CRIT effect (Figure 2 (c), (d)) requires only temperature changes of 1.6ºC to 4ºC for signal bandwidths of 1.5GHz to 5.6 GHz, respectively.

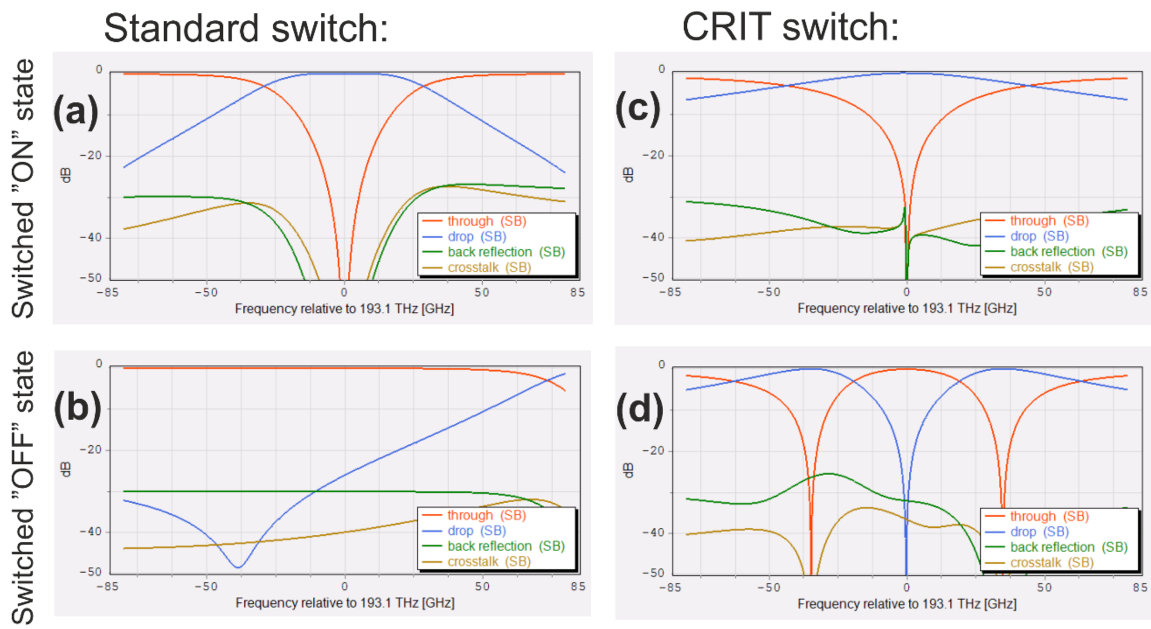

Figure 2. Transfer characteristics of different switching mechanisms

As a result, we suggest that instead of employing a thermo-optic effect for switching control, the possibility of utilizing the much faster, albeit much weaker, electro-optic effect is very real due to the significant increase in sensitivity of the CRIT based device. In case of realization in silicon, this could be the free carrier plasma dispersion effect for instance. Furthermore, we systematically analyzed the role of fabrication imperfections for yield and power consumption for both types of switching mechanisms in photonic elements, accounting for the role of parasitic interactions between different standard building blocks in large-scale networks.

Conclusion

We studied the properties of 2x2 photonic switching elements made of two intersecting waveguides coupled with two micro-rings and showed that they can exhibit the effect of coupled-resonator induced transparency (CRIT). Employing the CRIT effect promises reduction of power consumption compared to standard switching techniques, and thus, the potential of utilizing a fast (but weak) electro-optic effect for switching control. Even though non-ideal waveguide crossings add noteworthy complexity, we demonstrated its practical value for designing ultra-low-power optical networks-on-chip.

References

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