High-Fidelity Quantum Operation of Photonic Circuits with Resource-efficient Machine-learning-assisted Crosstalk Mitigation

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Photonic integrated circuits (PICs) are a compact, stable and widely used platform for generating, manipulating, and detecting quantum light. PICs can implement a wide range of operations on light thanks to their reconfigurable thermo-optic phase shifters, which induce phase shifts on light via localized waveguide heating. However, diffusion of the generated heat creates thermal crosstalk between the phase shifters, introducing unwanted phase shifts that degrade the PIC accuracy and thus the fidelity of the implemented quantum information protocols. Characterizing this crosstalk is challenging due to the large number of parameters involved and the difficulty of isolating individual effects. Previous studies [1, 2] have modelled crosstalk as an interaction only between the *controlled* phase shifters of PICs (see Fig. 1), leading to the measurement of unphysical crosstalk properties [3]. In this work, we propose an exhaustive description and systematic analysis of crosstalk by accounting for parasitic phase shifts in all waveguides. **We fully characterize crosstalk in physical devices using machine learning and introduce an exact mitigation framework.** Our approach is experimentally validated, and we demonstrate the efficacy of our machine learning model to accurately recover physical crosstalk properties, as well as to cancel crosstalk. Our mitigation framework reveals that some interferometer designs are inherently incapable of fully mitigating crosstalk. **We provide a graphical criterion (see Fig. 2) that certifies whether a given interferometer has enough degrees of freedom adequately laid out to mitigate crosstalk.** Our graphical criterion can be used to design PICs with reduced numbers of active elements without compromise on the fidelity of the implemented quantum operations on light.

References

[1] Milanizadeh, M et *al*. Journal of Lightwave Technology 37, 1325–1332 (2019).
[2] Bandyopadhyay, S. et *al*. Nat. Photon. 18, 1335–1343 (2024).
[3] Fyrillas et *al*. Optica, OPTICA 11, 427–436 (2024)
[4] Peruzzo, A. et *al*. Nat Commun 5, 4213 (2014).

Figures

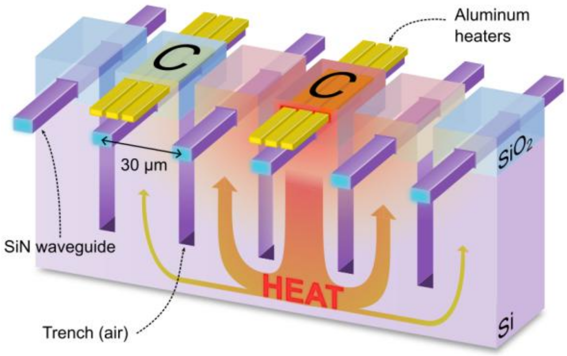

Figure 1: Physical simulations of thermal crosstalk indicate that every neighbouring waveguide acquires an unwanted phase shift due to heat diffusion. Waveguides marked “C” feature *controlled* phase shifters due to the presence of a heater.

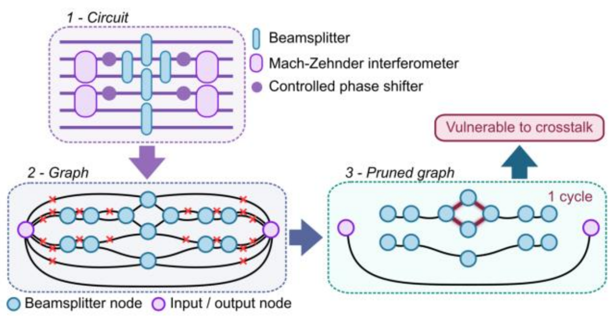

Figure 2: The graphical criterion shows that the PIC used in [4] is vulnerable to crosstalk. The PIC cannot fully cancel crosstalk from a fundamental point of view, due to an insufficient number of controlled phase shifters.