



**HAL**  
open science

## Non-adiabatic control in NxN integrated photonic switch

Anastasiia Sheveleva, Christophe Finot, Pierre Colman

► **To cite this version:**

Anastasiia Sheveleva, Christophe Finot, Pierre Colman. Non-adiabatic control in NxN integrated photonic switch. 40ièmes Journées Nationales de l'Optique Guidée, Optique Dijon 2021, Jul 2021, Dijon, France. hal-03246557

**HAL Id: hal-03246557**

**<https://hal.science/hal-03246557>**

Submitted on 9 Nov 2023

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# NON-ADIABATIC CONTROL IN NxN INTEGRATED PHOTONIC SWITCH

Anastasiia Sheveleva<sup>1</sup>, Christophe Finot<sup>1</sup>, Pierre Colman<sup>1</sup>

<sup>1</sup> *Laboratoire Interdisciplinaire Carnot de Bourgogne - UMR 6303 CNRS, Université de Bourgogne-Franche-Comté, Dijon (FRANCE)*

anastasiia.sheveleva@u-bourgogne.fr

## RÉSUMÉ

We demonstrate numerically that the flow of light in an array of non-interacting waveguides can be controlled by a periodic spatial modulation. Compared to other techniques, ours has fewer restrictions and free parameters to be adjusted. Consequently it can serve for the optimization of large scale but, still compact, photonics integrated systems.

**MOTS-CLEFS :** *coupled waveguides ; integrated-photonics ; photonic switch ; genetic algorithm optimization;*

## 1. INTRODUCTION

The massive use of integrated photonics devices for classical (e.g. Photonic Neural Processors - PNP [1]) and quantum computing would require the design and fabrication of ever more complex devices. In particular the efficient and compact routing/switching of light through the photonics chip is a critical feature. On one hand, current approach based on the cascade of 2x2 switches results in systems with increasingly larger -both lateral and longitudinal- footprint. On the other hand, densely packed arrays of (isolated) waveguides have a very small lateral footprint; but the intrinsic uncoupled nature of the waveguides, hence no cross-talk, makes the switching between them challenging. We show that, by relying on the analogy between the equations governing unidirectional propagation in optics and the time evolution in quantum physics, it is possible to control the routing of light in any waveguides array. Such a strategy greatly differs from the most common adiabatic design techniques which assume that the light cannot make transitions between the eigenmodes coexisting inside the optical systems. In contrast, the strategy that we propose here can be labeled as non-adiabatic. It unifies under the same framework some concepts that can be found in two-waveguide systems such as grating assisted contra-propagating couplers (sub-wavelength modulation), PPLN waveguides (modulation caused by optical Kerr nonlinearity), and long period gratings in fibers; and extends it to any waveguides array system. We are able to design compact switches where only small perturbations -of at most a few percents of the nominal array parameters- are required.

## 2. NON-ADIABATIC COUPLING

Let consider an array of a few coupled single-mode waveguides. The coupling hybridizes the individual waveguides modes to create super-modes (aka eigen-modes) that have different propagation constants, like the energy levels in a quantum system (Fig. 1, a). Consequently, by analogy with quantum mechanics [2], if we ‘excite’ the system with the right (spatial) frequency, we can redistribute the energy between two selected eigen-modes; the other eigen-modes that do not match the modulation frequency being left unperturbed. We present in (Fig. 1 b-d) the realistic configuration consisting in an array of 3 partially etched Silicon Nitride waveguides (Fig. 1 b).

The array is designed so that each waveguide corresponds to about also an eigen-mode, so they behave as isolated propagation channels. We apply a 87  $\mu\text{m}$ -period sinusoidal modulation between the two bottom waveguides over 400  $\mu\text{m}$ . Remarkably a modulation of the waveguides’ effective index by  $\Delta n_{eff} = 0.05$  (2 % relative variation,  $n_{eff} = 1.65$ ) is enough to switch light (Fig. 1, d1). In contrast (Fig. 1, d2), when light is injected into the upper waveguide then no switching is observed : unlike the traditional

couplers, we no longer need to spatially separate the waveguides in order to prevent cross-talk. Therefore we can switch ON and OFF the transitions by making local modulations on the selected waveguides.

If the application of such a control technique in the cases of very small perturbations in two-waveguide systems is quite straightforward [3], its extension to the general cases, and especially to larger arrays, can only be done through the extension of current adiabatic theory into the non-adiabatic regime. Indeed only the latter takes into account the coupling between eigen-modes. In particular, we found that the system must not only be modulated with the right periodicity -that may depend on the modulation strength-, but also obey some symmetry rules regarding the parameters which must be modulated : inter-waveguide coupling vs. effective index.

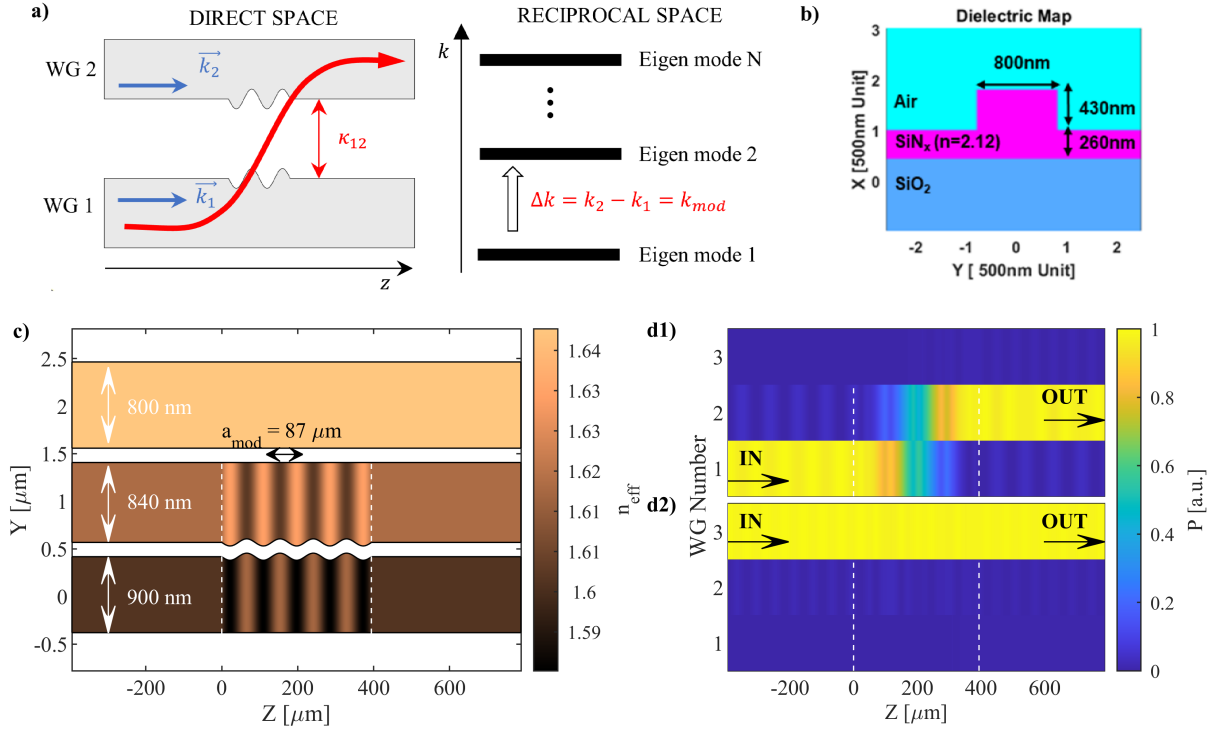


FIGURE 1 : a) Schematic representation of non-adiabatic transfer between two waveguides. b) Side view of the partially etched SiN waveguide whose parameters are further considered for the simulations. c) Geometry of the three-waveguides array in which light transition is enabled only by modulation of the lower waveguide's width. Total width variant is less than 50nm. d) The corresponding power distribution along the propagation direction when light is injected in either the waveguide 1 (upper panel) or 3 (lower panel).

### 3. GENETIC ALGORITHM OPTIMIZATION OF MICRO-PHOTONICS ARRAYS

In order to control a given transition only three free parameters (DoFs) are required : i) the position where modulation must be applied at, ii) the duration (i.e. length) of the modulation, and iii) the modulation's strength. All the other parameters are then set to their optimum by the non-adiabatic theory. In comparison, the brute-force coding of such an elementary operation would require tens of degrees of freedom by itself just to reproduce the modulation accurately. Hence by allowing only useful operations to be performed, we can greatly reduce the number of parameters that must be optimized; and therefore large switch array could be easily optimized. As an example, we have considered an array of 5 waveguides and targeted to make transitions displayed in Fig. 2-a. To optimize the design we have used a genetic algorithm, which is a powerful tool in a system with 'large' number of variables. The total length of the design is fixed to 1500  $\mu\text{m}$  as only weak and pure sinusoidal modulations (i.e. relative change

of parameters by less than 2%) are allowed. Much shorter design would of course be obtained if we relax these constraints. For this test-of-principle demonstration, the total number of Degrees of Freedom (DoFs) to optimize is 15.

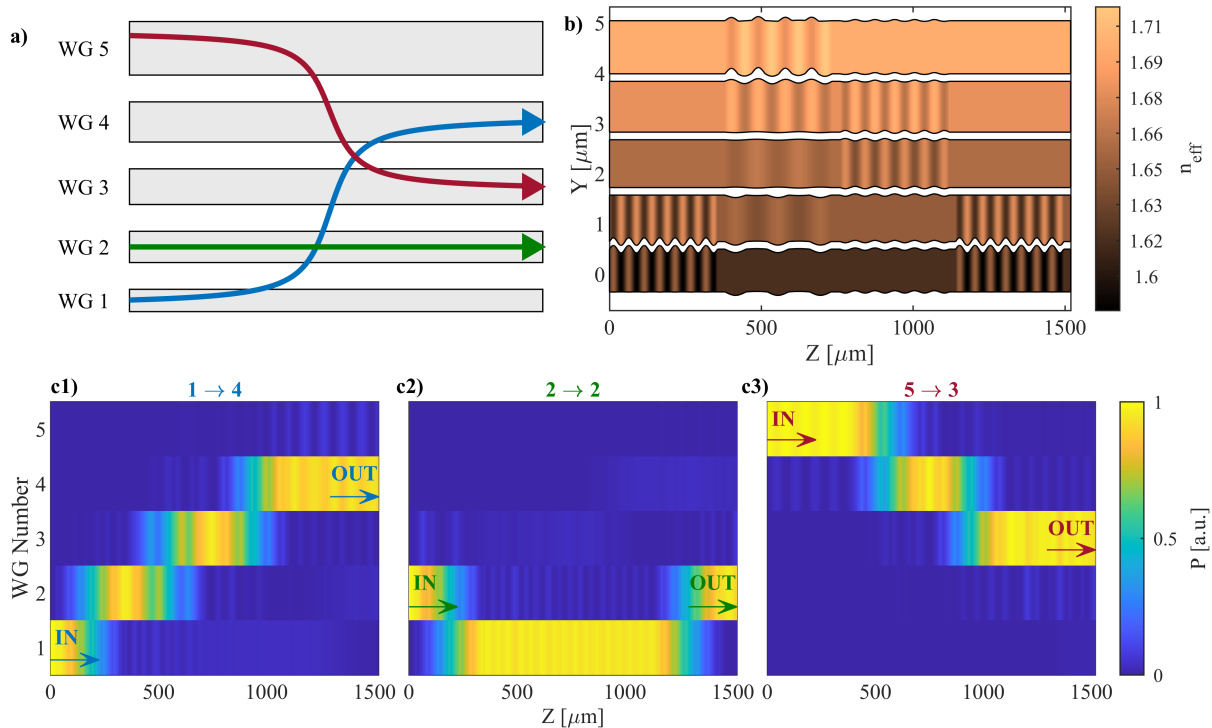


FIGURE 2 : a) Targeted light routing behavior. b) Resulting array geometry after optimization by genetic algorithm. c) Simulation of light propagation in the structure shown in b). Behavior conforms to the targets set in a).

## CONCLUSION

Using an analogy between optics and quantum mechanics we extended the adiabatic theory used to design photonic switches/couplers to the non-adiabatic regime. High selectivity based on spatial frequency matching conditions not only renders this strategy very suitable for control in complex densely packed photonic switches, but also makes it very robust to random perturbations, like fabrication errors. The optimal shape of the periodic perturbation can be approximated at first as a simple sinusoid, but more efficient routing can be obtained if the control method (e.g. nano-fabrication, thermal tuning, etc.) allows for more complex shapes. Finally, the approach we present here can of course be combined with any other (adiabatic) strategies to produce even more advanced - and efficient- solutions.

## RÉFÉRENCES

- [1] Nicholas C. Harris et al, “Linear programmable nanophotonic processors,” *Optica* **5**, 1623-1631 (2018).
- [2] S. Longhi, “Quantum-optical analogies using photonic structures,” *Laser & Photonics Reviews* **3**, 243–261 (2009).
- [3] G. Griffel, M. Itzkovich, and A. A. Hardy, “Coupled mode formulation for directional couplers with longitudinal perturbation,” *IEEE Journal of Quantum Electronics* **27**, 985–994 (1991).