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► To cite this version:

Hassan Oukraou, Laura Vittadello, Virginie Coda, Charles Ciret, Massimo Alonzo, et al.. Quantum-like adiabatic light transfer in photo-induced waveguides with longitudinally varying detuning. Photorefractive Photonics 2017 (PR 17), Jul 2017, Qingdao, China. pp.012024, 10.1088/1742-6596/867/1/012024 . hal-01579537

HAL Id: hal-01579537

<https://hal.science/hal-01579537>

Submitted on 16 Apr 2020

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This summary appeared in
Journal of Physics: Conf. Series 867,
012024 (2017).
doi:10.1088/1742-6596/867/1/012024

Quantum-like adiabatic light transfer in photo-induced waveguides with longitudinally varying detuning

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Abstract. Besides longitudinally varying coupling constants, the longitudinal variation of the propagation constants leads to an additional parameter for the control of adiabatic light transfer in coupled waveguide systems. Examples are given using waveguides structures recorded with the help of the photorefractive effect and mimicking the quantum processes of Rapid Adiabatic Passage (RAP) and two-state STimulated Raman Adiabatic Passage (two-state STIRAP).

1. Introduction

Photorefractive light-induced waveguides are a useful platform for testing of novel functionalities in integrated optics inspired by their analogies with quantum physical processes as well as for the “classical” verification of involved quantum analogies. The latter stem from the fact that waves passing from a waveguide to another via evanescent coupling represent a classical analogous to quantum population dynamics processes between levels being resonantly or non resonantly coupled by an appropriate exciting field [1, 2]. Both processes are described by a Schrödinger-type equation. In this context we use an approach based on lateral illumination of a properly shaped control-light in an electrically biased $\text{Sr}_{0.61}\text{Ba}_{0.39}\text{Nb}_2\text{O}_6$ (SBN) crystal. Our earlier studies concerned structures composed of waveguides with an identical propagation constant β (equivalent to a resonant transfer) and with adiabatically evolving coupling constants between them. For instance, systems mimicking the “STimulated Raman Adiabatic Passage” (STIRAP) in a record multistate system composed of 11 waveguides [3], or systems implementing novel broadband multiple beam splitters were demonstrated experimentally [4]. Here we discuss the role of an additional control parameter, the detuning of the propagation constants (proportional to the effective refractive indices) of the involved waveguides. Introducing an adiabatic evolution of this parameter leads to rich new functionalities. Examples are waveguide structures related to the quantum processes of “Rapid Adiabatic Passage” (RAP) and “Two-state STIRAP” leading respectively to broadband directional couplers and broadband 50:50 beam splitters [5].

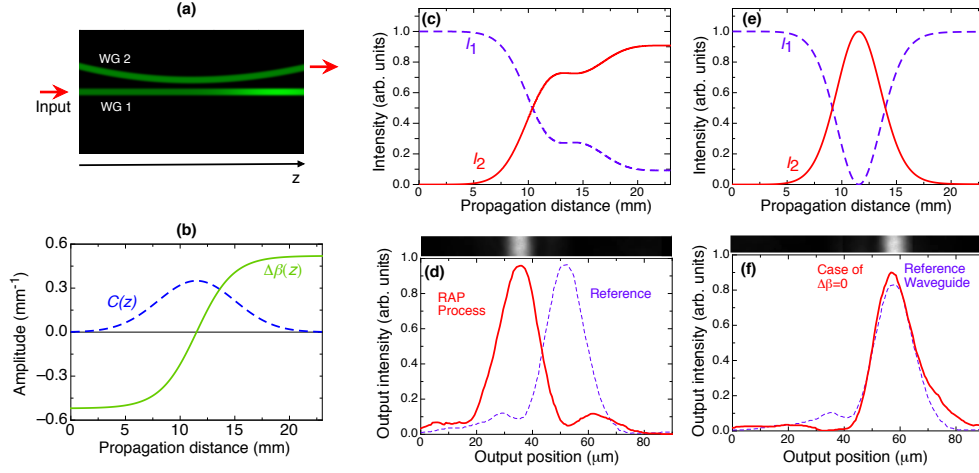


Figure 1. (a) Two-waveguide configuration for RAP-like light transfer; (b) Theoretical spatial evolution of coupling constant $C(z)$ and detuning $\Delta\beta(z)$; (c) Expected intensity evolution in the two waveguides; (d) Experimental output profile, the reference is in absence of WG 2; (e) and (f), same as (c) and (d) but for counterexample with $\Delta\beta(z) = 0$.

2. Example: Light transfer by Rapid Adiabatic Passage

We limit ourselves to a brief description of adiabatic light transfer in a structure that mimics the RAP process in a two-level quantum system [6], where the transition detuning crosses zero while the coupling pulse is applied. RAP leads to a robust and rapid way to adiabatically invert the two-state system. Figure 1(a) illustrates the optical analogous in a two-waveguides system for which the propagation constant β of one of the waveguides varies smoothly and its value crosses the one of the other waveguide at half propagation distance. At the same time the coupling constant C responsible for the evanescent light coupling has a maximum at half propagation (shortest distance between the waveguides) and diminishes towards the two ends (Fig. 1(b)). By integration of the appropriate coupled equations [5], the expected evolution of the light intensity in the two waveguides can be calculated (Fig. 1(c)), leading essentially to a transfer to the second waveguide for a broad wavelength range. Our photorefractive platform for the experimental implementation is described in [3, 4], the transfer to the second waveguide for the propagating wavelength of 633 nm is seen in Fig. 1(d), that shows the light profile at the output of our 23 mm long SBN crystal hosting the waveguides. The reference profile corresponds to the case where only the input waveguide is present. A similar transfer is observed also for propagation at the wavelength of 850 nm in the same waveguide structure, which prove the robustness of the approach. Finally, Fig. 1(e) and Fig. 1(f) show the simulations and results for the counterexample where there is no detuning of the propagation constants ($\Delta\beta = 0$). In this case no RAP-like process occurs and the results strongly depend on the probe wavelength. This proves the essential role played by the detuning $\Delta\beta$ on the RAP-like broadband light transfer.

3. References

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