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Mode-division (de)multiplexing using adiabatic passage and supersymmetric waveguides

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Integrated optical devices exhibiting both high fidelity and high speed transmission are expected to foster novel communication platforms paving the way for scalable photonic quantum technologies. Moreover, the emerging technology of Space-Division Multiplexing [1] has recently attracted a lot of attention due to the increasing demand of high-capacity optical transmissions and the proximity of the capacity crunch, being Mode-Division Multiplexing (MDM) one of the solutions proposed to take profit of the spatial degrees of freedom working with multimode channels. In this context, integrated MDM devices are being developed using many different approaches including Supersymmetric (SUSY) optical devices [2] which are one of the most promising alternatives to standard spatial multiplexing devices offering global phase-matching and efficient mode conversion in an integrated and scalable way. However, the main drawback of SUSY optical devices is their lack of robustness against variations of parameter values such as light's wavelength and their sensitiveness to experimental imperfections. This can be solved making use of Spatial Adiabatic Passage (SAP) techniques which have been proposed and experimentally reported as a high-efficient and robust method to transfer a light beam between the outermost waveguides in a system of three identical evanescently-coupled waveguides [3].

We propose to combine SUSY and SAP techniques to design an efficient and robust device which can be used for multiplexing/demultiplexing spatial modes, to manipulate and study the modal content of an input field distribution or to filter signals and remove non-desired modes [4]. We demonstrate that a system of three coupled waveguides, with two identical step-index external waveguides and a supersymmetric central one, engineered along the propagation direction to optimize SAP for the first excited spatial mode of the step-index waveguides, can be used to demultiplex a superposition of the two lowest (m=0,1) transverse electric TEm spatial modes. Thus, we obtain a great improvement in terms of robustness and efficiency with output fidelities F>0.90 for a broad range of geometrical parameter values and light's wavelengths, reaching F=0.99 for optimized values at the telecom wavelength λ=1.55 μm.

Although we have designed the device to operate at telecom wavelengths, it can be optimized to work at different wavelengths and moreover, due to its high efficiency for a broad wavelength range, it may be used for mode filtering of light pulses and it is fully compatible with wavelength division multiplexing. As a proof of principle, we have focused on the simplest possible case for which only two TE spatial modes can propagate through the step-indexplanar waveguides but this configuration can be generalized to a higher number of TE modes, to transverse magnetic modes or even to orbital angular momentum modes in multimode optical fibers. In addition, the device can be engineered to separate different modes by applying SUSY reiteratively and more complex devices can be constructed in order to demultiplex N spatial modes in an efficient and robust way by coupling in series different devices. Finally, the high obtained fidelities open promising perspectives in the field of quantum integrated photonics to, for instance, prepare and manipulate quantum states with minimal errors or by taking profit of the high dimensional Hilbert space associated to spatial modes.

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