Quantum-analogy-based solutions for robust photonics

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The equations describing the evolution dynamics of coupled few levels quantum systems bear direct analogy with those describing several processes in classical wave optics, including the cases of evanescently coupled waveguides, polarization transformation optics, and nonlinear optical frequency conversion. This allows to exploit the same kind of robust approaches used in the quantum field in order to reach a specific target state in a highly tolerant way. From the practical point of view the tolerance can manifest itself in a strongly extended wavelength range of operation, as well as increased immunity against temperature variations and/or design errors. This talk will summarize some of our recent works in this context. The examples will involve adiabatic approaches for light transfer, mode conversion or broadband polarization selective beam splitting in waveguide optics [1-4], a simple and robust composite optical rotator for polarization optics [5], and composite approaches for broadband nonlinear optical frequency conversion based on segmented crystals [6-8]. In the case of coupled waveguides, in some cases it is possible to test the concepts directly on light-induced waveguide structures written by means of a proper side illumination in a photorefractive material, such as $Sr_xBa_{1-x}Nb_2O_6$.

We will also discuss non-Hermitian systems, involving dissipation, that can be useful for specific purposes. An example concerns classical analogies to three-state (Λ-type) coupled quantum systems with a decaying intermediate state (see Fig. 1a). Here the input population can be represented as a superposition of so called "bright" and "dark" states, with only the dark state surviving the interaction. Such a concept can be applied to a system of three planarly arranged parallel coupled waveguides with dissipation in the intermediate one, leading to ultra-broadband wave splitting in the two external ones (Fig.1b) [9]. The same kind of approach can be linked also to cascaded frequency conversion in nonlinear optics, where a signal wave is partially converted to a target wave through an auxiliary intermediate wave at a lossy wavelength [10]. It is shown that such a system can act as a stable wave splitter between the input and target waves, the latter being nearly immune to power fluctuations of the involved pump waves. In both cases, coupled waveguides and nonlinear optics, the price to pay is a sacrifice of part of the input photons, 50% in the case where an equal splitting ratio is desired.

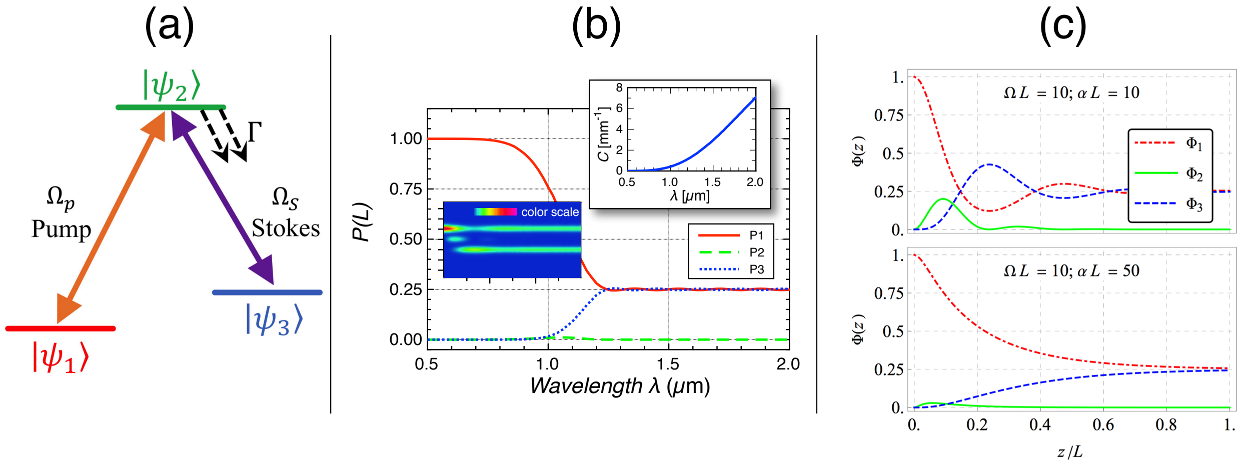

Figure 1: Non-Hermitian quantum system and two analogs in classical optics. (a) Λ-type three-state system with decaying intermediate state (decay rate Γ). Ω_p and Ω_s are the pump and Stokes coupling constants (Rabi frequencies). (b) Wavelength dependence of the output power in a system of three coupled parallel waveguides with dissipation in the central one. In the wavelength range above 1.2 µm the system acts as an ultra-broadband beam splitter with output in the first and third waveguide. The blue inset shows the spatial evolution of the wave in the waveguides (from left to right) simulated by the beam propagation method (BPM) at λ=1.5 µm. The top inset shows the wavelength dependence of the coupling constant C between neighboring waveguides. (adapted from [9]) (c) Cascaded nonlinear conversion (splitting) from an input signal wave (photon flux Φ_1) to a target wave (photon flux Φ_3) through a dissipated intermediate wave (photon flux Φ_2, amplitude absorption constant α). The graphs show the spatial evolution towards the steady-state for two values of the normalized absorption constant. The same final state with 25% of the initial photons in wave 1 and 25% in wave 3 is found in both cases. Here Ω is the effective nonlinear optical coupling coefficient assumed the same for both cascaded processes, for instance sum frequency generation (SFG) followed by difference frequency generation (DFG). Fulfillment of phase matching is assumed for both processes. (adapted from [10]).

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