Continuous supersymmetric transformations in optical waveguides

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Supersymmetry (SUSY), discovered in the 70s and originally developed to unify the mathematical treatment of bosons and fermions, has been extended from non-relativistic Quantum Mechanics to Helmholtz Optics [1]. In the last years, the application of SUSY to optical systems has attracted a lot of attention [2,3], with most of the devices based on evanescently coupling the modes of discrete SUSY structures. Here, instead, we introduce a novel approach, named continuous SUSY transformations [4], which offers a systematic way to engineer efficient and robust photonic devices by modifying the refractive index profile along the propagation direction connecting two superpartner structures (see Fig. 1). In particular, we demonstrate that such transformations provide a systematic way to design efficient and robust tapered waveguides and mode filters by using single-waveguide structures, and beam splitters and Mach-Zehnder Interferometers (MZI) by using two-waveguide structures. Numerically calculated fidelities above 0.999 and above 0.99 are achieved in a broad region of wavelengths for $L > 1.8\,\mathrm{mm}$ tapered waveguides and $L > 6\,\mathrm{mm}$ symmetric beam splitters, respectively. Moreover, we design a single-waveguide mode filter with fidelities above 0.9 and a MZI with a visibility of 98.6%.

Although we apply continuous SUSY transformations to single- and two-waveguide structures, more complex structures could be designed by increasing the number of waveguides, using waveguides with different widths, using optical fibers or combining continuous with discrete SUSY transformations. Such SUSY transformations could be incorporated in the design of novel quantum integrated photonic devices and even extended to other quantum platforms such as in atomtronics.

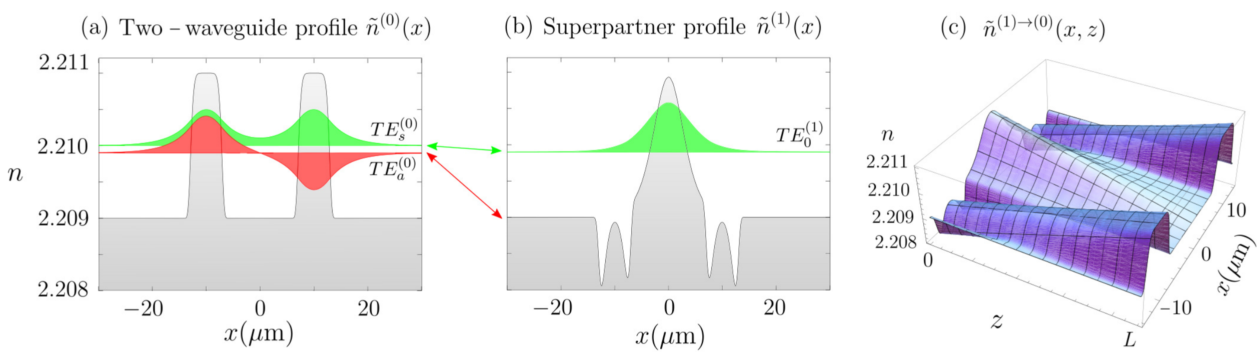

Figure 1: Refractive index profile and transverse mode amplitudes of (a) a two-waveguide super-Gaussian profile $\tilde{n}^{(0)}(x)$ with waveguide width of $8\,\mu$m and waveguide separation of $20\,\mu$m, and (b) its superpartner profile $\tilde{n}^{(1)}(x)$. The positions of the modes along the vertical axis correspond to the propagation constants and the diagonal arrows indicate the evolution of the modes when the index profile is adiabatically modified along the propagation direction. (c) Refractive index profile corresponding to the $\tilde{n}^{(1)\to(0)}(x,z)$ transformation between $0 \leq z \leq L$. This photonic device works as a robust and high-fidelity beam splitter and is at the basis of a MZI [4].

References

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