Modeling Nonlinear Optics with the Transfer Matrix Method

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The Transfer Matrix Method (TMM) is a widely used technique for modeling linear propagation of electromagnetic waves through stratified layered media. However, since its extension to inhomogeneous and nonlinear systems is not straightforward, much more computationally demanding methods such as Finite-difference time-domain (FDTD) or Method of lines (MoL) are typically used. In this work, we extend the TMM framework to incorporate the effects of nonlinearity. We consider the case when strong coupling between excitons (electron-hole pairs) and photons leads to the formation of exciton-polaritons. This extension is crucial for accurately simulating the behavior of light in polariton microcavities, where nonlinearities arising from exciton-exciton interactions play a key role. We perform efficient simulations of light transmission and reflection in a multidimensional system using the plane wave basis. Additionally, we compare our extended TMM approach with the state-of-the-art admittance transfer method, and highlight the computational advantage of extended TMM for large-scale systems. The extended TMM not only provides a robust and computationally efficient numerical framework, but also paves the way for the development of future low-power nonlinear optical devices, polariton-based photonic circuits, and quantum photonic technologies.

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