DOCTORAL THESIS

Mode Coupling in Non-Hermitian Heterostructure

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ABSTRACT

Non-Hermiticity means the system is in interaction with its environment i.e. an open system. The system is, therefore, complex, with many parameters that otherwise out of reach in a closed system. Among these parameters is the ability tune gain or loss. This is ubiquitous in optics. In non-Hermitian coupled systems, the intricate dynamics of mode coupling under various conditions give rise to a host of unique phenomena. In this work, we comprehensively investigated the influence of linear and nonlinear mode coupling in non-Hermitian systems, as well as the temporal interference, elucidating their optical properties.

In the linear regime, theoretical calculations using coupled mode theory (CMT) showing that the coupling characteristics within the heterostructure. For nonlinearity investigation, three types of nonlinearities: Kerr, gain saturation, and optical gradient force, into one of the cavities to break reciprocity. By employing nonlinear coupled mode theory (NCMT), the dynamic processes associated with these nonlinearities were investigated. Our findings showed how these nonlinear mechanisms contribute to nonreciprocal transmission and predict the emergence of optical bistability in the transmittance spectra. In addition, self-phase modulation (SPM) and cross-phase modulation (XPM) within Kerr material is able to induce spontaneous symmetry breaking (SSB) of right- and left- handed circular polarisation (RCP and LCP) light. Furthermore, we constructed temporal gratings by arranging varying numbers of slits in the time domain, which enables the observation of oscillatory patterns in the frequency domain, analogous to spatial optical wave interference.

The following numerical simulations exhibited a high consistency with the theoretical predictions. Moreover, in linear regime, we observed double EPs with

reflection coefficients equal zero for forward incidence. Experimentally, we fabricated the multilayer thin film heterostructure. The linear measurement results supported our theoretical analysis, highlighting the significant role of partition layer thickness in influencing mode coupling. Additionally, in nonlinear measurement, we observed the emergence of a newly orthogonal polarisation component at a wavelength of $653\,\mathrm{nm}$ when the input power exceeds $8\,\mathrm{mW}$, indicating the occurrence of SSB.

Our comprehensive investigation of the optical characteristics of coupled systems under various conditions has significantly enriched the field of non-Hermitian photonics. This research brings new possibilities for advancements in optical sensing, ultrafast optics, and quantum optical devices, while also providing valuable insights for studies of coupled systems in other physical platforms.