Generation of Entangled Photons via Parametric Down-Conversion in Semiconductor Lasers and Integrated Quantum Photonic Systems

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We propose and design a high-brightness, ultracompact electrically pumped GaSb-based laser source of entangled photons generated by mode-matched intracavity parametric down-conversion of lasing modes. To describe the nonlinear mixing in highly dispersive and dissipative waveguides, we develop a nonperturbative quantum theory of parametric down-conversion of waveguide modes which takes into account the effects of modal dispersion, group and phase mismatch, propagation, dissipation, and coupling to noisy reservoirs. We extend our theory to the regime of quantized pump fields with a new approach based on the propagation equation for the state vector, which solves the nonperturbative boundary-value problem of the parametric decay of a quantized single-photon pump mode and can be generalized to include the effects of dissipation and noise. Our formalism is applicable to a wide variety of three-wave mixing propagation problems. It provides convenient analytic expressions for interpreting experimental results and predicting the performance of monolithic quantum photonic systems.

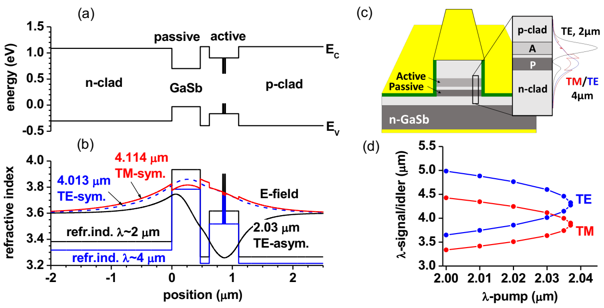

Figure 1: (a) Band diagram of the GaSb-based coupled-waveguide laser heterostructure and (b) refractive index and electric field profiles for the TE-polarized $\lambda = 2.03$ μm asymmetric pump mode (black solid line), TE-polarized $\lambda = 4.013$ μm fundamental signal mode (blue dashed line), and TM-polarized $\lambda = 4.114$ μm fundamental idler mode (red solid line). The passive waveguide width is 470 nm, and the separation barrier between two waveguide cores is 150 nm. The position is along the growth direction. (c) Sketch of a generic laser device with a coupled waveguide for mode-matched Type-II intracavity SPDC of laser photons. The profiles of mode intensities (same as in (b)) are superimposed on the inset. (d) Calculated wavelengths of the signal and idler modes at exact phase matching as a function of the pump mode wavelength

References

[1] M Tokman, Y Wang, Q Chen, L Shterengas and A Belyanin, Phys. Rev. A **105**, 033707 (2022)