Optimization of on-chip photonic structures for a hybrid InP/Si platform via deep learning approach

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The range of desired on-chip photonic components performing particular tasks in integrated circuits based on a single material platform like silicon-on-insulator is broad and often infeasible when it contains a well-defined quantum emitter. However, a heterogeneous integration with other platforms offers to merge both utilities, those which are well known in silicon platform and those which offer efficient light sources at telecom wavelengths. We aim to study numerically the photonic structures realized in InP/Si combined systems such as a ridge waveguide nanobeam cavity, ring resonator, directional coupler, and multimode interference (MMI) beam splitter as vital components for future quantum-integrated photonic chips. We used finite-difference time-domain (FDTD) commercial software to study the photonic device's performance in a broad spectral range within a single-shot simulation. First, we study a ring resonator which can be used as an interference filter for the propagation along the waveguide resulting in a free spectral range of ~50 nm and finesse of 20. Such high performance is found using a specific taper system near the ring structure. Next, using a grating structure design of nanoholes along an InP waveguide, we designed various systems that can enhance the dipole emission by a Purcell factor of 25 and 75 % of bidirectional transmission using only 7 periods of the grating design. It also allows a directional enhanced emission for asymmetric configuration of 10/5 periods resulting in a Purcell factor of 14 and 90 % of transmission within a 5-nm-wide spectral window. Then, we optimized the directional coupler and MMI beam splitter to get the highest transmission and a splitting ratio close to 50 %. Both geometries require specific tapering along the propagation direction for efficient light transfer.

Last, we realized an optimization algorithm for a 1D nanobeam cavity based on deep learning (neural network) [1,2,3] to achieve the optimized transmission along the waveguide from a single dipole source at 1.55 μm photon wavelength. In this step, we used inversed, fully-connected network with 3 hidden layers, which can learn from our 3D FDTD results. The trained network can predict the exact geometry of a photonic system based on spectral data, which serves as an input set of parameters to maximize the device's performance.

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