Machine-Learning-Assisted On-Chip Quantum Photonics: From Emitter Control to Integration

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Abstract

Scalable quantum photonics demands joint optimization of emitters, circuitry, and control under realistic noise and fabrication constraints. Machine learning (ML) provides a unifying framework for navigating high-dimensional photonic design spaces and for forecasting the temporal dynamics that limit coherence. In silicon nitride (SiN)–compatible photonic integrated circuits, generative and surrogate-based inverse design enables rapid co-optimization of waveguides, resonators, and emitter–circuit interfaces, supporting multiplexed architectures and manufacturable layouts. ML also enables anticipatory mitigation of decoherence: models trained on sparse spectral measurements can predict spectral diffusion and dephasing trajectories of solid-state emitters, allowing feed-forward stabilization and improved photon indistinguishability across devices. Complementing these ML-enabled capabilities, adjoint topology optimization of couplers between hexagonal boron nitride (hBN) room-temperature single-photon sources and SiN waveguides enables fabrication-aware, position-robust interfaces that mitigate modal mismatch and achieve high simulated coupling efficiencies. Together, decoherence-aware ML design and prediction, SiN-integrated emitters and circuitry, and robust emitter–waveguide coupling define a coherent path toward stable, scalable quantum photonic systems.

References

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Figures

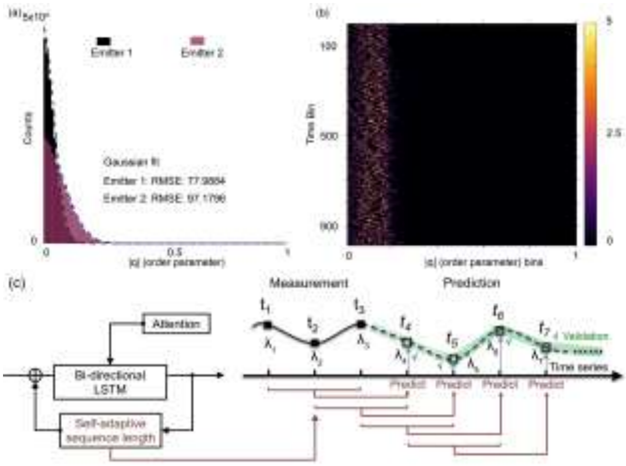

Figure 1: Statistical histograms of two different quantum emitters' decoherence behaviour and anticipatory prediction model architecture.

Figure 2: Topology optimization of the Si_3N_4–hBN hybrid coupler cavity design with different configurations. (c) Evolution of the coupling efficiency (black) and the Purcell factor (gray). (d) Corresponding evolution of the material density distribution inside the optimization area.