Integrating Single-photon Sources On-a-chip

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Abstract— Photonics has been proposed as an excellent platform to realize quantum systems [1]. Using photons that will form the backbone of a future quantum internet, quantum photonic integrated circuits (QPICs) [2] have been already been shown to realize practical and scalable applications in quantum information technologies such as computing [3], communication [4], and sensing [5]. As the non-classical light source for the QPICs, quantum emitters such as semiconductor quantum dots and point defects in crystals and 2-D materials have been attempted to be integrated into on-chip systems [6]. However, efficient integration of these sources with reasonable footprints is yet to be seen. Within this work, we optimize the single-photon emission coupling efficiency of a point defect in a hexagonal boron nitride (hBN) flake into a pre-defined fundamental mode of the silicon nitride (Si_3N_4) waveguide. Specifically, we apply an adjoint TO framework to optimize the SPS coupler to enable high-efficiency emission coupling into the Si_3N_4 waveguide. The proposed design method ensures robustness of the design against perturbations introduced by fabrication and uncertainty of the emitter position inside the hBN flake. Finally, we implement dimensionality reduction analysis on the TO designs, intending to gain an insight into the physics behind the complex geometrical structures that leads to high-efficiency coupling. We demonstrate that such a rigorous analysis of the topology-optimized datasets generates the initial material distribution, equivalent to an "educated guess" obtained with physics-driven human intuition. Using the initial material distribution obtained by this method, we show fully optimized designs with higher efficiencies at lower design time costs compared to direct TO. The proposed approach can output %78 coupling efficiency in a relatively small footprint of $4\,\mu m^2$ with materials platforms that offer very low refractive index contrast such as Si_3N_4 and SiO_2.

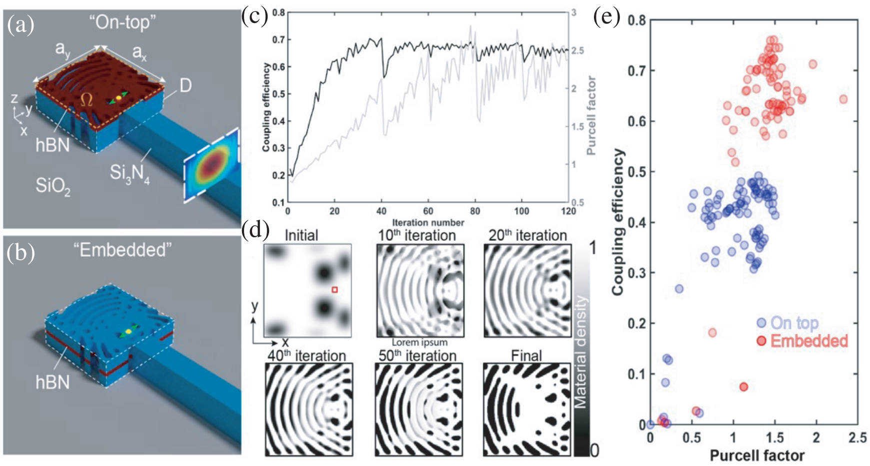

Figure 1: Topology optimization of the Si_3N_4-hBN hybrid coupler cavity. (a)–(b) Schematics of the optimization domain D for "on top" (a) and "embedded" (b) configurations. (c) Evolution of the coupling efficiency (black) and the Purcell factor (gray) during a TO run. (d) Corresponding evolution of the material density distribution inside the optimization area. Position of the SPS is shown with the red marker. (e) Distribution of the efficiencies vs. the Purcell factor for each of the designs for "on top" (blue) and "embedded" (red) configurations.

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