Single-photon collection efficiencies into silicon photonic waveguides for NIR quantum communication sources

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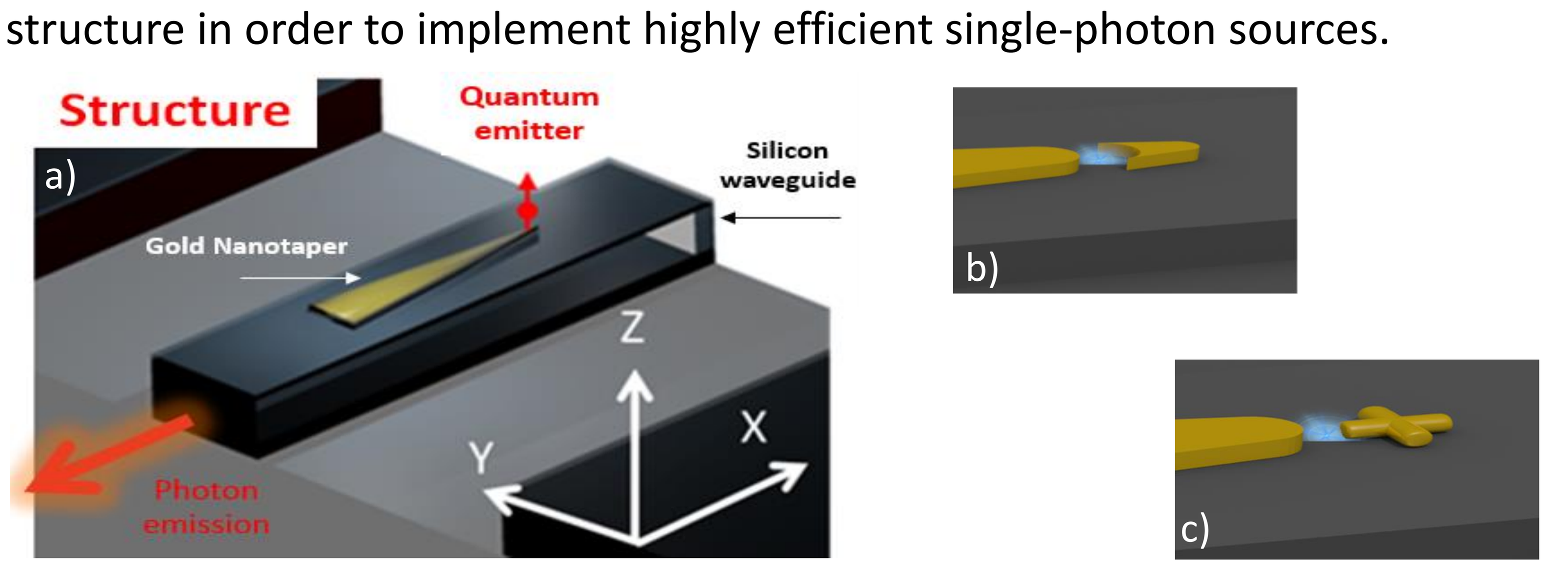
Introduction

Development of efficient single-photon sources based on quantum emitters, requires the enhancement and the effective collection of the radiation emitted by the emitters. Plasmonic waveguides supporting surface plasmon-polariton (SPP) modes provide an effective route to reduce by an order of magnitude the effective mode volume, therefore increasing the emission rate of quantum emitters, while improving collection efficiency as well. Realization of on-chip devices compatible with silicon photonics platform adds a key functionality and provides opportunities for on-chip signal processing, and communications.

Objective

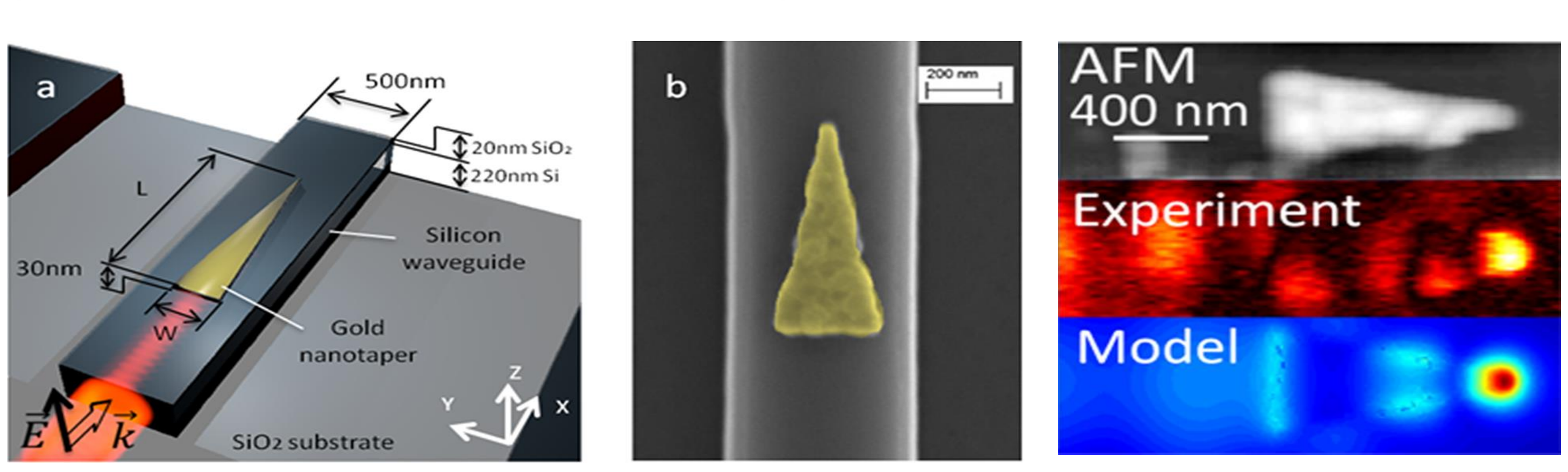
To explore different configurations to achieving efficient coupling between quantum emitters and plasmonic modes supported by integrated plasmonic structure in order to implement highly efficient single-photon sources.



a) Main structure proposed to enhance the spontaneous emission of PbS quantum dots. b) Gold parabolic bar placed ahead the nanotaper tip. c) Gold cross ahead nanotaper tip.

Background

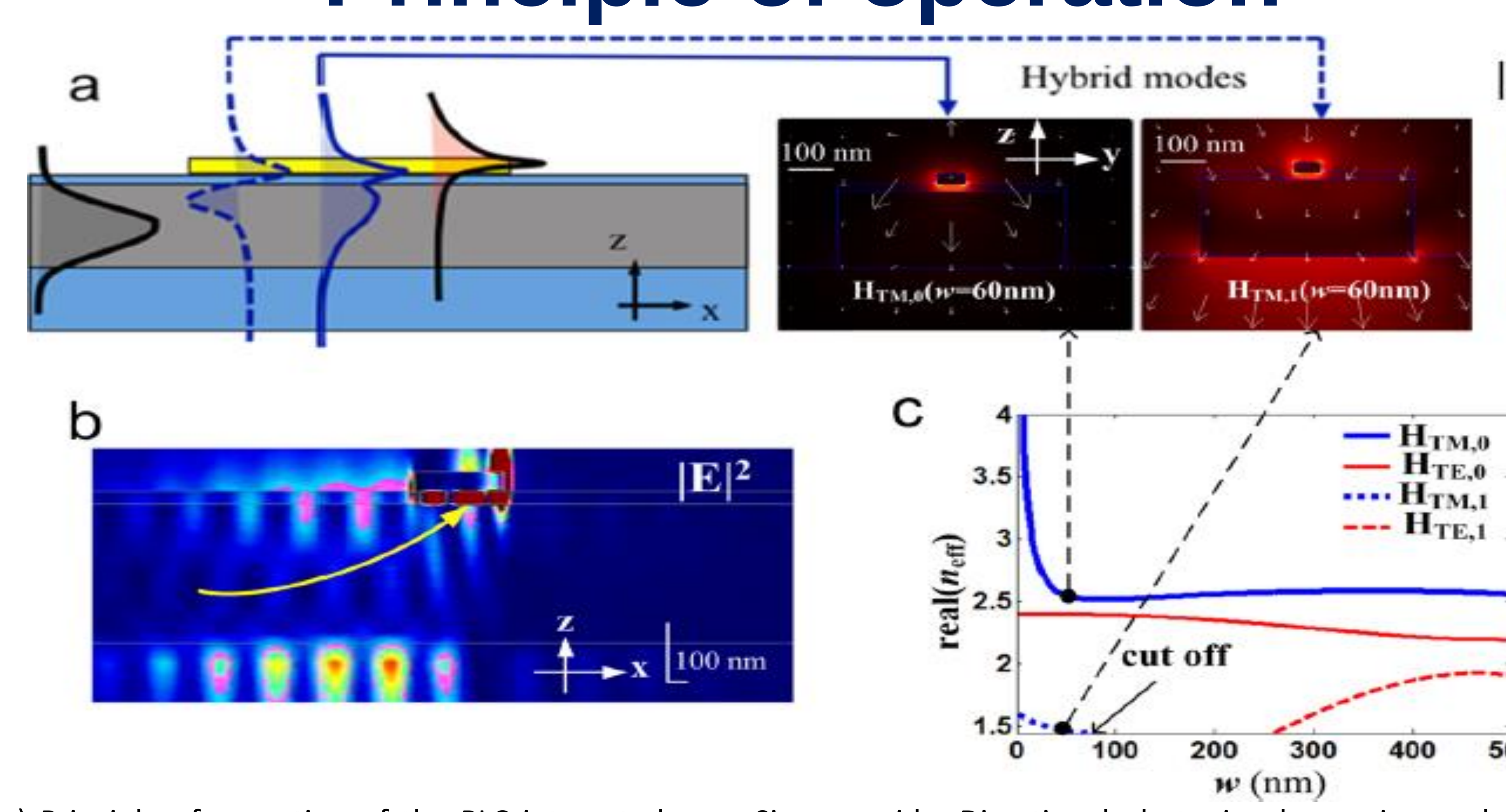
We recently reported the design, implementation, and experimental demonstration of efficient light nanofocusing in an on-chip hybrid photonic−plasmonic light concentrator (PLC) vertically integrated on a Si waveguide [1]. The vertical integration of the PLC with the photonic waveguiding structure is compatible with the dense integration of different photonic and plasmonic functionalities on the same chip.



(a) The hybrid PLC consists of a gold isosceles triangle of 300 nm base width and 750 nm length placed on top of a 500 nm by 220 nm Si waveguide with a 20 nm thick SiO2 buffer layer. The PLC tip has radius of curvature of 20−30 nm. (b) Scanning electron micrograph (SEM) of a fabricated structure.

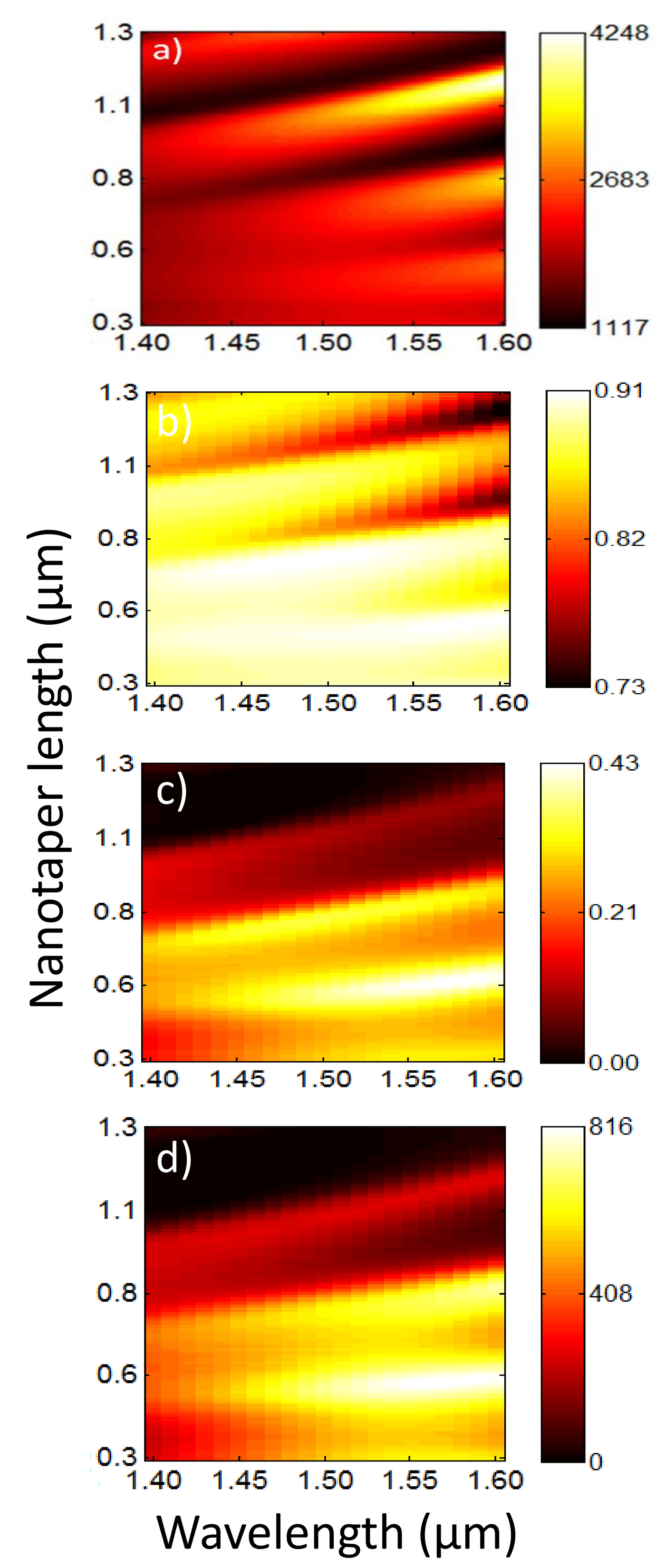
To characterize the performance of the hybrid photonic−plasmonic device for the focusing of light at nanoscale, we used a near-field scanning optical microscope (NSOM). Both characterizations were performed on our device: (1) measurement of the near-field pattern around plasmonic nanotaper of the PLC, and (2) experimental mode analysis of the photonic modes in the regions of the bare waveguide before and after the plasmonic nanotaper region.

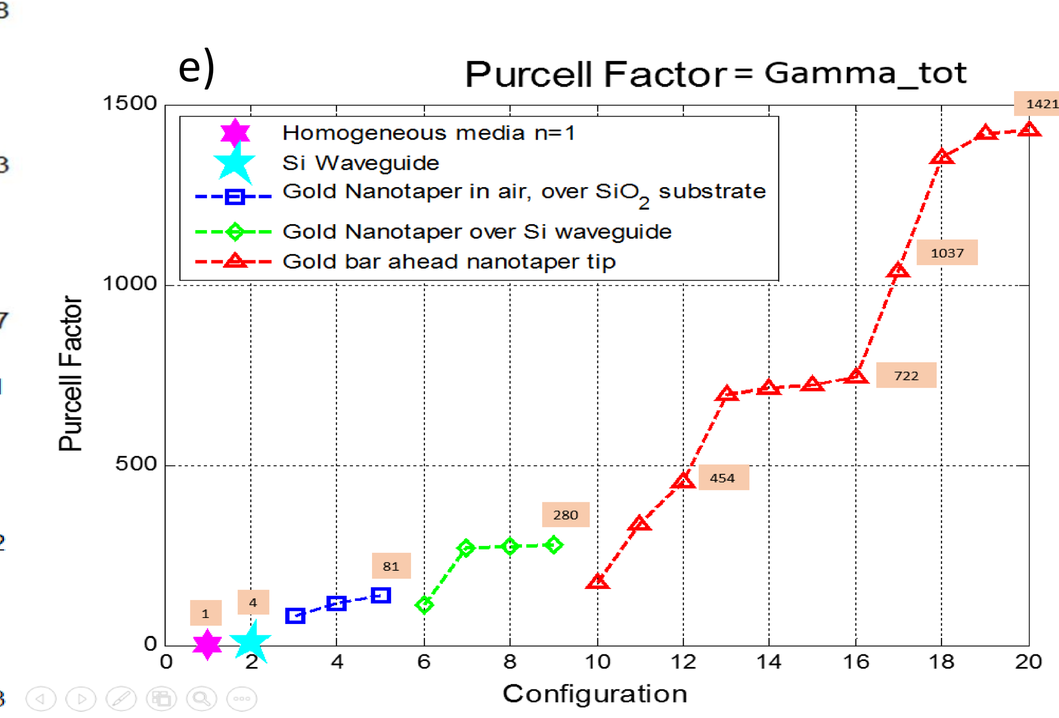
Principle of operation

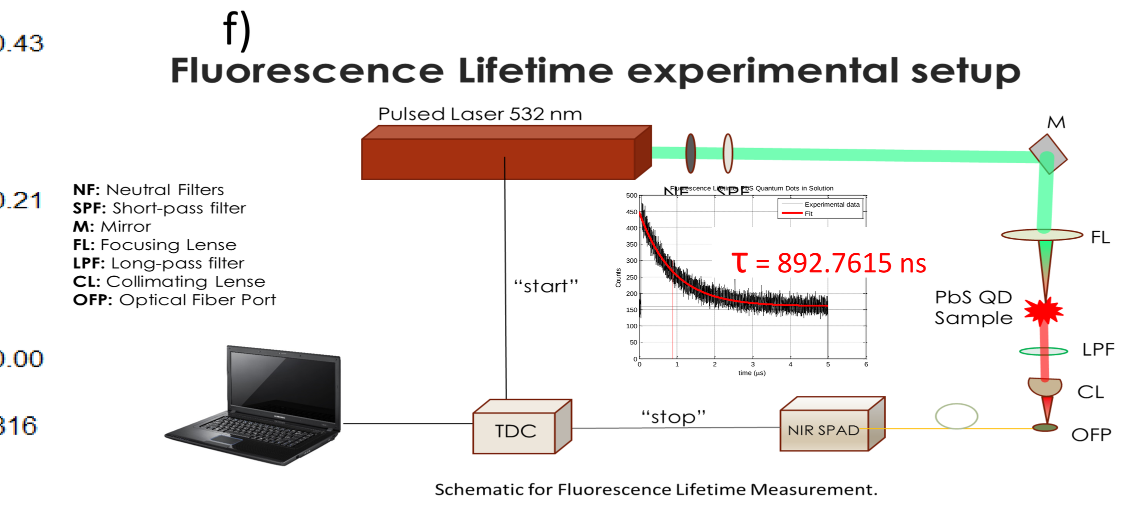


(a) Principle of operation of the PLC integrated on a Si waveguide. Directional photonic−plasmonic coupler in the plane x−z at y = 0. The normalized electric field profiles for the asymmetric $H_{TM,0}$ and the symmetric $H_{TM,1}$ modes in the transversal plane y−z for w = 60 nm calculated at λ = 1550 nm. (b) Snapshot of a time-domain light propagation using in the longitudinal plane x−z at y = 0. The yellow arrow is a guide for visualizing the energy transfer from the dielectric waveguide into the apex of the nanotaper. (c) Modal analysis of the vertical plasmonic−photonic coupler. Mode effective indices of the TM-like ($H_{TM,0}$ and $H_{TM,1}$) and TE-like ($H_{TE,0}$ and $H_{TE,1}$) modes (blue and red curves, respectively), as a function of the width w of the corresponding gold strip.

Parametric Study and Results







Simulations for the quantum-plasmonic single-photon source integrated on silicon photonics. a) Purcell factor, b) Quantum efficiency, c) Single-photon collection efficiency and d) Figure of Merit: a*b*c; for a quantum emitter placed 15 nm above the surface of the Si waveguide, 10 nm in front of the gold nanotaper tip, and oriented along the x-axis. e) Comparison of Purcell Factor for different environments. f) Fluorescence lifetime setup and results for the PbS quantum dots in solution.

Conclusions

Recent simulations show that the efficient light nanofocusing in an on-chip hybrid PLC, vertically integrated on a Si waveguide could successfully be used as a highly efficient single-photon source. Several geometries were explored and a complete parametric study was carried on, showing that the Purcell effect grows with the complexity of structures, the polarization and the position of the emitter along X axis. Achieving up to 800 times enhancement into the TEM coupled mode of the Si waveguide. SNOM measurements and experimental demonstration are in progress.

References

[1] Luo, Y., Chamanzar, M., Apuzzo, A., Salas-Montiel, R., Nguyen, K. N., Blaize, S., & Adibi, A. (2015). On-chip hybrid photonic-plasmonic light concentrator for nanofocusing in an integrated silicon photonics platform. Nano Letters, 15(2), 849–56.

Acknowledgements

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