Strain-tunable quantum integrated photonics

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Keywords: nanowires, strain tuning, quantum dot, quantum integrated photonics, ring resonator, single photon

Supplementary Information

S1. Efficiency estimation

In the presented work the aim is to realize a novel strain-tuneable quantum photonic circuit combining different materials in a single platform. The design was not optimized to achieve the highest coupling efficiency between the nanowire quantum dot and the waveguide, and the highest off-chip coupling. In this proof of concept, the team relied on butt coupling of the quantum emitter, since the nanowire can be simply transferred to the piezoelectric circuit after integration of the waveguides. The drawback of this approach is that the coupling efficiency is low compared to encapsulating the nanowire. To estimate the efficiency, scanning electron microscope images were taken for the coupler region with measurements of the distance between the nanowire and the coupler, as well as the misalignment between the two. We performed FDTD simulation to calculate the efficiency of coupling. Figure S-1 shows a top schematic of the 3D simulated device (left), and coupling efficiency as a function of the distance and misalignment (right). We estimate the coupling efficiency to be approximately 1% including the loss of TM photons emitted from the quantum dot, not supported in the presented geometry. This efficiency is not a fundamental limit in the platform, we have recently demonstrated 24% experimental coupling efficiency of quantum emitter to single mode silicon nitride waveguides, with close to 90% coupling efficiency using optimized waveguide design and material choice[1].

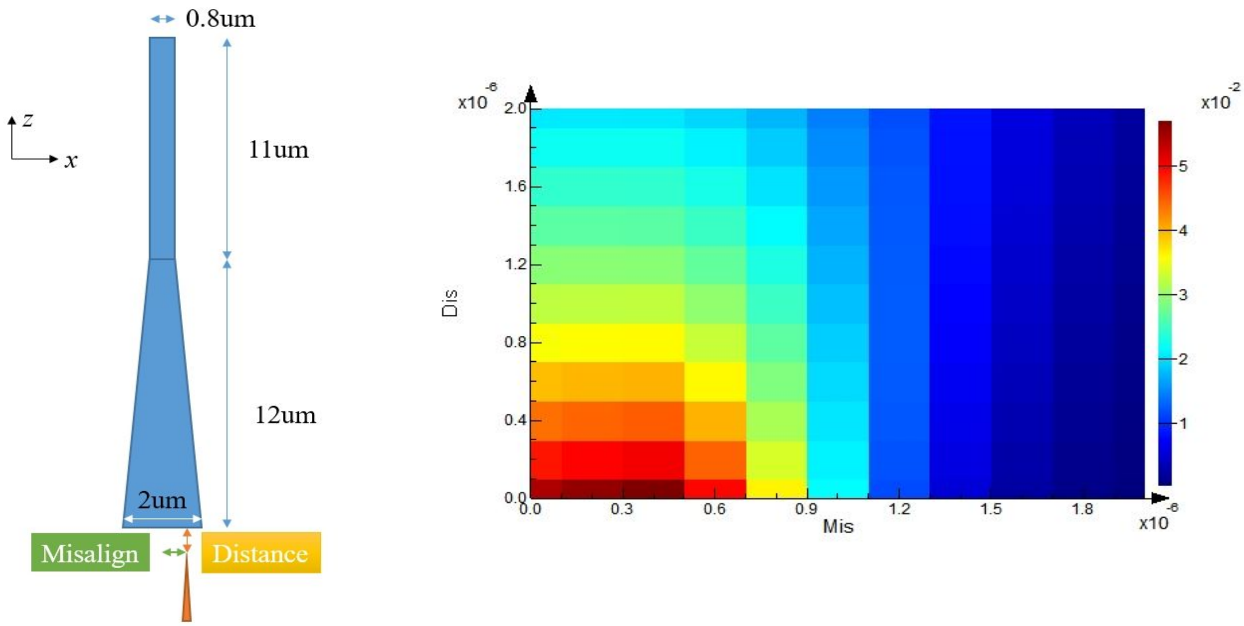

Figure S-1 Coupling efficiency VS misalignment and distance between of the nanowire.

To calculate the efficiency of the spectrometer and CCD system after the input slit, we couple 2.08 μW of laser with ND filter (68.71) to the spectrometer. The number of integrated counts on the CCD was measured and compared to the number of the photons in the laser pulse. From the measurement we estimate the detection efficiency after the slit to be 6.6%.

We also estimate the coupling efficiency between the tapered optical fiber and the silicon nitride waveguide. The tapered fiber is single mode at 840 nm with 5/125um core to cladding ratio and NA of 0.25. The fiber provides a focusing spot of size 2.9 μm at working distance of 13um. In the circuit, the silicon nitride waveguide has dimensions of 800 nm X 200 nm at the facet. The overlap integral between the focused light from the fiber and the fundamental TE mode in the waveguide was calculated to be ~5%, the modes are shown in Figure S-2. Note that with proper design of an adiabatic inverse taper, this value can be higher by at least and order of magnitude[2].

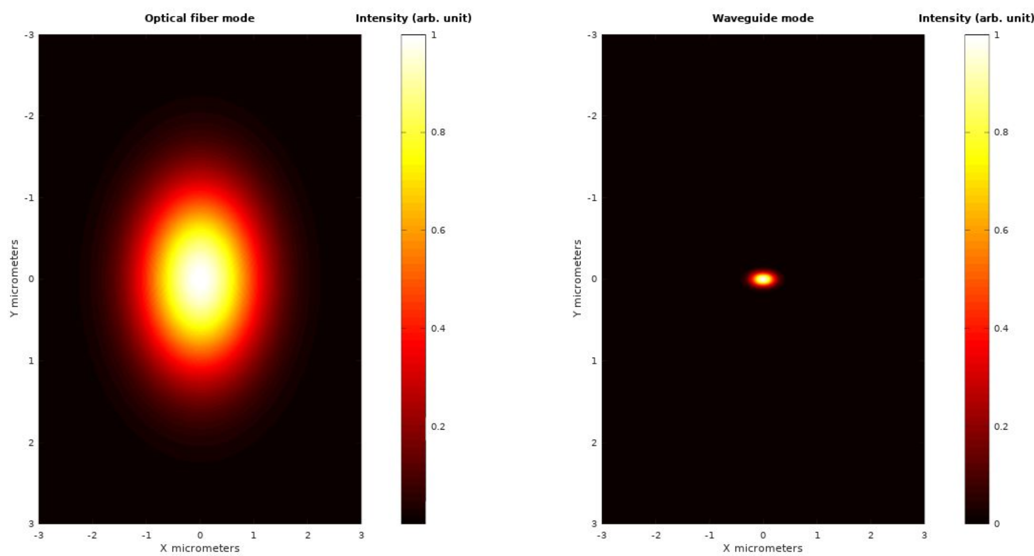

Figure S-2 Mode size of comparison between the fiber spot and the SiN waveguide.

S2. Additional data

Here we provide data for another nanowire integrated with a silicon nitride waveguide on a PMNPT crystal, as shown in Figure S-3.

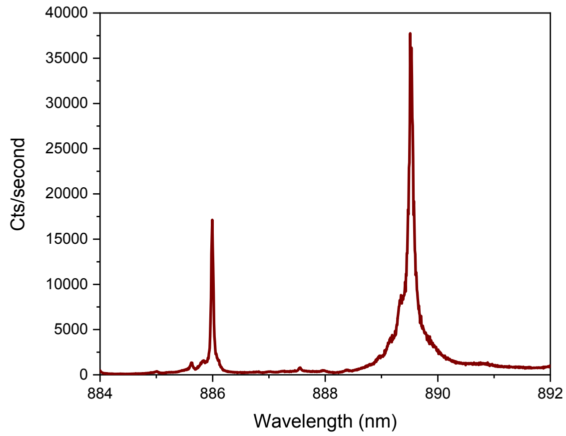

Figure S-3 Emission spectrum of nanowire quantum dot coupled to photonic waveguide fabricated on piezoelectric crystal

The nanowire was tuned using strain as shown in Figure S-4, with tuning rates of 0.179 pm/V and 1.13 pm/V, before and after the cladding, respectively. We measure an increase in the strain transfer by a factor of > 6, a larger increase compared to the nanowire in the main manuscript, but with overall less tuning range of 1.35 nm (voltage tuned between -600V and 600V).

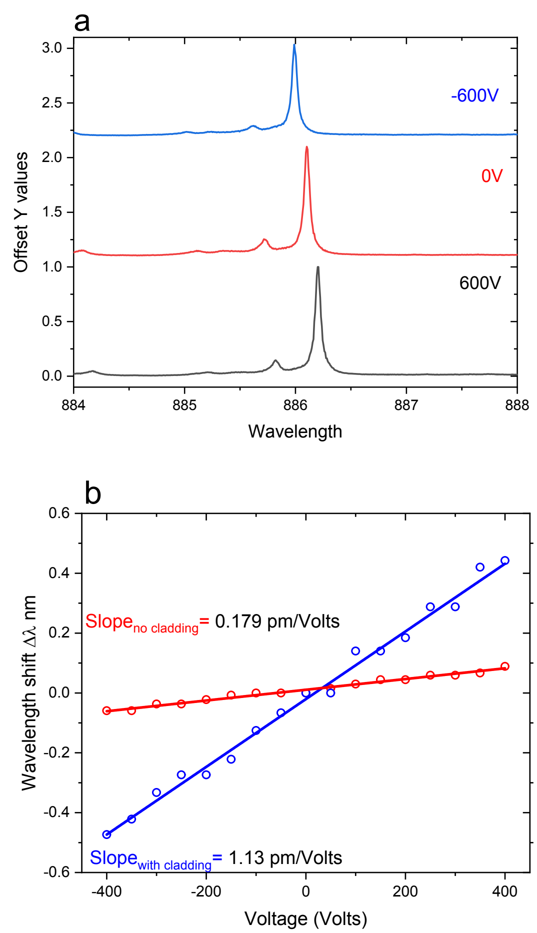

Figure S-4 (a) Tuning of nanowire quantum dot coupled to photonic waveguide. (b) Tuning comparison before (red circles and red line fit) and after (blue circles and blue line fit) after cladding with silicon nitride and silicon oxide

References

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(2) Almeida, V. R.; Panepucci, R. R.; Lipson, M. Opt. Lett. 2003, 28, (15), 1302-1304.