SiN/ GaAs quantum photonic platform with efficient fiber-coupling

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Abstract: High demands on quantum photonic experiments necessitate full integration of its building blocks. We integrated GaAs nanobeams embedded with InAs quantum dots on SiN as well as SU8 spot size convertors for efficient fiber coupling.

1. Main text

The uTP4Q project aims to develop a fully integrated quantum photonic platform on a SiN interposer to target quantum communication applications with very high demands on photon loss. For a single-photon source, InAs quantum dots embedded in GaAs nanobeam waveguides are integrated using micro-transfer printing. On its native platform [1], these sources have shown $> 99\%$ purity and $> 96\%$ coherence for single photons at a wavelength of 930 - 950 nm but they suffer from significant scattering losses on the order of 7 dB/ mm during propagation. This illustrates the motivation for integration on the ultra-low loss SiN. Here, we report on the successful integration and first characterization of quantum dot emission. After electron beam lithography (EBL) and reactive ion etching (RIE), patterned GaAs devices were encapsulated in photoresist 'coupons' with tethers anchored to the GaAs substrate. After HCl underetching, the sacrificial AlGaAs layer was removed and freestanding coupons were heterogeneously integrated on a SiN target using a commercial micro-transfer printing tool. The sample was then mounted in a 10 K cryostat and addressed through a microscope objective. In this way, quantum dots are excited using quasi-resonant excitation and their photoluminescence is collected from the GaAs grating coupler. The collected light is characterized in a Hanburry-Brown and Twiss (HBT) experiment and a preliminary antibunching dip is shown in Fig. 1(b).

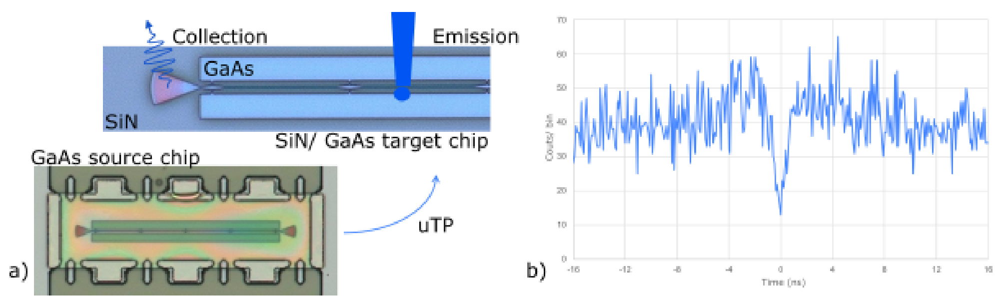

Fig. 1: (a) Microscope pictures of the GaAs device before and after micro-transfer printing. (b) Antibunching dip observed in the HBT experiment

After adiabatically coupling the light into SiN waveguides, SiN grating couplers could be used for fiber coupling. Unfortunately, these are expected to be rather inefficient because of their low index.

Furthermore, the required microscope objective and beam splitters are also expected to be a significant source of photon loss. Horizontal fiber coupling inside the cryostat is expected to greatly enhance the outcoupled photon numbers. While a typical 780HP fiber has a mean field diameter (MFD) of around 5 microns, lensed fibers were used in this work because of their reduced 2 µm spot size. To overcome the modal mismatch with a 300 nm thick SiN waveguide, SU8 spot size convertors were developed. SU8 is an ideal candidate material because of its wide transparency window above 450 nm and easy back-end patterning using only lithographic processes, allowing for high aspect ratio geometries. A square waveguide with 2.5 µm at the side was used to optimize the modal overlap with a 2 µm Gaussian beam, achieving up to 96 % overlap. Additionally, 5% Fresnel reflections are expected at the facet without using adhesive between fiber tip and SU8 waveguide. For the adiabatic mode transfer into the SiN waveguide, a mode coupler is designed. A stepwise linear profile is developed to allow for robustness against realistic fabrication errors, such as a lateral misalignment up to 750 nm from UV lithography and a waveguide width deviation of up to 30 nm from EBL.

The resulting design was found to accommodate $> 80\%$ transmission within the fabrication constraints as shown in Figure 2(a). Lastly, a SU8 slanted edge was used to reduce reflections from the SU8 waveguide end.

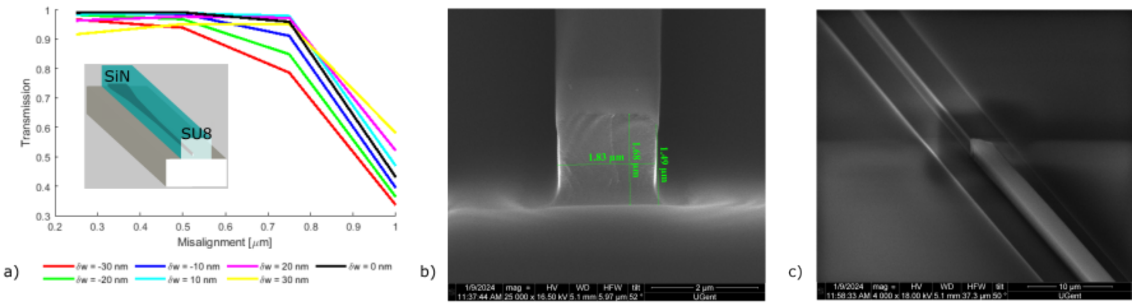

Fig. 2: (a) Simulated transmission of the SiN mode coupler for different width variations δw as a function of misalignment. Inset: Mode coupler visualization (b,c) SEM images of the SU8 waveguide

LPCVD SiN was used and patterned using EBL and RIE. SU8 was spin coated on top and patterned using UV lithography. After exposure, the sample is baked to crosslink the SU8 material. After development, the chip is cured at 150 degrees to further crosslink the material. The chip is then cleaved to achieve smooth SU8 facets. In an optimized room temperature setup, 4 (+- 0.5) dB coupling losses were found fiber-to-fiber across the SiN sample. When mounted inside our cryostat for proof-of-concept experiments, the setup imperfections caused for 6.6 (+- 1.3) dB of optical losses at room temperature. After cooling down the chamber to 7 K, 6.2 (+- 1.3) dB coupling was retrieved to validate its low temperature performance.

2. Conclusion

A GaAs/ SiN platform has been developed in which the photoluminescence of the embedded InP quantum dots has been characterized. On the same platform, SU8 spot size convertors have been realized that perform well at cryogenic temperatures. We believe these basic building blocks will be essential in a future completely integrated quantum photonic circuit.
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