Waveguide-coupled Localized Excitons From an Atomic Monolayer Integrated on a Silicon Nitride Photonic Platform

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ABSTRACT

Monolayers of transition metal dichalcogenides (TMDCs) have attracted much attention since the discovery of single photon emission due to localized exciton formation. The possibility to integrate these materials directly on photonic integrated circuits makes them an interesting candidate for realizing quantum photonic devices. Here, we demonstrate the coupling of localized excitons from a tungsten diselenide (WSe_2) monolayer into a silicon nitride waveguide by measuring the waveguide-coupled fluorescence from the WSe_2. This result could pave the way towards scalable fabrication of on-chip single photon sources.

Keywords: Quantum photonics, 2D transition metal dichalcogenides (TMDCs), silicon nitride, single photon sources.

1 INTRODUCTION

Since the discovery of deterministically created quantum light emitters in atomically thin layers of transition metal dichalcogenides (TMDCs), there has been a booming interest in 2D material based single photon sources. By transferring the TMDC onto a nanopillar, one can create localized deformations that enable quantum confinement of excitons [1], [2]. Combining such strain-induced quantum emitters with photonic integrated circuits (PICs) provides a promising approach towards fully scalable optical quantum circuits because photons in a PIC can be routed in low-loss single mode waveguides, and the use of PICs moreover allows integration of several photonic functionalities on a single chip, including photonic cavities, filters and waveguides [3]. Here we report direct integration of a WSe_2 monolayer on top of a silicon nitride (SiN) photonic waveguide. The majority of 2D-based single photon sources emits in the visible (500-800 nm), so SiN is chosen as photonic platform because of it's transparency in this wavelength region. Our approach allows easy integration with existing PICs, as well as electrical contacting. We demonstrate the coupling of localized excitons from a WSe_2 monolayer and a SiN waveguide by measuring the waveguide-coupled fluorescence. This result could pave the way towards scalable fabrication of on-chip single photon sources.

2 EXPERIMENTAL SETUP AND RESULTS

A commercially available GelPak stamp is used for the dry transfer of a monolayer WSe_2 flake onto a single mode SiN waveguide, with a height of $\approx$ 220 nm and width of $\approx$ 700 nm (see left inset image in Figure 1(a)). Localized emitters created in the WSe_2 will predominantly have a dipole moment $\mathbf{d}$ in the plane of the monolayer, which makes integration on top of the waveguide interesting since the coupling of the dipole with the electric field of the TE-mode ($\mathbf{E}_{TE}$) scales with $\mathbf{d} \cdot \mathbf{E}_{TE}$. As such this geometry provides, by fabrication, a natural route for improved single photon extraction into the guided mode of the waveguide.

The sample is cooled to 4.5K in an optical cryostat and confocally excited by a green laser (λ =532 nm) through the top window (see Figure 1(a)). The excitation beam is scanned over the sample area by 2 galvo mirrors in front of the objective. While the beam is scanning the sample area, the 2D material will emit fluorescence, both to free space as well as to the waveguide. The free space fluorescence is collected in a confocal way (passing through the dichroic mirror) while the waveguide-coupled fluorescence is captured using an edge-coupled lensed fiber. An XYZ piezo stage is used for accurate positioning of the fiber. In both cases, the signal can be coupled to an APD or spectrometer. The right inset of Figure 1(a) shows an image obtained by scanning the beam over the chip and collecting the scattered laser light. When zooming in near the waveguide (red-dashed area) and collecting the photoluminescence (PL) obtained by scanning the excitation beam over the sample, one obtains the maps shown in Figure 1(b). The left map shows the confocally collected PL while the right map shows fiber-collected PL. For the fiber-collected PL we indeed see that only when the flake is sufficiently close to the waveguide, the PL is coupled to the fiber.

Subsequently we fix the excitation beam to a position on the waveguide and collect the PL spectrum from that spot. The spectrum collected from the top (green curve Figure 1(c)) shows the neutral exciton peak around

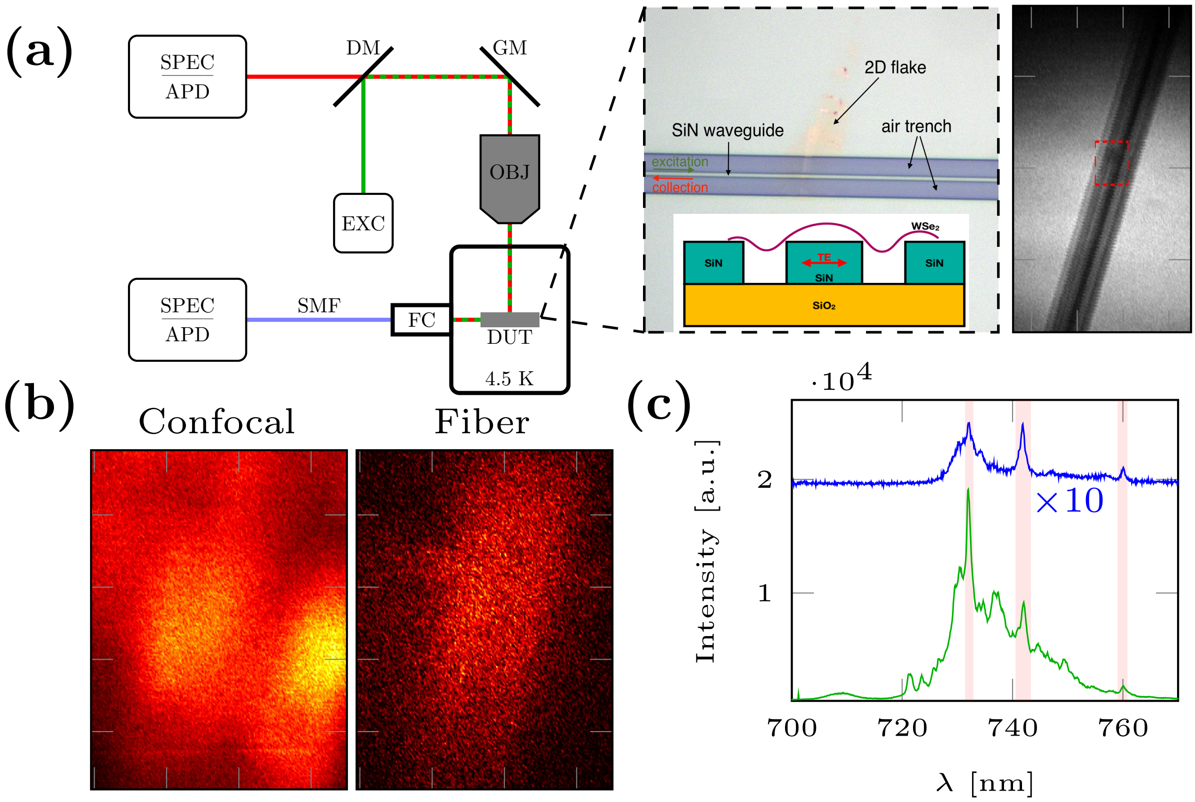

Figure 1. Integration of WSe_2 on SiN waveguides. **(a)** Experimental setup. DUT: Device under test mounted in 4.5K Montana cryostat. FC: fiber coupling unit (the fiber is mounted on an XYZ piezo in the cryostat). SMF: Single mode fiber. SPEC: Spectrometer. APD: Avalanche Photodiode. EXC: excitation laser (532 nm). OBJ: Objective (NA=0.55). GM: Galvo Mirror. DM: Dichroic Mirror. Left inset: microscope view of the flake and SiN waveguide; bottom: schematic cross-section showing the polarization direction of the TE-mode. Right inset: laser scanning image. **(b)** Confocally collected PL (left) and fiber-collected PL (right) image of the red-dashed area of Figure 1(a). **(c)** Confocal PL spectrum (green, integration time: 10 sec) and fiber PL spectrum (blue, integration time: 60 sec), generated by confocal excitation (50μW). The fiber PL spectrum was offset by a fixed amount and multiplied by 10 for improved visualization.

710 nm as well as a broad defect band extending to about 770 nm. Several narrower lines pop up in this defect band and it is expected that the strain caused by transferring the material over the waveguide creates these localized exciton peaks, similar to earlier reports of 2D materials on top of nanopillars [1], [2]. Some of the localized exciton peaks (shaded red areas) are also coupled to the waveguide mode as evidenced by the spectrum collected through the fiber (blue curve Figure 1(c)). A mismatch between the dipole moment of the emitter and the waveguide mode could be a potential reason why not all peaks show up in the waveguide-collected spectrum. Such a mismatch can significantly reduce the coupling rate ($\propto \mathbf{d} \cdot \mathbf{E}_{TE}$) between the emitter and the waveguide. When we slightly misalign the fiber with respect to the waveguide, the fiber-coupled PL spectrum disappears, signaling that we are indeed collecting PL that is coupled to the guided mode of the waveguide. Further improvements to the fiber collection and stability of the fiber-coupling should allow us to use a much lower excitation power in order to get a reduced power-broadening of the localized exciton lines. Optimized waveguide designs could also significantly increase the waveguide coupling efficiency as shown in [4]. Moreover, we aim to further reduce the linewidth by encapsulating the 2D-material in a hexagonal boron nitride matrix.

3 CONCLUSION

We have experimentally demonstrated the coupling of localized exciton peaks to the guided mode of a SiN waveguide by transferring a WSe_2 monolayer on top of the waveguide and measuring the waveguide-coupled fluorescence spectrum. Currently we are working on improving the coupling efficiency between the localized emitters and the waveguide, tuning the localized exciton lines and scaling up our approach to multiple waveguide-emitter systems. This could ultimately enable a scalable approach towards electrically tunable single photon sources which can be readily integrated with a CMOS-compatible photonic chip.

ACKNOWLEDGMENT

F.P. acknowledges support from an FWO (Fonds Wetenschappelijk Onderzoek) postdoctoral fellowship. D.E. and F.P. acknowledge partial support from the Army Research Laboratory Center for Distributed Quantum Information (CDQI) and the NSF EFRI-ACQUIRE program ”Scalable Quantum Communications with Error-Corrected Semiconductor Qubits.” We also acknowledge Liesbet Van Landschoot for performing the e-beam lithography of the SiN chips.

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