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Guided exciton-polaritons in a subwavelength dielectric slab integrated with a 2D semiconductor

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Abstract. New-generation nonlinear planar polaritonic devices based on 2D semiconductors demonstrate great potential for a wide range of practical applications. In this work, we experimentally study strong light–matter coupling between waveguide photons and excitons in a photonic system based on dielectric slab waveguides integrated with 2D transition metal dichalcogenides.

1. Introduction

One of the challenges facing the field of nanophotonics and nanoelectronics is the development of on-chip active photonic devices, where light can be controlled by light of very weak intensity. A possible solution could be a polaritonic system, where efficient photon-photon interactions at low intensities could be achieved via strong photon-exciton coupling, resulting in the emergence of new quasiparticles, so-called exciton-polaritons. Strong light-mater coupling has been demonstrated in different designs of photonic structures based on III – V semiconductors. In particular, these types of semiconductor structures have been used to demonstrate several interesting nonlinear optical effects associated with exciton-polaritons, such as waveguide polariton lasers [1], parametric effects [2], and polariton solitons [3, 4].

Along with the study of polaritonic systems where III–V materials are used as an active medium, two-dimensional transition metal dichalcogenides (TMDs) attract the attention of the scientific community because excitons in these monolayer semiconductors have large oscillator strengths and binding energies, which makes them an excellent active medium for new polariton systems, with possibilities of room temperature operation [5].

In this work, we demonstrate strong light–matter coupling between waveguide modes and excitons in a photonic system based on slab dielectric waveguides with embedded TMD monolayers as an active medium with high optical nonlinearity.

2. Result and discussion

To realize the proposed polaritonic system, we chose an unpatterned Ta_2O_5 waveguide on a SiO_2 sublayer, where light is coupled in/out through grating couplers. After preliminary characterization of the waveguide transmission, the WSe_2 monolayer, which was fabricated by mechanical exfoliation from a commercial bulk crystal from HQ Graphene, was transferred onto the waveguide surface between the grating couplers (Fig.1).

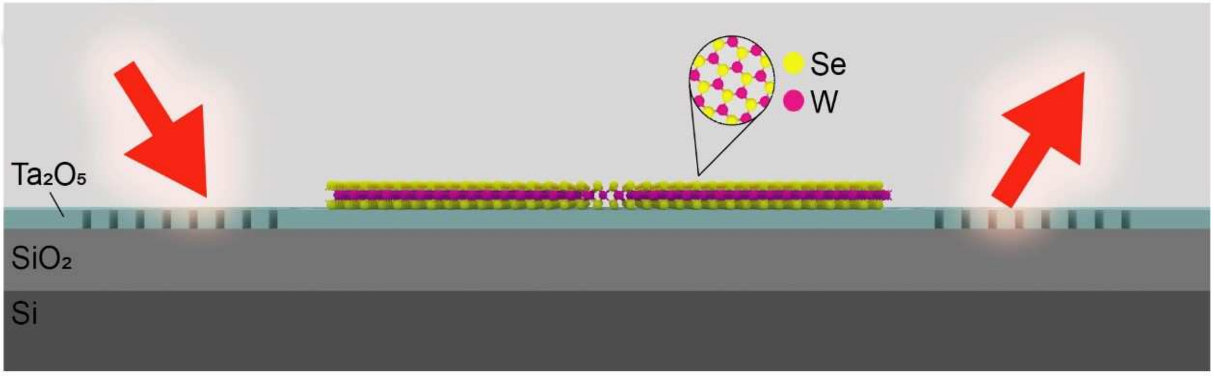

Figure 1. Schematic diagram of a waveguide integrated with a WSe_2 monolayer.

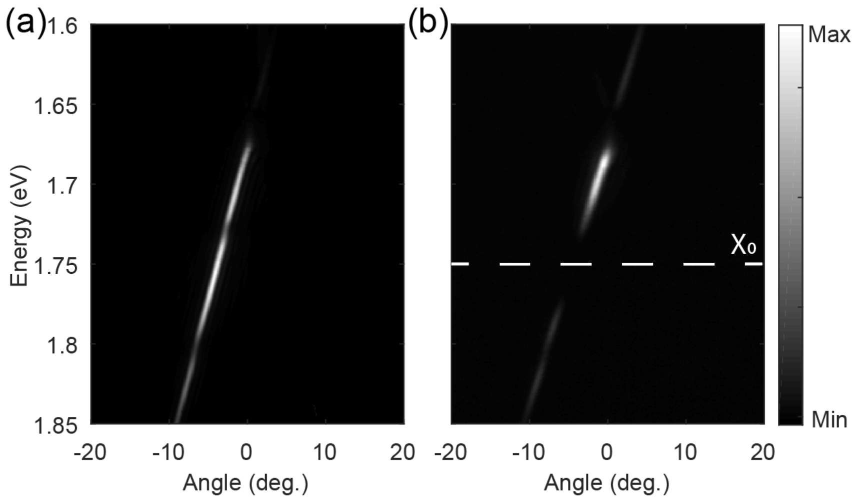

Figure 2. Angle- and photon-energy-resolved transmittance maps (a) before and (b) after transfer of a monolayer. For the transmission measurements, a halogen lamp was used as a white light source. The exciton spectral position is highlighted by a dashed white line.

In order to characterize the transmission of the fabricated hybrid structure, we used a setup for Fourier plane imaging combined with a closed-cycle helium cryostat. During the experiment, we used a halogen lamp as a white light source for the transmission measurements. The white light (polarized along the grating that corresponds to transverse-electric (TE) field mode) from a tungsten halogen lamp (Ocean Optics HL-2000) was focused onto the input grating coupler using an objective lens (Mitutoyo Objective 50x/0.65). Light coming from the sample was collected by the same microscope objective and spatially filtered. As a result, only light from the output grating was detected. The spectrally resolved signal was measured by projecting the Fourier plane of the objective onto the entrance slit of an imaging spectrometer (Princeton SP 2550) and detecting the light with a CCD detector (PyLoN 400BR eXcelon).

Figures 2a, b show the measured angle-resolved transmission maps before and after TMD monolayer transfer (the sample temperature is 7 K). We observed a dip in the transmission spectrum at the wavelength corresponding to the neutral exciton in the WSe_2 monolayer centered around 1751 meV.

Finally, we measured the evolution of ps laser pulses (OPA Light Conversion Ltd + pulse shaper) in the transmittance spectra after their propagation through the waveguide with

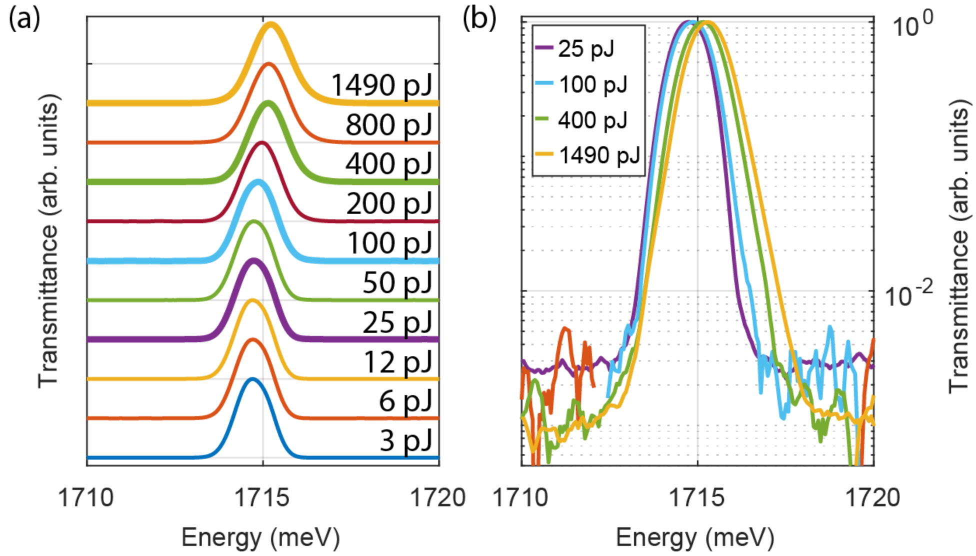

Figure 3. (a) Measured laser transmission spectra for pulse energy increasing from bottom to top. Selected spectra (bold lines) are plotted in log scale (b).

increasing pulse energy in order to verify the realization of the strong coupling of light and matter in the hybrid structure (Fig. 3 a,b). The sample is excited by pulses with a spectral full width at half maximum of 1 nm corresponding to a ∼1 ps temporal duration. The pulses are coupled in through the input grating, propagate 100 um, and coupled out through the output grating. But only 50 um of the waveguide length is covered by a TMD monolayer. The detuning of the laser spectrum from the exciton resonance is approximately -36 meV, despite this, in the experiment, we observed a blue shift of the laser spectrum. Such behavior is typical for polariton systems and related to nonlinear phenomena [6].

3. Conclusion

To summarize, we have experimentally observed strong light–matter coupling between waveguide photons and excitons in a hybrid photonic system based on slab dielectric waveguides integrated with two-dimensional semiconductors. Our results suggest a new platform for future TMD-based polariton devices where various nonlinear effects can be observed.

Acknowledgments

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