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Experimental study of all-van-der-Waals waveguide polaritons at room temperature

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Abstract. In this work, we experimentally investigate guided polaritons utilizing only 2D van der Waals materials, with hexagonal boron nitride (hBN) as the waveguide layer and WS_2 monolayer as the excitonic medium. We place the WS_2 monolayer at the maximum of the waveguide mode electromagnetic field, therefore reaching optimal conditions for the strong coupling between the exciton resonance and waveguide mode. To excite and detect the non-radiating waveguide polariton modes, we use the back focal plane microscopy with a high-index solid immersion lens. Polaritons in such all-van-der-Waals structures observed in ambient conditions reveal new possibilities for studying fundamental aspects of light-matter interaction and provide strong advantages in terms of miniaturization and integrability of future photonic devices.

Keywords: van der Waals materials, 2D semiconductors, exciton-polaritons, waveguide polaritons

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Материалы конференции
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Экспериментальное исследование Ван-дер-Ваальсовых волноводных поляритонов при комнатной температуре

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Аннотация. В этой работе мы экспериментально исследуем волноводные поляритоны, используя только двумерные Ван-дер-Ваальсовы материалы, с гексагональным нитридом бора (hBN) в качестве волноводного слоя и монослоем WS_2 в качестве экситонной среды. Мы помещаем монослой WS_2 в максимум электромагнитного поля волноводной моды, тем самым достигая оптимальных условий для сильной связи между экситонным резонансом и волноводной модой. Для возбуждения и обнаружения неизлучающих волноводных поляритонных мод мы используем метод микроскопии задней фокальной плоскости с высокоиндексной твердотельной иммерсионной линзой. Поляритоны в таких полностью Ван-дер-Ваальсовых структурах, наблюдаемые при комнатных условиях, открывают новые возможности для изучения фундаментальных аспектов взаимодействия света с веществом и открывают новые возможности для миниатюризации и интегрируемости будущих фотонных устройств.

Ключевые слова: Ван-дер-Ваальсовы материалы, двумерные полупроводники, экситон-поляритоны, волноводные поляритоны

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Introduction

Over the last several years, polaritonics has attracted substantial attention as a promising approach to developing non-linear optical and opto-electronic devices. Polaritons arise from strong coupling between light and resonance transitions in matter and manifest themselves in the energy spectrum as Rabi splitting between the transition and optical mode. One promising class of materials for polaritonics is the family of transition metal dichalcogenides (TMDCs). In the monolayer limit, TMDCs are direct bandgap semiconductors [1], and their optical response is dominated by the excitonic resonance. Excitons in TMDCs have large oscillator strengths and large binding energies; moreover, they are stable in ambient conditions, which makes monolayer TMDCs ideal candidates for room-temperature polaritonic devices [2].

Strong light-matter interaction can be achieved through coupling of excitonic resonances in TMDCs to resonant optical modes supported by stand-alone resonators, such as distributed Bragg reflector mirrors [3], plasmonic nanoparticles [4], or subwavelength gratings [5]. Despite the associated chip-compatible planar geometries, such systems often require complicated fabrication processes, which limits their tunability and creates challenges for applications in real devices.

Here, we study excitons in monolayer WS_2 strongly interacting with a waveguide mode in a subwavelength-thickness hBN waveguide. To excite and detect intrinsically non-radiating polaritons propagating below the light line, we use the back focal plane microscopy approach with a high-index solid immersion lens [6]. The complete device can be fabricated in a straightforward way with the dry transfer technique. The geometry of the studied structure allows us to position the WS2 monolayer precisely at the maximum of the waveguide mode's electromagnetic field by controlling the thickness of the hBN layers. Our results provide a basis for future investigations of waveguide polaritons in devices fabricated entirely from van der Waals 2D materials.

Results and Discussion

The fabricated all-van-der-Waals polariton waveguide is schematically shown in Fig. 1, *a*. A WS_2 monolayer and hBN flakes were mechanically exfoliated from bulk crystals and then dry transferred onto a SiO_2 substrate. In order to place the WS_2 monolayer at the maximum field strength of the waveguide mode with account for the presence of SiO_2 substrate, the bottom hBN layer had a thickness of ~ 30 nm, and the top layer had a thickness of ~ 70 nm. The black solid curve in Fig. 1, *b* represents the electromagnetic field distribution along the out-of-plane direction in the sample. We used atomic force microscopy to accurately determine the thickness of the constituent hBN layers and the final assembled structure.

In Fig. 1, *d*, one can see the experimentally measured angle-resolved reflectivity spectra, which exhibit mode anticrossing at ~ 2.01 eV arising from the strong coupling between the excitonic resonance in monolayer WS_2 and the waveguide mode in hBN. To support the experimental observations, we performed a numerical simulation of the angle-resolved reflectivity from the fabricated structure using the transfer-matrix method [7].

The simulation results are shown in Fig. 1, *c*. As observed in Fig. 1, *c*, *d* the experimental results show qualitative agreement with the numerical simulations, with Rabi splitting values on the order of tens of meV.

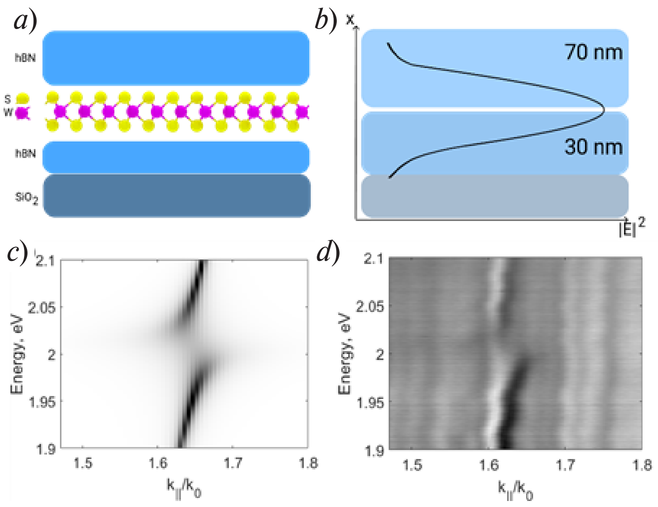

Fig. 1 Schematic representation of the sample. The thicknesses of the top and bottom hBN layers are 70 nm and 30 nm, respectively. The thickness of SiO_2 is 1 um (*a*). Exemplary distribution of electromagnetic field in the sample (*b*). Numerically calculated angle-resolved reflectance map with transfer matrix method (*c*). Angle-resolved reflectance map observed in the experiment using the back focal plane microscopy approach with a high-index solid immersion lens (*d*)

Conclusion

We experimentally demonstrate waveguide polaritons in an hBN waveguide with an embedded TMDC monolayer in ambient conditions. Our results pave the way towards miniature and chip-compatible room-temperature polaritonic devices based entirely on 2D materials.

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