Fourier-tailored van der Waals heterostructure for enhanced light-matter coupling

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Achieving strong light–matter interactions is crucial for advancing optoelectronic and quantum technologies. Dielectric waveguides provide a promising platform for integrating excitonic materials due to their low optical losses, but their confined electromagnetic fields often limit direct coupling with external active materials. Here, we demonstrate an approach to enhance light–matter interactions by embedding a monolayer of tungsten disulfide (WS_2) within a hexagonal boron nitride (hBN) van der Waals (vdW) heterostructure (Fig. 1a). This configuration maximizes spatial and dipole alignment between the excitonic states and the optical waveguide modes while simultaneously protecting the 2D material from environmental degradation (Fig. 1c-d). To enable efficient coupling between free-space light and the confined optical modes, we pattern Fourier surfaces in the top hBN layer using thermal scanning probe lithography, creating sinusoidal topographies with nanometer precision (Fig. 1b). This method allows controlled diffractive coupling, facilitating selective excitation of waveguide modes and engineering photonic bandgaps in the optical dispersion. Using reflectance spectroscopy, we observe the formation of exciton-polaritons with a Rabi splitting that indicates the system is at the onset of strong coupling (Fig. 1e). These results demonstrate the potential of Fourier-engineered vdW heterostructures as a versatile platform for exploring fundamental light–matter interactions and developing advanced optoelectronic and quantum devices.

References

[1] D. R. Danielsen, N. Lassaline, S. J. Linde, M. V. Nielsen, X. Zambrana-Puyalto, A. Sarbajna, D. H. Nguyen, T. J. Booth, N. Stenger, and S. Raza, "Fourier-Tailored Light-Matter Coupling in van der Waals Heterostructures", arXiv:2502.02114 (2025)

Figures

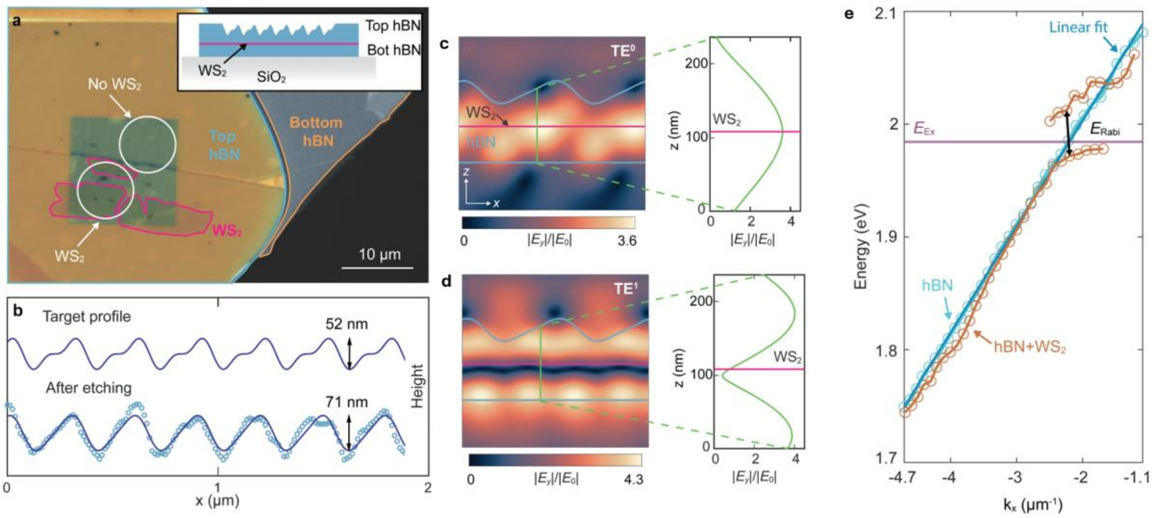

Figure 1: (a) Bright-field microscopy image of a vdW heterostructure with monolayer WS_2 encapsulated in hBN. **(b)** Target surface profile and AFM measured surface topography for the Fourier grating in (a). **(c)** In-plane electric-field distributions in the grating structure with WS_2 for the TE^0 mode. The vertical position of WS_2 aligns with the field maxima of the TE^0 mode. **(d)** As in (c), but for the TE^1 mode, where the position of WS_2 aligns with the field minima of the TE^1 mode. **(e)** Resonance energies for the coupled system with hBN and WS_2, together with the mode dispersion of the uncoupled hBN waveguide mode and the exciton resonance.