Nonlinear and waveguide optics in rhomohedral-stacked transition metal dichalcogenides

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Transition metal dichalcogenides have led to a paradigm shift in nanophotonics due to their huge nonlinear susceptibilities and high refractive indices that support small mode volumes in waveguides. Nevertheless, integrated photonic components based on two-dimensional materials are still in an early stage of development when compared to their conventional counterparts, but may ultimately exceed the device performance of commercialized photonic platforms. In this talk, I will discuss the potential of rhombohedral-stacked transition metal dichalcogenides: First, we demonstrate how 3R-MoS_2 can achieve record nonlinear optical enhancement from a van der Waals material, $>10^4$ stronger than a monolayer [1]. The slabs exhibit similar conversion efficiencies of lithium niobate, but within 100-fold shorter propagation lengths. Next, we build on laser writing to pattern grating structures into the material with grooves as sharp as 250 nm [2]. Using thin flakes that act as waveguides for near-infrared light, we demonstrate the functionality of the grating couplers with two complementary experiments: nano-optical imaging of waveguide modes [3] and waveguide second-harmonic generation. Our results highlight the potential of 3R-stacked transition metal dichalcogenides for integrated photonics, demonstrate the feasibility of compact frequency converters, and provide crucial parameters for designing highly efficient on-chip optical devices.

[1] X. Xu, …, F.M. *et al.*, "Towards compact phase-matched and waveguided nonlinear optics in atomically layered semiconductors," *Nat. Photonics* **16**, 698–706 (2022).

[2] F. Mooshammer *et al.*, "Enabling Waveguide Optics in Rhombohedral-Stacked Transition Metal Dichalcogenides with Laser-Patterned Grating Couplers," *ACS Nano* **18**, 4118–4130 (2024).

[3] F. Mooshammer *et al.*, "In-Plane Anisotropy in Biaxial ReS_2 Crystals Probed by Nano-Optical Imaging of Waveguide Modes," *ACS Photonics* **9**, 443–451 (2022).